CHARACTERIZATION AND OPTIMIZATION OF DRYING CONDITIONS OF CACTUS CLADODES (*Opuntia ficus-indica*) BASED ON THE QUALITY PARAMETERS OF DRIED PRODUCT.

M.Sc. thesis

By

HADISH HADGU BERHE

March, 2025

Haramaya University

CHARACTERIZATION AND OPTIMIZATION OF DRYING CONDITIONS OF CACTUS CLADODES (*Opuntia ficus-indica*) BASED ON THE QUALITY PARAMETERS OF DRIED PRODUCT.

A Thesis Submitted To Post Graduate Program Directorate through Department of Food Science Postharvest Technology.

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By

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APPROVAL SHEET

POSTGRADUATE PROGRAM DIRECTORATE

HARAMAYA UNIVERSITY

As thesis research advisors, we hereby certify that we have read and evaluated this thesis prepared under our guidance by Hadish Hadgu Berhe ,entitled with "Characterization of drying and optimization of drying conditions of cladodes (*Copuntia ficus-indica*) based on the quality parameters of dried product" We recommended that the thesis be submitted as it fulfills the requirements.

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As member of the board of examiner of the final M.Sc. Thesis open defiance Examination, we certify that we have read and evaluated the thesis prepared by Hadish Hadgu Berhe and examined the candidate. We recommend that the thesis be accepted as it fulfills the requirements for the award of degree of Master of sciences in Food Science and technology.

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DEDICATION

I dedicated this manuscript to: my wife Abrhet Miglase, my father Hadgu Berhe, my mother Brhanu Lemlem , my brothers Berhe Hadgu, Tesfay Hadgu, Teklehaymanot Hadgu and my sisters Abeba Hadug and Sheweet Hadgu. I also dedicate it to my aunt Haregu Hagose, who always wishes my success.

STATEMENT OF THE AUTHOR

First, I declare that thesis is my original work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment for the requirements for M.Sc. degree in Food Science and Technology at the Haramaya University and is deposited at the University Library to be made available to borrowers under rules of the library. I solemnly declare that this thesis is not submitted to any other institutions anywhere for the award of any academic degree, diploma or certificate.

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BIOGRAPHICAL SKETCH

The author was born in March, 1986 GC in Gola Genhity special name Adway Beatifelaso, Adigrat, Ethiopia. He attended the elementary school education at Gola elementary school from 1997 to 2000 GC and junior secondary school education at Sifra Jeganu in 2001 and 2002 GC. He then went to Yalembrhan high school in 2003 and 2004 GC and to Agazi comprehensive secondary school for preparatory education in 2005 and 2006 GC. In the following year he joined Modawolabu University and graduated with B.Edu. Degree in chemistry and from 2010-2014 GC he worked in Ethiopian Somali regional state in Jijiga Secondary and Preparatory school in teaching. He joined the school of graduate studies of Haramaya University in July 2014 to pursue further study leading to M.Sc. degree in food science and technology through self-sponsor.

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ACRONYMS AND ABBREVIATIONS

AOAC	Association of Official Analytical Chemists
BoARD	Bureau of Agricultural and Rural Development
CF	Cladodes Flour
CPPI	Cactus Production and Processing Initiative
FAO	Food and Agriculture Organization
HCDP	Helvetas Cactus Development Project
NGO	Non- Government Organization
RAPES	Regional Agricultural Product Expansion Support Program
SAERT	Sustainable Agriculture and Environmental Rehabilitation of Tigray
SAS	Statistical Analysis System
TCP	Technical Cooperation Program
USDA	United States Department of Agriculture

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES IN APPENDIX

ABSTRACT

Cactus (Opuntia ficus-indica),which was introduced to Ethiopia in 1848, is a drought resistant and lif-saving crop. In Ethiopia, particularly in Tigray, Cactus has been used as a major source of household income and nutrient-rich food. Eventhough Cactus cladodes are processed into flour via optimization of drying condition to use in various food industries globally, this practice is not yet adopted in Ethiopia. Therefore, the main objective of this thesis work was to optimize the drying process of cactus cladode for the purpose of powder production based on the drying temperature (55, 65 and 75 ^{o}C), pretreatment (unblanched, blanched with and without removing skin) and slice thickness (0.5, 1 and 1.5 cm) factors. The experiemt was designed with factors in full factorial arrangement of 3x3x3 in a completely randomized design (CRD) with three replications. The functional properties, phytochemicals and anti-nutritional factorsof cladodes powder were analaysed by response-surface method of Box-Behnken design using Design Expert software (version 6.0.8). The Curve Expert 32 (version 1.4) was applied to select the best fitting model and get the various equations used for the ploting of the graph of moister ratio and drying rate based on the value of R^2 and standard devaition, while the Design Expert software (version 6.0.8) was used to fit various responses. The obtained data of proximate composition and mineral contents were statistically interpreted using one-way ANOVA. The findings of this study indicated that the moister content of fresh and dried powder of leaf of Cladodes was obtained 87.81% and 7%, respectively. The values of water abospriton capacity, water solubility index, and chlorophyll-a for the unblanched, blanched with and without removing skin of the cladodes' leaves were found to be 5.63 g/g-26.73g/g, 24.17%-45% and 0.032 mg/g-0.041 mg/g, respectively. In this finding, the un-blanching treatement, drying temperature of 55 °C, and a slice thickness of 1.5 cm were found to be the optimal conditions for the drying process of cladodes' leaves. In conclusion, the majority of the proximate compositions and mineral contents were not significantly affected by drying temperature and slice thickness. The anti-nutrient contents were not affected at all by the indicated factors. It is recommended that further research on the determination of shelf-life of dried powder of various species and its application for the formulation of various food products be conducted.

Keywords: *Cactus Pear, Cladodes, drying conditions, slice thickness*

1. INTRODUCTION

1.1. Background of the Study

Cactus (*Opuntia ficus-indica*), commonly known as prickly pear, belongs to the family Cactaceae. Family Cactaceae is reported to contain about 130 genera and nearly 1500 species, which were originally native to the New World (Kaur, *et al*. 2012). Cactus was originated in central and southern part of Mexico (Shushay, 2014; Rodrigues, *et al*., 2016; Guedes, *et al*., 2023; Shoukat, *et al*., 2023). The production in Mexico has a tangible history and they started producing the crop using modern technologies 60 years ago. There were many universities and research organizations working on cactus based developmental issues in Mexico (Nefzaoui, *et al*., 2010).

Cactus was introduced to Ethiopia in the latter half of 19th century and widely distributed in eastern, south eastern and the northern arid and semi-arid regions of the country (Nefzaoui, *et al*., 2010; Meaza, *et al*., 2024). In response to famine due to frequent droughts and wars, a Catholic missionary brought cactus cladodes to eastern Tigray, northern Ethiopia in 1848 (Dulume, 2010; Shushay, 2014; Meaza, *et al*., 2024). Subsequently, the cactus has propagated to the eastern and southern parts of Tigray over time (Belay *et al*, 2010). In Tigray, Cactus is known by the vernacular name "Beles'' (in Tigrigna) (Melaku, *et al*., 2021). The cactus plant grows profusely in Ethiopia and has been adapted to the arid zones of the country characterized by droughty conditions, erratic rainfall, and poor soils subject to erosion. Its cladodes and fruits are a source of nutrients for humans and livestock (Dubeux, *et al*., 2021; Nassrallah, *et al*., 2021; Barba, *et al*., 2022; Lahboukia, *et al*., 2022). Thus contributes in times of drought, serving as a life-saving crop to both humans and animals. Nowadays, it plays an enormous cultural, economic and food security role in the region. In the eastern and southern part of Tigray, cactus has become the major income generating crop and used as a food source for about four months of the year (May-August) and it is very much part of the culture and livelihood of the people in spite of the limited uses (Nefzaoui, *et al*., 2010). The crop has high traditional value mentioned by songs and local says like "A farmer without Beles is like a stream without water" (Nefzaoui, *et al*., 2010; Shushay, 2014).

An extensive Cactus cladodes distribution exists in Tigray has covered areas of 355,242 hectare of which 30,352 ha are in the form of cultivation alone (Meaza, *et al.*, 2024). In Tigray, wild cactus harvest is estimated to only 128,660 tons from 30,520 ha. Despite the fact that cactus in the region is very abundantly grown, it is done traditionally due to lack of knowledge on the planting method and management practices (Nefzaoui, *et al.*, 2010). The Regional Government of Tigray devised poverty alleviation strategies including cactus promotion and utilization. In the last decade, alone the Bureau of Agriculture and Rural Development (BOARD) tried to introduce cultivation of pear cactus to the non-cactus growing areas. In 2007 and 2008 cropping seasons, more than 1,425,426 cladodes were distributed and planted covering 1,419 ha. From this, 9,723 households were expected to benefit (Nefzaoui, *et al.*, 2010).

Numerous country have Cactus, which have long been valued for its varied applications and qualities. Because there were few other meals available, humans learned to preserve the leaves and fruits, which could be stored for an extended period of time without going to spoiling. (Corrales and Flores, 2003). In recent years, interest has increased in the benefits for human health by consumption of functional foods as bioactive sources of antioxidants, vitamins, minerals, fiber, n-3 fatty acids, antioxidants, and phenolic compounds. Functional foods include vegetables, fruits, herbs, and oil seeds (Maniaci, *et al.*,2024).

The most popular parts of the plant for food remain the fresh fruit and the fleshy and tender stems. Many productive sectors use cactus pear fruits and their fleshy leaves as industrial raw materials for cosmetics, alcoholic drinks and food additives (the latter closely linked to the pharmaceutical industry). The plant is also used as a living fence in gardens and fields and it helps to combat desertification.

Cladodes are one of the aerial parts of cactus and it has high fiber content and this fiber can be obtained by drying and grinding. The resulting powder or flour is used in the food, food supplement and pharmaceutical industries. Tablets or capsules of cladode fiber have been available on the Mexican market for many years where they are used to control obesity and diabetes (FAO, 2013; Guedes, *et al.*, 2023). Due to drought resistant properties, the cladodes

are more available and play a vital role in minimizing the food security problems; food shortage and scarcity of meal during sever dry periods. Even though cactus cladodes have been used as ingredients in different food industry in the form of powder or flour and consumed in various modes, these haven't been practiced in Ethiopia and cactus has never been consumed in other form yet than the cactus pear fruits.

Cactus cladodes can be prepared and produced in the form of powder or flour in many ways. Drying and grinding processes are some of the methods which enable produce powder from cladodes and other perishable fruits and vegetables that have several advantages. Dry products make them easy to store and to transport because of the light weight, and this also extends the shelf-life of the product. The various drying methods have their own impact on the quality of cactus cladodes flour. Oven drying is one of those drying methods which have been applied to produce cactus cladodes powder.

1.2 . Stetment of the problem

Despite the great importance of cactus pear in Ethiopia, there is lack of awareness on consumption and processing of the cladodes. To overcome such problems, generation of information on cactus cladode processing and development of various products should be encouraged and this will have great contribution in ensuring food security in the country. It can improve the nutritional composition of the farmers' diet in the arid areas where erratic rainfall can lead to crop failure. Therefore, it was necessary to conduct studies on the possible methods of processing dried leaf of cladode to prerpare powder product. To that effect, this work was initiated to study the drying method of cladodes' leaf for powder production.

1.3.Objective of the Study

1.3.1. General objective

The general objective of this study was to optimize the drying process of cactus cladode for the purpose of powder production.

1.3.2. Specific objectives

 To determine the drying characteristics of cladodes leaves as influenced by drying temperature, blanching time and slice thickness.

 To determine the effects of drying conditions on the functional and nutritional properties as well as anti-nutritional factors of cladodes powder.

 To optimize oven drying temperature, slice thickness and pre-treatments of cladodes for powder production.

2. REVIEW OF LITERATURE

2.1. The Historical Origin of Cactus plant

The prickly pear, or cactus is a member of the Cactaceae family. There are around 1500 species and 130 genera in the family Cactaceae, which were formerly indigenous to the World (Kaur, *et al*., 2012). Central and southern Mexico is the origin of cactus pear leaf. (Shushay, 2014; Rodrigues, *et al*., 2016; Guedes, et *al*., 2023; Shoukat, *et al*., 2023). his amazing plant was brought to Ethiopia around the close of the 1800s and is now extensively found in the country's northern dry and semi-arid regions. (Nefzaoui, *et al*., 2010; Meaza, *et al*., 2024). The plant was introduced to Ethiopia through eastern Tigray in 1848 by Catholic missionary following the famine caused by frequent droughts and wars (Dulume, 2010; Shushay, 2014; Meaza, *et al*., 2024). The cactus has since spread over Tigray's eastern and southern regions. (Belay, *et al*, 2010). The vernacular name of the cactus is "*Beles*'' (Melaku,*etal*,.2021).More than 85% of the population in Tigray, as in other parts of the county directly depends on agriculture for their livelihood. However, the country experiences prolong ed droughts and unpredictable rainfall, which are exacerbated by excessive human and livestk pressures on the land, leading to a high level of food insecurity.In this regard, the cactus pear becomes an increasingly important food and feed source.Its fresh, ripe fruit serves as a limited source of household income, and it is also utilized as fuel, a live fence or hedge, and to conser ve soil. (Nefzaoui, *et al*., 2010).

In this sense, cactus may be an essential and striking component of Tigray rural culture and the economy. However, this abundant resource in the area is still underdeveloped as a result of neglect. (SAERT, 1994;Nefzaoui, *et al*., 2010;FAO. 2013).

2.2. Ethno Botany and Distribution of Cactus Pear (Opuntia ficus-indica)

They were brought to northern Africa by the Arabs from southern Spain, and now reside in Algeria, Egypt, Eritrea, Ethiopia, Libya, Morocco, and Tunisia. (Nefzaoui, *et al*., 2010; FAO, 2013; Meaza, *et al*., 2024). Due to their ability to thrive in a wide range of agroclimatic conditions throughout the American continent, opuntia species evolved in the tropical and subtropical Americas (De Waal et al., 2015). As people traded and relocated to Africa, Asia,

Europe, and Australia, the plant was carried and spread further. (Rodrigues, *e tal.*, 2016; Martin, *et al.*, 2023). Where food and fiber are still produced from both wild and farmed plants. These days, southern Spain and the Mediterranean region which includes France, Greece, Israel, Italy, and Turkey are home to both wild and cultivated varieties of these plants (Prisa, 2021; Erol, 2021; Shoukat, *et al.*, 2023; Meaza, *et al.*, 2024).

The cactus pear is a member of the genus Opuntia and family Cactaceae. Because it resembled prickly plants that flourished in the Greek town of Opus, Tournefort gave it the scientific name Opuntia in 1700 (Nefzaoui, *et al.*, 2010; FAo,2013). Opuntias can reach heights of 3.5 to 5 meters and can grow either upright or crawling. (Sudzuki, *et al.*, 1993; Sudzuki, 1999; Villegas and de Gante, 1997). The elongated or oval racquet-shaped succulent and jointed cladodes (stems) can reach lengths of 60–70 cm, contingent on the availability of nutrients and water (Sudzuki, *et al.*, 1993). The cladodes are edible as a vegetable when they are between 10 and 12 cm long. In the numerous nations where it is found, the Opuntia species is referred to by different names. For example, it's called higo chumbo in Spain, fico d'India in Italy, figue de Barbarie in France, and cactus pear in Australia, South Africa, and the United States. It's called sabras in Israel, and Beles in Ethiopia and Eritrea. Depending on the area, it is referred to as chapathi balli, anda torra, or nagphani in local dialect in India. Palma forrageira is the name given to it in Brazil because it is grown mostly as livestock feed (FAO, 2013).

2.3. Types and Characteristics of *Opuntia* Species

The Opuntia species have a complicated taxonomy. To recognize and identify each species, as well as the variants and adaptations represented in its phenotypic, a thorough field of research is required (Nefzaoui, *et al.*, 2010; FAo,2013). Although the genus Opuntia contains about 300 species, only 10 to 12 of these have been used thus far for their fruit, fragile leaves (cladodes), fodder, or cochineal for the creation of colorants. Opuntia ficus-indica, Opuntia amyclae, Opuntia xoconostle, Opuntia megacantha, and Opuntia streptacantha are the most commonly grown species for their fruit. Opuntia hyptiacantha, Opuntia leucotricha, and Opuntia robusta are examples of wild species. *Opuntia ficus-indica* is the species that is most often grown worldwide. It serves a number of functions and is the only Opuntia grown in the Mediterranean region. (Uzun, 1997). For instance, *Opuntia ficus-indica's* sensitive stems, known as nopalitos, are mostly consumed as a vegetable in Mexico. The preferred species for

raising cochineal insects are *Opuntia ficus-indica* and *Opuntia cochenilli*. *Opuntia ficus-indica* is also utilized as animal feed in countries like as Brazil, Chile, Mexico, and others. The cladode shapes, the presence or lack of spines, the size and color of the fruit, and other botanical traits are all different among these Opuntia species.

2.4. Use and Consumption of Cactus Pear Leaves

Numerous nations are home to opuntias, which have long been valued for their varied applications and qualities. Because there were few other meals available, humans learned to preserve the leaves and fruits, which could be stored for an extended period of time without going bad. (Corrales and Flores, 2003). Even now, people still eat these products, however the fresh fruit and the soft, meaty stems are still the most favored plant components. Cactus pear fruits and their meaty leaves are used as industrial raw materials in many different sectors of the economy for food additives, alcoholic beverages, and cosmetics (the latter being closely related to the pharmaceutical business (Guedes, *et al.*, 2023). The plant aids in the fight against desertification and is also utilized as a living barrier in fields and gardens.

2.5. Cactus Pear Production and Utilization in Ethiopia

This cactus species is known as the "Bridge of life" in Ethiopia because its stems and fruit store a lot of water, which helps farmers and their animals survive by providing food for livestock herders and fodder for cattle during dry spells (Nefzaoui, *et al.*, 2010; Meaza, *et al.*, 2024). It might be feasible to lower malnutrition and enhance the quality of life for people in nations like Ethiopia and others if they were made aware of the extensive applications of cactus pear, as in Mexico, for instance. The Opuntia species is a viable plant resource for humanity due to its characteristics. (FAO. 2013). Cactus pear has many uses and huge potential mainly as human food, (Mondragon-Jacobo, C. and Chessa I., 2010; Berhe, *et al.*, 2023). It also gives better yield in suitable lands (Lemma, *et al.*, 2010; Berhe, *et al.*, 2023). The cactus plant is widely distributed in Ethiopia, has adapted well, and is a crop that can save the lives of both people and animals (Shushay, 2014). For roughly four months of the year, Beles has emerged as the primary source of food and money in the eastern and southern regions of Tigray. (May - August) and Despite its restricted applications, it plays a significant role in people's culture and way of life. (Nefzaoui, *et al.*, 2010). It is now completely incorporated into the highland landscape. In many places, cactus pear has taken over as the

main plant. It is increasingly recognized as an essential component of peoples' environments and food security, even though it is a foreign plant that can spread rapidly in the absence of any natural opponents. The rural women's organization (NGO) called "Mum for Mums" was drafted into the project implementation and given the task of conducting training on cactus utilization for human consumption from February to June 2008 in Tigray and from September to November 2008 in North Wollo. This marked a breakthrough in the use of the technology of developing cacti as a food source, with 27 schools, 50 teachers, and 3,000 students participating. (FAO, 201). The "Mum for Mums" quickly included the potential of cactus as a food crop into their operations after realizing its potential. Because of its ability to adapt to little rainfall and poor soils, as well as the fact that it does not compete with grain production because it grows in places that would not typically be used for grain cultivation, they began to actively promote it. The cactus provided the disadvantaged communities with an extra coping strategy to stabilize household food security as soon as it was approved as a food crop. This helped them absorb the effects of the cyclical stocks they encounter, which are all too typical in Ethiopia. (Nefzaoui, *et al*., 2010).

2.6. Chemical Composition and Nutritional Value of Cactus Pear Leaves (Cladodes)

The desire from consumers for meals with greater nutritional value and health advantages has been on the rise recently, leading to the creation of a new category known as "functional foods." Disease prevention is one of the health advantages. (Sáenz, 2004; De Waal, *et al*., 2015; Nazareno, 2014; Guedes, *et al*., 2023). Cladodes are rich in fiber and provide a lot of water to the diet, much like many other vegetables. They are common in the southern United States, where a large population is of Mexican descent, and are a staple of the Mexican diet. Similar to other fruits and vegetables like mango, melon, apricot, grapes, spinach, artichokes, beets, eggplant, broccoli, and radish, the vegetable is high in nutritional fiber. (Zambrano, *et al*., 1998; Schmidt-Hebbel, *et al.*, 1990). Interesting sources of functional chemicals, such as fiber, hydrocolloids (mucilage), pigments (betalains and carotenoids), minerals (calcium and potassium), and vitamins with antioxidant qualities, such vitamin C, can also be found in the fruit and cladodes of Cactus. These substances are prized for their ability to prevent a number of illnesses and for their use as building blocks in the creation of novel cuisines. (Sáenz,, 2004). These substances can be found in a brand-new category of foods called "functional

foods," which are meals or drinks that have physiological advantages. Through the use of suitable biotechnologies or the addition of one or more functional components, they increase physical or mental performance, promote health, and aid in the prevention or treatment of disease. (Sloan, 2000; Guedes *et al.*, 2023).

Based on fresh weight, their chemical makeup is as follows: lipids (0.2%), proteins (0.5–1%), reducing sugars (0.64–0.88%), minerals (1–2%), fiber (1–2%), and carbohydrates (3–7%). The chemical makeup of the plant's many components must be determined in order to use it industrially. This aids in choosing the best processing methods and the prerequisites needed to produce goods that are wholesome, safe, and of the highest caliber. Since water makes up the majority of cladodes (88–95%), they are low in calories (27 kcal/100 g). Young cladodes also contain minerals, including potassium (2.35–55.20 mg/100 g), calcium (5.64–17.95 mg/100 g), magnesium (8.8 mg/100 g), phosphorus (0.15–2.59 mg/100 g), sodium (0.3–0.4 mg/100 g), manganese (0.19–0.29 mg/100 g), iron (0.09 mg/100 g), and zinc (0.08 mg/100 g). These constituents are in addition to ascorbic acid (10–15 mg/100 g), carotenoids (30 _g/100 g), primarily _-carotene, and chlorophyll (12.5 mg/100 g). The pH of around 4.6, 0.45% titratable acids (a low-acid vegetable), and 6.9% total soluble solids (TSS) have been reported in a number of investigations involving cladode juices. (Martin, *et al.*, 2023). *Opuntia Ficus indica* Cladodes may be a useful component in the creation of foods that promote health because they are a rich source of dietary fiber and bioactive substances. The purpose of this study was to create cookies by using varying amounts of powdered cladodes in place of wheat flour. (Guedes, *et al.*, 2023; Aparicio-Ortuño, *et al.*, 2024). Season, plant age, cladode order (position), cultivar, fertilization and harvest management, planting density, and environmental factors that affect the plant's physiological adjustment all affect the chemical makeup of cactus cladodes. For example, calcium plays a key role in the mechanism by which stomata open, and the concentration of minerals and proteins is sensitive to changes in the plant's nutritional supply. The amount of protein in cactus cladodes increases as the quantity of N fertilization rises. (Dubeux, *et al.*, 2021).

Tegegne (2004) found similar results in an experiment conducted in Ethiopia. In contrast to the cladodes or stems, the juvenile pads exhibited lower levels of ash, and the ash content did not follow the same pattern. The quantity of elements and compounds in the ash, their close

connection to soil chemistry, and the intricate processes influencing their availability to plants were the causes of this difference. (Nefzaoui, et *al.*, 2010). The chemical makeup of fresh young cladodes was primarily water (91 g/100 g), with 1.5 g/100 g proteins, 0.2 g/100 g lipids, 4.5 g/100 g total carbs, and 1.3 g/100 g ash, of which 90 mg/100 g was calcium, according to a research by Rodriguez-Felix and Cantwell (1988). Additionally, they discovered that the fiber content (1.1 g/100 g) has 30 µg/100 g carotenoids and 11 mg/100 g vitamin C, which is equivalent in value to spinach.

2.7. Medicinal Benefits of Cactus Aerial Part

It is a valuable source of pure antioxidants, including flavonoids and ascorbic acid, when consumed as food (Shoukat, *et al.*, 2023). One of the Cactus' aerial components, cladodes, contains a large amount of fiber, which can be extracted by grinding and drying them. Conventional applications Mexico uses *Opuntia ficus indica* as a traditional medicine to treat wounds, burns, edema, and dyspepsia (Msaddak, *et al.*,2017). According to reports, its alcoholic extract has antiviral, hypoglycemic, and ant-inflammatory properties. (Nazareno,2014; DeWaal, *et al.*,2015; Welegerima, *etal.*,2018; Guedes, *et al.*, 2023; Shoukat, *et al.*, 2023). Additionally, the stems of prickly pear cacti have long been used to treat diabetes in Mexico. To cure type 2 diabetes, Mexican healers advise consuming fresh cladode juice and cladode that has been fried, grilled, or otherwise prepared (Martin, *et al.*, 2023). Additionally, it has been claimed to be used medicinally to treat obesity and hyperlipidemia (an excess of lipids in the blood) (Sáenz, 2000; Nazareno, 2014;De Waal, *et al.*, 2015). Studies indicate remarkable anticancer activities displayed by cactus pear extracts (Harlev, *et al.*, 2013a). For many years, cladode fiber tablets and capsules have been sold in Mexico as a means of managing diabetes and obesity. Numerous investigations on the medicinal uses of *Opuntia streptacantha* and *Opuntia ficus-indica* were carried out in Mexico in the 1980s. The use of commercial capsules containing dried cladodes of *Opuntia ficus-indica* in individuals with diabetes mellitus was assessed in a study on diabetes control (Frati-Munari, *et al.*, 1992). Due to its scientific recognition for preventing certain ailments, such as gastrointestinal disorders and lowering blood cholesterol levels, dietary fiber is highly valued (Villanueva-Suarez, *et al.*, 2003; Feugang, *et al.*, 2006). The amount of dietary fiber in Cactus might differ according on the product form and age. This plant is well-known for its therapeutic qualities, which

include treating obesity and gastrointestinal or cardiovascular conditions. Additionally, these extracts lower serum glucose and cholesterol levels. (Ou, *etal.*, 2001; O´Connor, *etal.*, 2003; Dukas, *et al.*, 2003; Lee, *et al.*, 2006; Shoukat, *et al.*,2023). Fruits and cladodes perfect candidates for the production of health promoting food and supplements (Jana,S., 2012). Additionally, the primary contemporary uses of feuture in human diet, medicine, disease prevention, rehabilitation, cosumatics, and waste water treatment bioremediations (Shoukat, *et al.*, 2023). Because of their flocculant qualities, the cladodes of Opuntia ficus-indica (L.) Mill have a lot of promise for use in creative, affordable, renewable, and environmentally friendly water treatment (Trindade et al., 2021). Betalains, which are compounds with strong antioxidant properties that guard against oxidative stress and reduce inflammation, are found in cactus cladodes. Glucuronoxylans, which are found in cladodes, have been demonstrated to have anti-diabetic properties and function as biological hypoglycemic natural agents. (Shoukat, *et al.*,2023) cladodes extracts of *Opuntia ficus-indica* have potential antibacterial effects against both gram positive and gram negative bacteria (Welegerima, *et al.*, 2018)

2.8. Use of Cladodes in Food Products

Tender leaves cooked in brine or pickled in vinegar, sauces, juices, drinks, jams, candies, and sponge cakes are the primary cactus pear items made by the food industry in Mexico and the southern United States. (El-Safy, 2013). The most common product, which has been produced since the 1970s, is leaves preserved in vinegar or brine. The ingredients for tender-leaf sauces are pulverized leaves, different peppers, tomatoes, onions, and spices in different amounts, and sometimes a preservative Vinegar steeps the mixture. Depending on the desired result, cooking the leaves is optional. Additionally, the addition of white wine, lemon juice concentrate, and other components varies based on the product and producer. Depending on consumer preferences, cladodes may be ground or diced and added to sauces. Tender leaves (nopalitos), which are canned leaves in a variety of sauces like chili or hot pepper (Capsicum annuum L.), are among the new items that have just been introduced in Mexican marketplaces. Cladode pate with soy beans is a jarred puree of nopalitos flavored with texturized soybean and chicken or beef. Tuna fish nopalitos are a type of salad known as "Azteca," which is made with tuna fish, beans, cladodes, and fiery peppers. The product is sold in cans. With additional ingredients, nopalitosa collection of soft leaf-based products combine with tuna

fish, mushrooms, sausage, or vegetables to create a sauce. In Mexico, they have gained a lot of popularity Cladode. Cereal is a pelletized food made from a blend of wheat flour and bran, to which malt dextr in a water-soluble fiber, and dehydrated cladode powder are added. For distribution and retail, it is first packaged in plastic bags before being placed in cardboard boxes. After the bran and other ingredients are removed, dried cladodes are ground with cereal grains to create cereal flour and cladodes, a fine flour (FAO, 2013).

2.9. Importance of Drying

One of the techniques used in food processing is drying because it reduces the moisture content, which inhibits the growth of spoilage organisms. The taste, look, and nutritional content of fresh food are better preserved by canning and freezing, therefore drying will never be able to fully replace these techniques. However, drying is a great technique to preserve items that may create tasty, wholesome snacks and add variety to meals. The fact that dried foods require far less storage space than canned or frozen goods is one of their main benefits. Drying is one method of preserving perishable fruits and cladodes, preventing loss due to deterioration and/or disease, preserving them past the production season, particularly during periods of scarcity, and supplying foods that help create a more balanced diet. Since the basic tools and technology needed to prepare these foods at home are usually already present, little to no capital is needed (FAO, 2013). In order to effectively preserve and store various fruits and vegetables for extended periods of time, drying is employed to reduce their moisture content. Simultaneous mass and heat transmission under transitory conditions is a complicated procedure. Enhancing the quality of dehydrated items directly depends on understanding the process's heat and mass transport mechanisms as well as the function of the drying parameters. The drying air's temperature, velocity, and relative humidity are the primary factors influencing the drying process. The impact of drying parameters on the drying process of fruits and vegetabled has been the subject of numerous published research. Krokida et al. (2003) investigate the drying kinetics of vegetables, including potatoes, carrots, peppers, garlic, mushrooms, and more.

2.10. Use of Cladodes in Food Preparation

Cereal flour with cladodes: once the bran and other ingredients are removed, dehydrated cladodes are ground with cereal grains to create this fine flour. In the food sector, various finely crushed products are commonly referred to as "flour." (FAO, 2013).

3. MATERIALS AND METHODS

3.1. Experimental Site

The experiments were conducted at Haramaya University in the Food Science, Animal Nutrition and Soil laboratories.

3.2. Experimental Material

3.2.1. Plant material

Mature and well developed cladodes leaves of wild grown Cactus were collected from Haramaya University main campus, Haramaya during summer season, 2017.

3.2.2. Chemicals and reagents

In this study the following chemicals and reagents were used for the experimental analysis: Na_2SO_4, $CuSO_4$, H_2SO_4, 40% NaOH, 0.1 N HCl, petroleum ether, HNO_3, ZnO, $NaCO_3$, Gallic acid, Folin-Ciocalteus reagent, methanol, vanillin, and ethanol.

3.2.3. Apparatues and equipments

The apparatuses and equipments used in this study were: digital caliper, electronic balance, plant grinder, oven dryer, 250 μm sieves, Kjeldahl digestion flask, Soxhlet apparatus, crucible, atomic absorption spectrophotometer, Bunsen burner, Muffle furnace, centrifuge, and Uv-Visible spectrophotometer.

3.3. Drying Procedure of Cladodes Leaf

3.3.1. Sample preparation

Cladodes of about 40 cm in length, 25 cm in width and 2 cm in thickness were selected for the study. The cladodes were cut gently at the foot part with a sharp knife to separate them from the parent plants. The spines of the cladodes were removed using plastic brush and the skin was peeled with a knife and washed by tap water. Excess water on the cladodes surface was removed with absorbent paper. Then they were cut into pieces of 2 cm width and 10 cm length having thickness of 0.5, 1.0 and 1.5 cm as per the experimental design. The dimensions were

measured using a digital caliper. The initial weight of each sample was determined using the electronic balance with accuracy 0.00 g. The cut pieces of cladodes were pretreated as per the experimental design and dried at different temperature (55, 65 and 75°C).The blanching was done by immersing in hot water at 90 ^{0}C for 2min. During drying the weight of the samples was measured at each 15 minutes interval up to about 6 hrs and then 30 minutes interval until the end of the drying as the change in weight was less. After drying, the cladodes were milled using laboratory mill to pass through 250 µm sieves. The powder was packed and sealed in low density polyethylene bag. The sealed powder bag was kept in another high density polyethylene bag and stored in dry place at room temperature until required for the analysis.

The procedure for preparation of cladodes powder is shown diagrammatically in a flow chart (Fig.1). Various factors that affect different steps are also shown there. Levels of different factors were selected based on literature or by conducting preliminary trial runs.

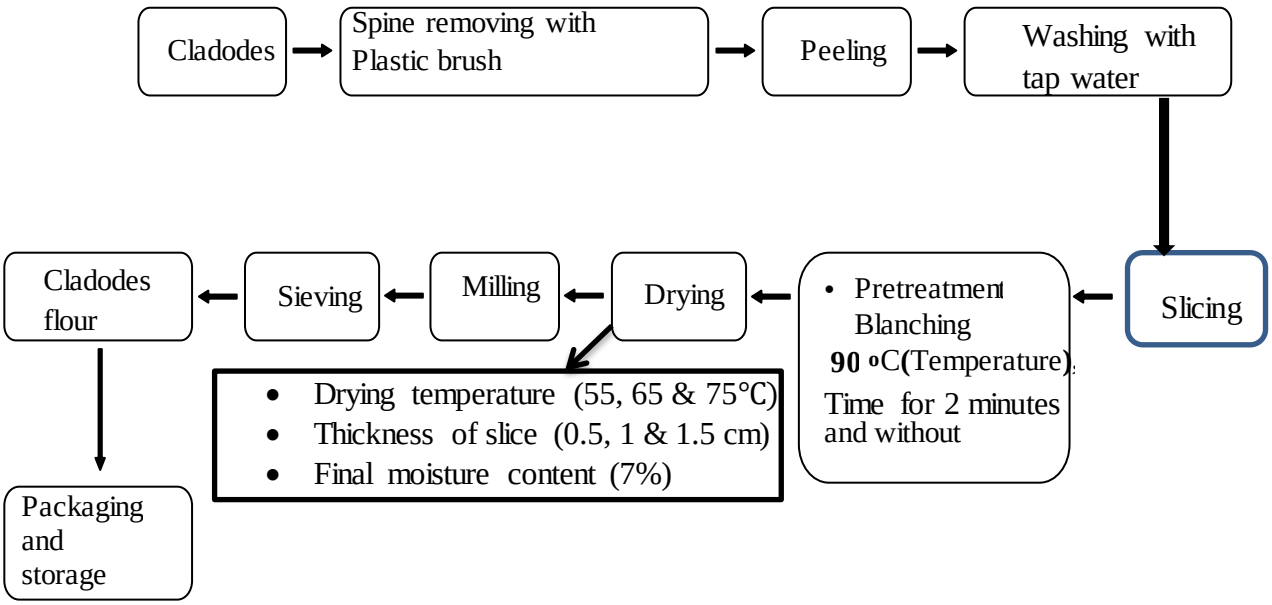

Figure 1. Flow diagram for preparation of cladodes flour

3.3.2. Drying characteristics of cladodes

The laboratory scale hot air oven dryer was used to determine drying characteristics of cladodes. The drying was carried out by keeping the weighed slices in steel plates. The drying experiment was conducted at 55, 65 and 75 ^{o}C air temperatures with 0.5, 1 and 1.5 cm slices thickness and 2 minutes blanching time at 90°C temperature. In each experimental unit, about 300 g of cladodes samples was used. Weight of samples was recorded at 15 min interval initially up to about six hours and at 30 min afterwards as the change in weight was reducing. To determine the moisture loss of drying samples during experiments, cladodes samples were taken out of the dryer and weighed until the moisture content was down to 7%. The weight of samples was taken with the help of a digital electronic balance with 0.01g least count. The moisture content was calculated on dry basis by following equation.

Moisture ratio data were plotted in graphs as a function of drying time expressed as a ratio of actual time during the record to the total time needed to reach the target final moisture content. Therefore, Curve Expert 32 (version 1.4) was used to get the various equations fitting the data and selection of the model based on coefficient of determination, R^2 and physical phenomena. The calculated actual drying rate data was used to select the best fitting model and using this model the predicted drying rate values were computed. Using the data of estimated values the predicted drying rate curve was then drawn. It was found that nonlinear relationship existed between moisture ratio and drying time.

$$M(\%\ \text{d.b}) = \frac{W_w - W_d}{W_d} \times 100\% \qquad (1)$$

Where: M = the moisture content of the sample on (d.b., %),

Ww = weight of sample at different time interval; and

W_d = the dry weight of the sample in grams.

The drying rate was calculated at different time intervals in all experimental conditions using following formula:

$$\frac{dm}{dt} = \frac{Mt - M_{\Delta t}}{\Delta t} \qquad (2)$$

Where: dm/dt = drying rate (kg water/kg of dry material · min),

Mt = moisture content at time t,

$M_{\Delta t}$ = moisture content at time t+Δt, Δt = time (min).

Thin layer drying procedure is generally practiced for characterizing the drying parameters (Akgun, 2005). The empirical models present the direct relationship between the average moisture content and drying time by means of regression analysis, neglecting the fundamental of drying process.

The moisture ratio of cladodes during the drying was calculated by using the following equation:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (3)$$

Where:- M_t, M_o, and M_e are the moisture content on dry basis at any time, t, initial time, and equilibrium, respectively.

The value of dynamic equilibrium moisture content is relatively small as compared to M_t and M_o, hence the error involved in the simplification is negligible (Doymaz, 2004) and hence moisture ratio was calculated as:

$$MR = \frac{M_t}{M_o} \quad (4)$$

3.4. Experimental Design

The experiments were conducted with three factors in full factorial arrangement of 3x3x3 in a completely randomized design with three replications. These were three drying conditions namely; drying temperature (55, 65 and 75 ^{0}C), slice thickness (0.5, 1 and 1.5cm) and in three different samples pre-treatment (un-blanched, blanched without removing the skin and blanched with removing the skin) blanching being done at 95^{0}C for 2 min.

Table 1. Box-Benken experimental design

Independent variables	Symbols		Level	
	Nature	Code	Nature	Code
Temperature, (℃)	T	X1	55	-1
			65	0
			75	1
Thickness, (cm)	Tk	X2	0.5	-1
			1	0
			1.5	1
Pretreatments	Pr	X3	UB	-1
			BWORS	0
			BWRS	1

Where: UB = un blanched, BWORS = blanched without removing skin and BWRS = blanched with removing skin

3.5. Determination of Chemical Composition of Cladodes Powder

In this work, a method of American Association of Cereal Chemist (AACC, 2000) was used to analyze functional properties, phytochemicals, anti-nutritional factors, proximate composition, and mineral contents of cladodes powder.

3.5.1. Proximate composition

3.5.1.1. Moisture

Moisture content of all the samples was determined according to AACC (2000). Clean and dry dish was prepared and the mass was weighed as (W_1). Representative sample (5.00 g) was weighed (W_2) (mass of sample with mass of dish before drying), dried at 100^0C for 6 hours and cooled to room temperature in a desiccator. The mass after cooling was measured as W_3. The moisture content of flour was then calculated by using the following formula:

$$MC = \frac{W2 - W3}{w2 - w1} X100$$

Where: MC = Moisture content of sample (%, w.b) ,W_1 = Mass of dish (g)

W_2 = Mass of sample and dish before drying (g) ,W_3 = Mass of sample and dish after drying (g)

3.5.1.2. Crude protein

The crude protein content of all flour samples was determined according to AACC (2000). Ground samples were analyzed using the Kjeldahl method. Briefly, sample weight (1.0 g) was added into a Kjeldahl digestion flask. Catalyst mixture (Na_2SO_4 mixed with anhydrous $CuSO_4$ in the ratio of 10:1) of 1.0 g was added. After addition of 5 ml of H_2SO_4, digestion flask was placed in the digester and the temperature was brought to 350 ^{0}C allowed digesting for over 2 hr until digestion is completed. The flask was removed from the digester and allowed to cool. After cooling, the content in the flask was diluted by 30 ml of distilled water followed by addition of 25 ml and a concentrated 40% NaOH into the digestion flask to neutralize the acid and to make the solution slightly alkaline. Then, the contents were distilled immediately by inserting the digestion tube line into the receiver flask that contains 25 ml of 4% boric acid solution and about 150 ml of distillate was collected. Finally, the distillate was titrated by a standard acid (can 0.1N HCl). The % of nitrogen was converted to % of protein by using appropriate conversion factor (protein (%) = 6.25 x % N). Urea was used as control in the analysis.

$$N = \frac{V_{HCl} \times N_{HCl} \times 14}{m \times 1000} \times 100 \qquad (2)$$

$$P = F \times N \qquad (3)$$

Where:
V_{HCl} = volume of HCl consumed to the end point of titration,
N_{HCl} = the normality of HCl (used often is 0.1N),
m = sample weight on dry matter basis,
14.00 = the molecular weight of Nitrogen,
N = Nitrogen (%),
F = conversion factor (6.25),
P = protein (%).

3.5.1.3. Crude fat

The content of crude fat was determined using Soxhlet extraction method according to AACC (2000). Briefly, ground sample (3.00 g) was weighed and added into a thimble. The thimble with sample was placed in 50 ml beaker and dried in an oven for 2 hr at 110^{0}C. 150-250 ml dried beaker was weighed and rinsed several times with petroleum ether. The sample

contained in the thimble was extracted with petroleum ether in a Soxhlet extraction apparatus for 6-8 hr. After the extraction is completed, the extracted fat was transferred into a pre-weighed beaker (m_i). The beaker with extracted fat was placed in a fume hood to evaporate the solvent on a steam bath until no odor of the solvent is detectable. Then, the beaker with content was dried in an oven for 30 minutes at 100 ^{0}C. Finally, the beaker with its contents was removed, cooled in a desiccators and weighed (m_f). The amount of fat in flour was then calculated by using the following formula:

$$\text{Fat}(\%) = \left(\frac{m_f - m_i}{m}\right) \times 100 \qquad (4)$$

Where: m_f = dried mass of fat with beaker (g), mi = Mass of beaker (g) and m = sample mass (g) db.

3.5.1.4. Ash

According to AACC (2000), total ash content of the flour was determined by gravimetric method. Crucible was cleaned, dried and ignited at 550^{0}C for 1 hr and weighed (m_1). Ground sample (3.00 g) was weighed (m_2). The sample was dried at 120 ^{0}C for 1 hr. Then, the dried sample was carbonized over a blue flame and ignited in a muffle furnace at 550 ^{0}C until the ashing completed (over 12 hr). After being ignited, the sample was cooled to ambient temperature and weighed (m_3). Finally, total ash content was calculated as follows:

$$\text{Ash}(\%) = \left(\frac{m_3 - m_1}{m_2 - m_1}\right) \times 100 \qquad (5)$$

Where: - m_1 = mass of crucible (g),
m_2 = sampled mass with crucible (g) and
m_3 = final mass of sample with crucible (g).

3.5.1.5. Crude fibre

The crude fiber was analyzed according to AACC (2000). Ground sample (3.00 g) was weighed (m_1) and placed in 500 ml beaker. This was digested with 1.25% sulfuric acid and washed with water and further digested with 1.25% sodium hydroxide, filtered in coarse porous (75 µm) crucible in apparatus at a vacuum of about 25 mm. The residue left after refluxing was washed again with 1.25% sulfuric acid at near boiling point. Then, the residue

was dried at 110 ^{0}C overnight, cooled in a desiccators and weighed (m_2). After being dried, the sample was ashed at 550 ^{0}C until the ashing process was completed; cooled in a desiccators and weighed again (m_3).

The total crude fiber was then expressed in percentage as follows:

$$F = \frac{(m_2 - m_3)}{m_1} \times 100\% \quad (6)$$

Where: F = total crude fiber (%), m_1 = mass of sample (g, db), m_2 = mass of sample before ashing (g), and m_3 = mass of sample after ashing (g, db).

3.5.1.6. Utilizable carbohydrate

The content of utilizable carbohydrate was determined by subtracting the sum of other constituents from 100.

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

(7)

3.5.1.7. Energy content

The energy content of the sample was calculated by multiplying the percentage of crude protein and carbohydrate content with 4 and crude fat with 9. The values were then converted to kilo calories per 100 gm of the sample.

3.5.2. Mineral analysis

3.5.2.1. Calcium

The calcium content was determined by atomic absorption spectrophotometer (AACC, 2000). Briefly, sample of 2.00 g was weighed into ash vessel (that has been pre-ignited at 550 ^{0}C and cooled in desiccators). The sample was first carbonized over a blue flame of Bunsen burner and put in the muffle furnace at 500 ^{0}C until ashing was completed. Then, the ash was dissolved in 10 ml diluted 3M HCl. The solution was boiled and evaporated nearly to dryness on steam bath. The residue was re-dissolved quantitatively in 20ml of 2M HCl and was filtered through course porosity filter paper into 100 ml volumetric flask. The paper was washed and the residue thoroughly with water and dilute to 100 mL mark. Standard solution

(25 µg Ca/ml) was prepared from analytical grade calcium wire by dissolving 1.249 g in 30 ml HCl and 50 ml distilled water and then it was diluted to 1 L. Finally, calcium was measured by adding enough La stock solution to make the final dilution 1% La (i.e., 5 ml Lantinium solution to 25 ml flask, 20 ml to 100 ml flask) and this was added to the sample and final standard solution. The absorbance of sample was then read with Atomic Absorption spectrophotometric at 422.7 nm. Calcium content was calculated with the following formula:

Calcium content (mg/100g) = C × 100/S (8)

Where: C = the concentration of the sample from plot of absorption in µ/m
S = Sample mass (g)

3.5.2.2. Iron

Iron analysis was conducted by UV-VIS spectrophotometer method (AACC, 2000). Sample of 1.00 g was weighed into vessel which has been pre-ignited at 550°C and cooled in desiccators. The sample was carbonized over a blue flame of Bunsen burner and put in the muffle furnace at 550°C until ash was completed. Then, the ash was dissolved in 5 ml diluted HCl (0.1M). The solution was boiled and evaporated nearly to dryness on steam bath. The residue was dissolved quantitatively in 20 ml 1MHCl and was filtered through course porosity filter paper in to 100 ml volumetric flask. Standard solution (10μg Fe/ml) was prepared from analytical grade iron wire by dissolving 0.1g in 20 ml HCl and 50ml distilled water and then it was diluted to 1 L. Finally, 100 ml of this solution was diluted to liter. Sample (5 ml) was taken in to 20 ml volumetric flask and 1ml of 1, 10-phenantholine was added and a series of standards solution (0.2-4.0 μg Fe/ml) was made. After 25 minutes, absorbance of sample, standard and blank was read with UV-VIS spectrophotometric at 510 nm. Iron content was calculated with the following formula:

$$Iron\ content\ (\frac{mg}{100g}) = \frac{C \times DF \times F}{sample\ mass\ in\ g\ (db)} \quad (9)$$

Where: C = concentration of sample in ppm, DF = dilution factor (if any used) and F = 10 is a conversion factor since 10 ml was analyzed from 100ml.

3.5.2.3. Zinc

This was also determined based on AACC (2000) method and sample with weight of 3.00 g was added into ashing vessel which is pre-ignited at 500-550℃ and was cooled in desiccators. The sample was charred on blue flame or on hot plate and was ashed at 550℃ until ashing was completed. If ashing will not complete the sample will be cooled and wetted with few drops of concentration HCl and HNO_3. It was dried at low heat and re-ashed. The cake was broken up with stirring rod and was dissolved in 5ml of concentrated HCl. The solution was boiling and evaporated nearly to dryness on a steam bath to dissolve the reused. The residue was re-dissolved quantitatively in 15 ml 1M HCl. It was filtered through coarse porosity filter paper into 100 ml volumetric flask. The paper and the residue were washed thoroughly with water and diluted to 100 ml mark. Standard zinc solution containing 0.1-1.0mg/ L was prepared from ZnO or Zn metal using the same 0.1mol/L of HNO_3 solution. Both the same standard solution and the samples were analyzed using the atomic absorption spectrophotometer and absorbance was measured at 213.8 nm. Concentration of sample was read from plot of absorbance against μg/mL Zn.

$$Zinc\ content\left(\frac{mg}{100g}\right) = \frac{(Cs-Cb)v\times D}{S} \qquad (10)$$

Where: Cs and Cb = concentrations in μg /mL of analytic and blank, respectively.
V = original volume (100 mL),
D = dilution factor (if original solution is diluted) = dilution volume (mL/original aliquot volume (mL) used for dilution.
S = sample mass in g.

3.6. Determination of Anti-nutritional Factors in Cladode Powder

3.6.1. Total phenolic content

The total polyphenol content (TPC) was determined by spectrophotometer, using Gallic acid as standard, according to the method described by the international organization for standardization (ISO 14502-1, 2005). Briefly, 0.1 g for powder and 0.1 ml for cladodes infuse of the dilute sample extract were transferred in duplicate to separate tubes containing 5.0 ml of 1/10 dilution of Folin-Ciocalteus reagents in water, then 4.0 ml of a sodium carbonate

solution (7.5 % W/V) was added. The tubes were then allowed to stand at room temperature for 60 minutes before absorbance at 765 nm was measured using a spectrophotometer (6505)/uv/vis spectrophotometer, model 6505,U.K,GENWAY) against water.

The TPC was expressed as Gallic acid equivalents (GAE) in g/100 g material. The concentration of polyphenol in samples was driven from a standard curve of Gallic acid ranging from 10 to 50 μg /mL (Pearson's correlation coefficient: $r^2 = 0.9996$).

$$\text{Total phenolic content (ppm)} = \frac{{}^{\mu g}/_{mL} \times D_f \times 100}{sample\ mass\ (g\ or\ ml)} \qquad (11)$$

Where: µg/mL= absorbance reading concentration, DF = dilution factor

3.6.2. Condensed tannins

Condensed tannin content of the sample was determined according to the modified Vanillin-HCl methanol method as described by Price *et al.* (1978). The Vanillin-HCl reagent was prepared by mixing equal volumes of 8% concentrated HCl in methanol and 1% Vanillin in methanol. The solutions of the reagent were mixed just prior to use. About 0.2 g of the ground sample was placed in a small conical flask. Then, 10 ml of 1% HCl in methanol was added. The conical flask was capped and continuously shaken for 20 minutes and the content was then centrifuged at 2500 rpm for 5 minutes. About 1.0 ml of the supernatant was pipetted into a test tube containing 5 ml of Vanillin-HCl reagent. Absorbance at 450 nm was read on spectrophotometer after 20 minutes incubation at 30^0C, a blank sample was carried out with each run of sample. A standard curve was prepared and the result was expressed as catechin equivalent (mg/ml) as follows:

$$\text{Tannin}(\%) = \frac{(C \times 10) \times 100}{200} \qquad (12)$$

Where: C = Concentration of corresponding to the optical density

10 = volume of the extract (ml), 200 = sample weight

3.7. Phytochemical (Carotenoids, Chlorophyll a and Chlorophyll b) Content

The entire reagent used was analytical grade. Spectrophotometer (model 6505, U.K, GENWAY) was used for the absorbance measurements. The chlorophylls and carotenoid was extracted with ethanol (100% alcohol), according to the methods described by Kukric, *et al.*, (2012) and Chang *et al.,* (2013). For extraction a representative portion of sample, 0.1 ±0.001 gram powders and 0.1 ±0.001 ml for cladode's extract were accurately weighed and transferred to a glass test tube. Then, 5 ml ethanol was added to it and the test tube was held in dark for 15 minutes with occasional shaking at room temperature. The chlorophyll and carotenoids contents were analyzed using spectrophotometer by absorption measurements at 440, 649 and 665 nm (6505 uv/vis spectrophotometer, model 6505, U.K., GENWAY) and calculated according the following equations.

$$\text{Chlorophyll a}\left(\frac{mg}{g}\right) = \frac{13.7A665 - 5.76A649}{mass\ (200)} \quad \text{(14)}$$

$$\text{Chlorophyll b}\left(\frac{mg}{g}\right) = \frac{25.8A649 - 7.56A665}{mass\ (200)} \quad \text{(15)}$$

$$\text{Carotenoides}\left(\frac{mg}{g}\right) = \frac{4.7A440 - 0.263C\ (chl\ a + chl\ b)}{mass\ (200)} \quad \text{(16)}$$

Where: C = chl ^{a} + chl ^{b}, A = absorbency reading (Kukric *et al.*, 2012 and Chang *et al.*, 2013)

3.8. Functional and Physical Properties of Cladodes Powder

3.8.1. Water absorption capacity

Water absorption Capacity of the flour was determined according to Anderson, *et al.* (1969). Sample (0.625g) was placed in 10 ml centrifuge tube and suspended in 7.5 ml distilled water. It was incubated in water bath at about 25℃ for 30 min and was centrifuged at 3000 g for 5 min. The clear supernatant was decanted and mass of the sediment was determined. The WAC was calculated as grams of absorbed water per gram of dry sample. The clear supernatant of the centrifugation was transferred into pre-dried (105℃) glass beaker (50 ml) and was weighed for the estimation of the water solubility index (WSI).

$$WAI = \frac{Ws - Wo}{Wo} \quad (20)$$

Where: Ws = weight of sediment (g) , Wo = weight of sample (g)

3.8.2. Water solubility index

The supernatant collected after centrifugation during WAI measurement was evaporated at 105℃ for overnight in a drying oven. The WSI was calculated as a ratio of weight of dry residue to the weight of original sample used to estimate WAI. The results are expressed in percentage (Anderson, *et al.*, 1969)

$$WSI(\%) = \frac{Wr}{Ws} \times 100 \quad (23)$$

Where: Wr = is the weight of dry residue after evaporation of supernatant (g)

Ws = weight of sample (g)

3.8.3. Swelling power

Swelling power was determined based on the method stated by El-Safy **(**2013**).** First, 1.00 g of powder was weighed and transferred into a pre-weighed centrifuge tube. Then, 10 ml of distilled water was added into centrifuge tube and mixed well. After that, the tube was heated at 80^0C for 30 minutes (in a hot water bath) with continuous shaking during the heating. After that, the suspension was centrifuged at 2280 rpm for 15 minutes, and the supernatant decanted and the weight of the centrifuge tube and the paste was measured. The swelling power was calculated by dividing the weight of paste by weight of dry sample. The result was expressed as:

$$\text{Swelling power } (\%) = \frac{W3 - W2}{W1} \times 100 \quad (21)$$

Where: - W1= weight of cladodes flour sample, g

W2 = weight of the centrifuge tube with cladode powder sample, g

W3 = weight of the centrifuge tube with swollen materials, g

3.8.4. Oil absorption capacity

First, 1.00 g of cladode powder sample was added with 10 ml of corn oil in a test tube. Then, the suspension was stirred for 5 minutes and was centrifuged at 3600 rpm for 30 minutes. The supernatant produced was decanted and measured in a 10 ml graduated cylinder. Oil

absorption was then calculated as the difference between the initial volume of the oil and the volume of the supernatant. The result was expressed as milliliter of absorbed oil per g of powder (ml / g) (El-Safy, 2013**).**

3.8.4. Bulk density

Fifty gram of flour sample was put into a 100 ml measuring cylinder. The cylinder was tapped several times on a laboratory bench to a constant volume. The volume of sample was recorded and the bulk density was calculated using following formula:

$$Bulk\ density\ \left({}^{g}/_{cm^3}\right) = \frac{Weight\ of\ sample}{Volume\ of\ sample\ after\ tapping} \quad (22)$$

3.9. Data Analysis

Design Expert software (version 6.0.8) portable was used to fit various responses and optimize the numerical values and catagorical factors. Curve Expert 32 (version 1.4) was used to get the various equations fitting the data and selection of the model based on the coefficient of determination, R^2 and standard deviation. The data of proximate and mineral compositions was statistically analysed using ANOVA.

4. RESULTS AND DISCUSSIONS

4.1. Drying Characteristics of Cladodes

4.1.1. Moisture ratio (MR)

The average value of the moisture content of the fresh cladode of the cactus pear was 87.81% (w.b.) These findings closely align with those reported by Razzak *etal.*(2024) 88.2% .The drying curves in terms of moisture ratio as a function of drying time for all drying experiments are presented in Figures 2 through 10. The moisture ratio was expressed as a ratio of actual drying time to the time needed to bring down the water content of the drying samples to the target level (7%) when dried at the lowest temperature considered in the study. Figures 2 to 4 show the effect of drying temperature for un-blanched samples at different slice thicknesses. As shown in the figures the moisture ratio decreased with increase in drying temperature. That was because the loss of moisture at higher temperature was high and therefore the drop in moisture content was fast leading to fast drop in values of MR. The final moisture content was targeted at 7% which is generally considered as safe for long term storage as reported by El-safy-(2013). Time required to reach 7% moisture content decreased with increase in drying temperature for all slice thicknesses. The drying time was reduced by 60 and 40% when the drying tempreture was set at 65 and 75 ^{o}C, respectively, compared to the 55 ^{o}C dryint tempreture needed for the 0.5 and 1.0 cm slices. Whereas the drying time used for the 1.5 cm slice thickness was slightly loger by 45% to reach 7% moisture content due to the relatively longer distance that the water in the tissue travels to reach the drying surfaces.

For the samples blanched before drying, the drying time needed to reach the target 7% moisture content was generally longer than those for un-blanched ones. For samples of 0.5 cm thickness blanched without removing the skin, the time needed to reach the target 7% moisture content at 65 and 75^{o}C drying temperatures was 70 and 60%, respectively, while for the 1.0 cm thickness it was 90 and 75%, respectively, of that needed at 55^{o}C. The time for slices of 1.5 cm thickness, on the other hand, was 75 and 57% of that needed for the 55^{o}C drying temperature. From these it can easily be observed that the drying temperature had an impact on the time needed to reach the target moisture content. For samples blanched after removing the skin, the drying time to reach the target 7% was even longer. Furthermore, both

the higher drying temperatures (75 and 65^{o}C) needed more than 70% of the time required for drying at 55^{o}C for slices of all three thicknesses.

The data of moisture loss as drying time progressed was modeled using Curve Expert 32 (trial version 1.4) software and it was found that a polynomial equation fitted best for the data. However, based on physical phenomena of exponential decay, Page's equation of the formula $Y= e^{-atb}$ was selected due to higher coefficient of determination (R^2) and lower standard deviation, and the results are reported in Table 3. R^2 varied from 0.9999 to 0.9945 and the standard deviation also ranged from 0.023 to 0.003. The statistical results in terms of R^2 - value and standard deviation in the curve expert32 version 1.4 as well as drying constant, a and b for the page model are shown in Table 3 where temperature, thicknesses and treatments were variable factors.

Table 2. Best fit mathematical model result for moisture ratio verses time ($Y= e^{-atb}$)

Exp. No	Temp. (^oC)	Thick. (cm)	Tre.	R^2-value	S-value	Coefficients	
						a-value	b-value
1	55	0.5	UB	0.9999	0.0032	5.4721	1.3164
2	65	0.5	UB	0.9987	0.0164	4.2350	1.4029
3	75	0.5	UB	0.9994	0.0106	4.3932	1.5007
4	55	1	UB	0.9987	0.016	4.6017	1.1708
5	65	1	UB	0.9992	0.0138	4.5624	1.3965
6	75	1	UB	0.9995	0.0103	4.1714	1.3577
7	55	1.5	UB	0.9982	0.0194	3.5035	1.1736
8	65	1.5	UB	0.9985	0.0185	3.7571	1.3259
9	75	1.5	UB	0.9985	0.0181	3.9536	1.3411
10	55	0.5	BWORS	0.9995	0.0096	4.7486	1.3200
11	65	0.5	BWORS	0.9995	0.0100	4.9566	1.3174
12	75	0.5	BWORS	0.9992	0.0131	4.2592	1.4257
13	55	1	BWORS	0.9987	0.017	4.4088	1.2810
14	65	1	BWORS	0.9996	0.0093	4.6330	1.3570
15	75	1	BWORS	0.9991	0.0144	4.9293	1.3622
16	55	1.5	BWORS	0.9988	0.0157	4.2491	1.2305
17	65	1.5	BWORS	0.9990	0.0151	4.4867	1.2507
18	75	1.5	BWORS	0.9991	0.0141	4.7522	1.2712
19	55	0.5	BWRS	0.9989	0.0152	3.7939	1.4372
20	65	0.5	BWRS	0.9993	0.0119	4.1975	1.3999
21	75	0.5	BWRS	0.9980	0.0202	5.0185	1.3850
22	55	1	BWRS	0.9977	0.0233	4.7785	1.4673
23	65	1	BWRS	0.9987	0.0172	5.4248	1.5162
24	75	1	BWRS	0.9978	0.0220	4.0285	1.4768
25	55	1.5	BWRS	0.9974	0.0253	4.4523	1.3933
26	65	1.5	BWRS	0.9985	0.0194	4.6398	1.4571
27	75	1.5	BWRS	0.9995	0.0116	5.7525	1.4931

***Where: Exp.No** = Experiment number, **Temp** = Temperature. **Thic** = Thickness, **Tre** = Treatment, **S-value** = Standard deviation value, **UB** = Unb-lanched, **BWORS** = Blanched without removing skin. **BWRS** = blanched with removing skin*

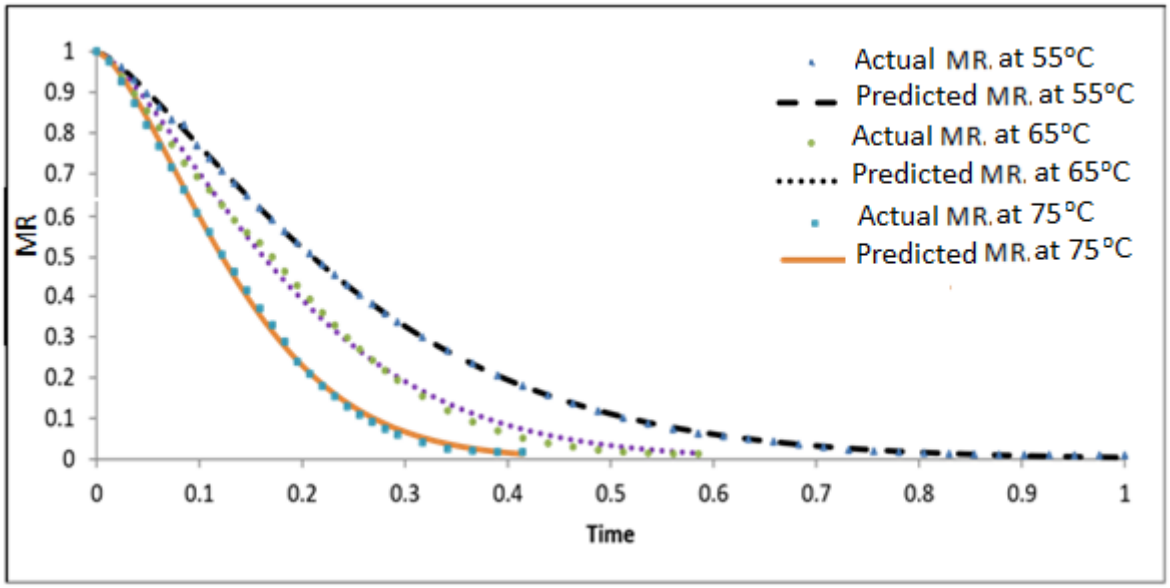

Figure 2. Effect of drying temperature on moisture ratio of Cactus cladode without blanching and with 0.5 cm slice thickness (**Time** is in minutes, and **MR** is in %)

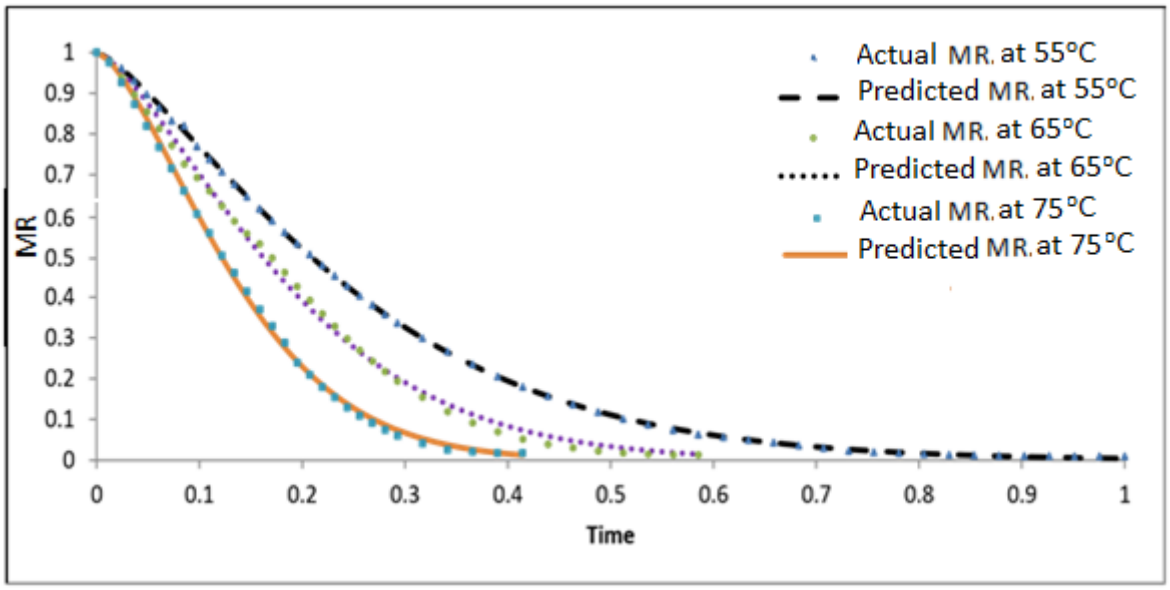

Figure 3. Effect of drying temperature on moisture ratio of Cactus cladode without blanching and with 1.0 cm slice thickness (**Time** is in minutes, and **MR** is in %)

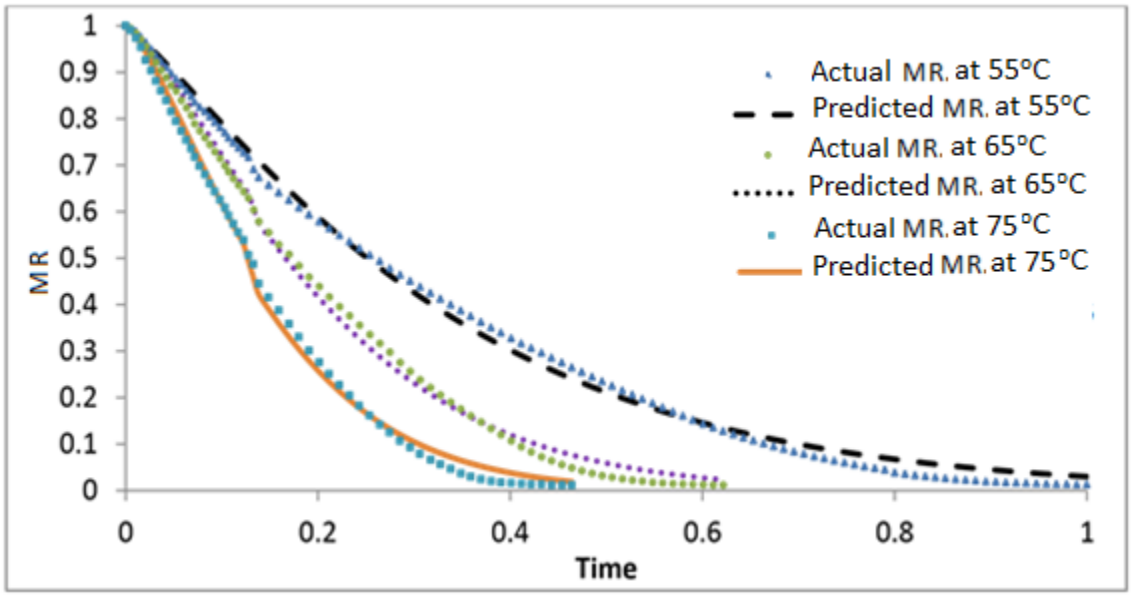

Figure 4. Effect of drying temperature on moisture ratio of Cactus cladode without blanching and with 1.5 cm slice thickness (**Time** is in minutes, and **MR** is in %)

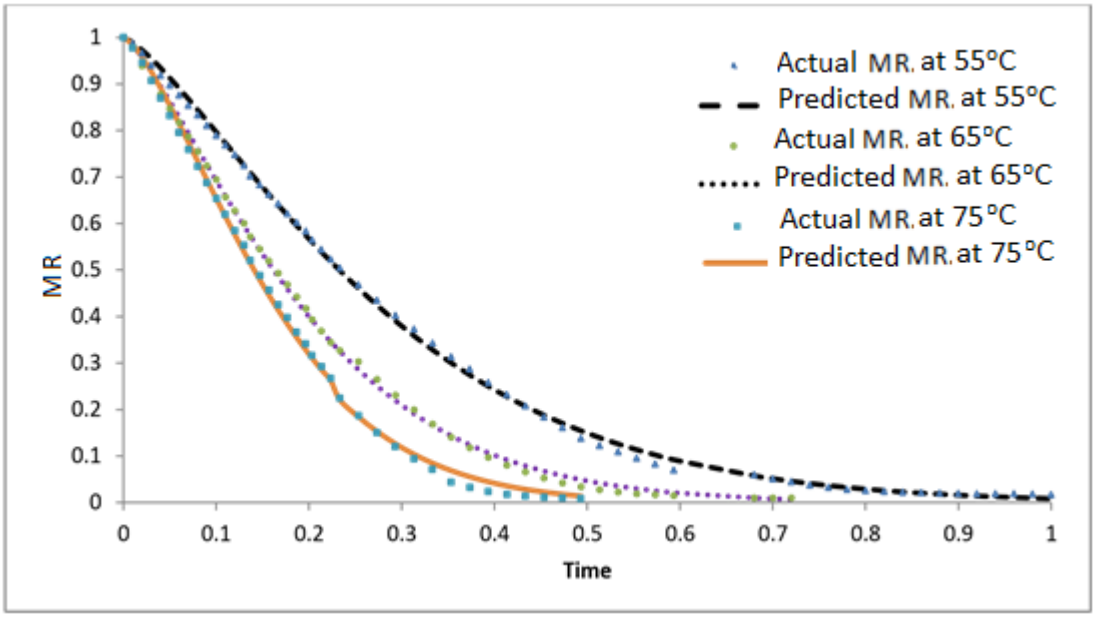

Figure 5. Effect of drying temperature on moisture ratio of Cactus cladode blanched at 90 ^{o}C for 2 min without removing skin and with 0.5 cm slice thickness (**Time** is in minutes, and **MR** is in %)

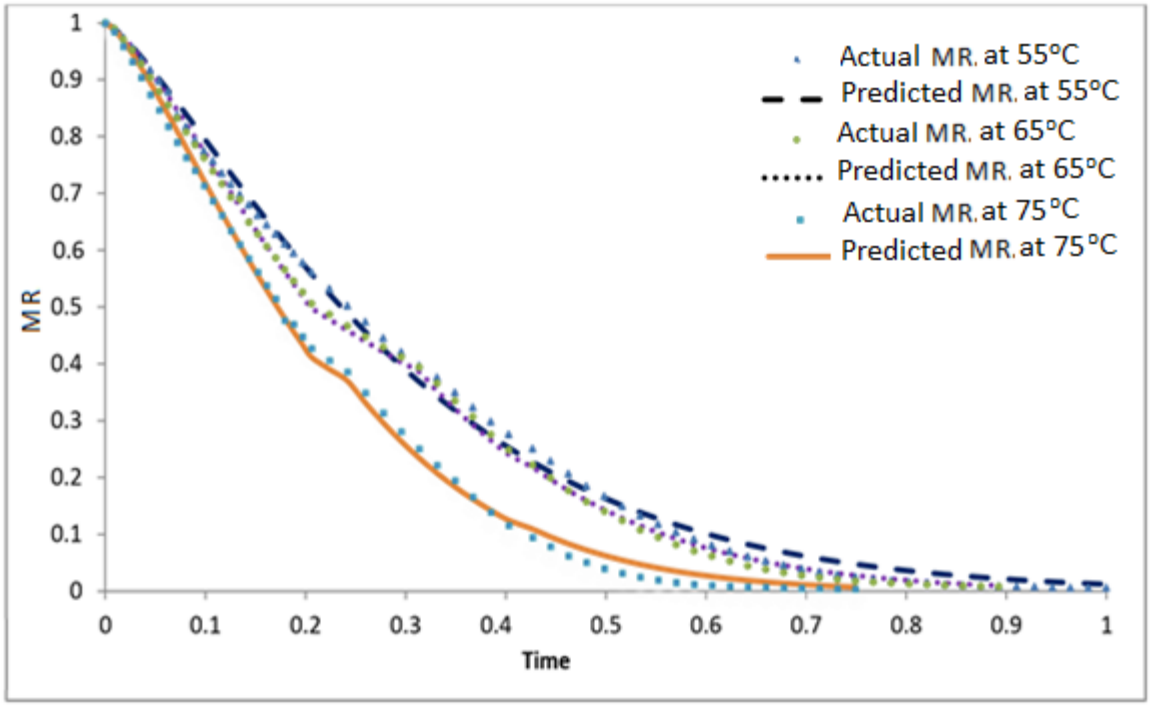

Figure 6. Effect of drying temperature on moisture ratio of cactus cladode blanched at 90 ^{o}C for 2 min without removing skin and with 1.0 cm slice thickness (**Time** is in minutes, and **MR** is in %)

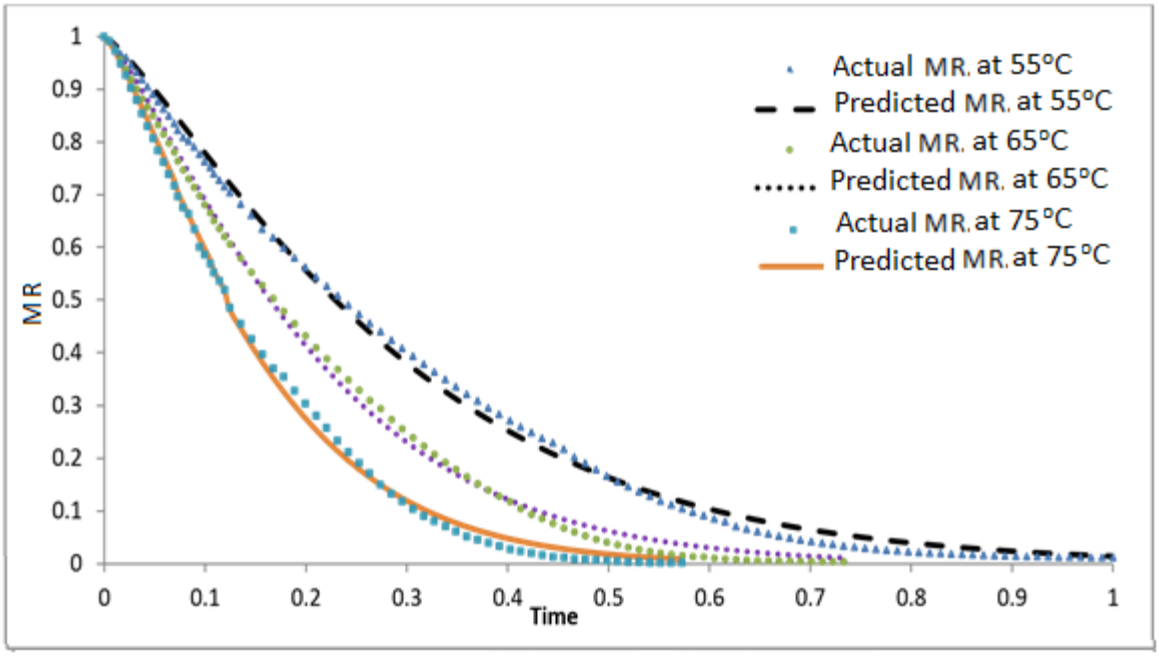

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Figure 7. Effect of drying temperature on moisture ratio of cactus cladode blanched at 90 ^{o}C for 2min without removing skin and with 1.5 cm slice thickness (**Time** is in minutes, and **MR** is in %)

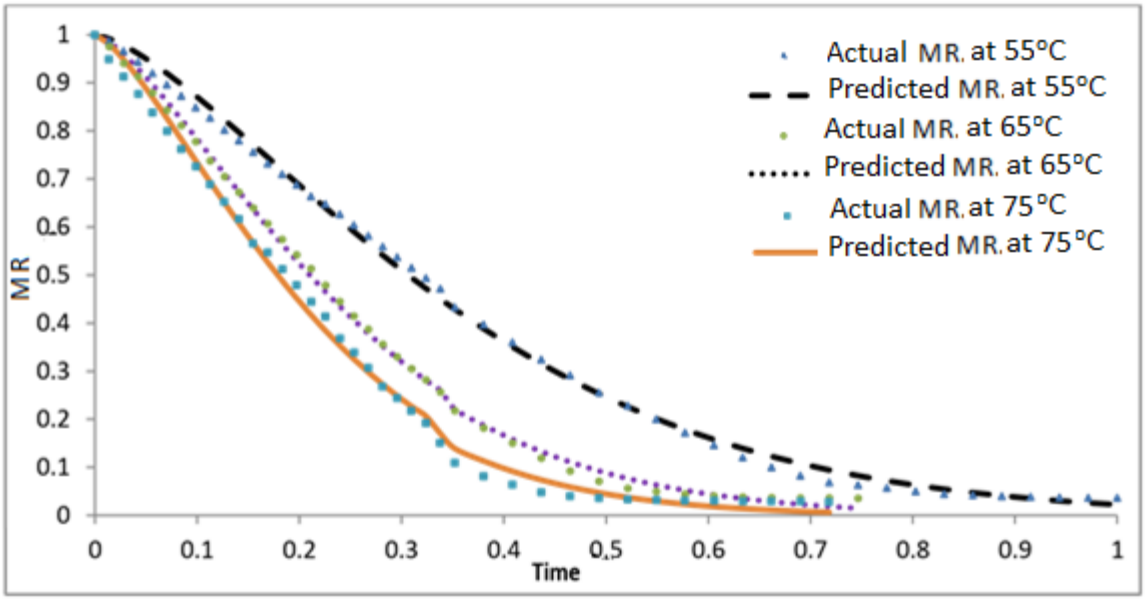

Figure 8. Effect of drying temperature on moisture ratio of cactus cladode blanched at 90 ^{o}C for 2 min after removing skin and with 0.5 cm slice thickness (**Time** is in minutes, and **MR** is in %)

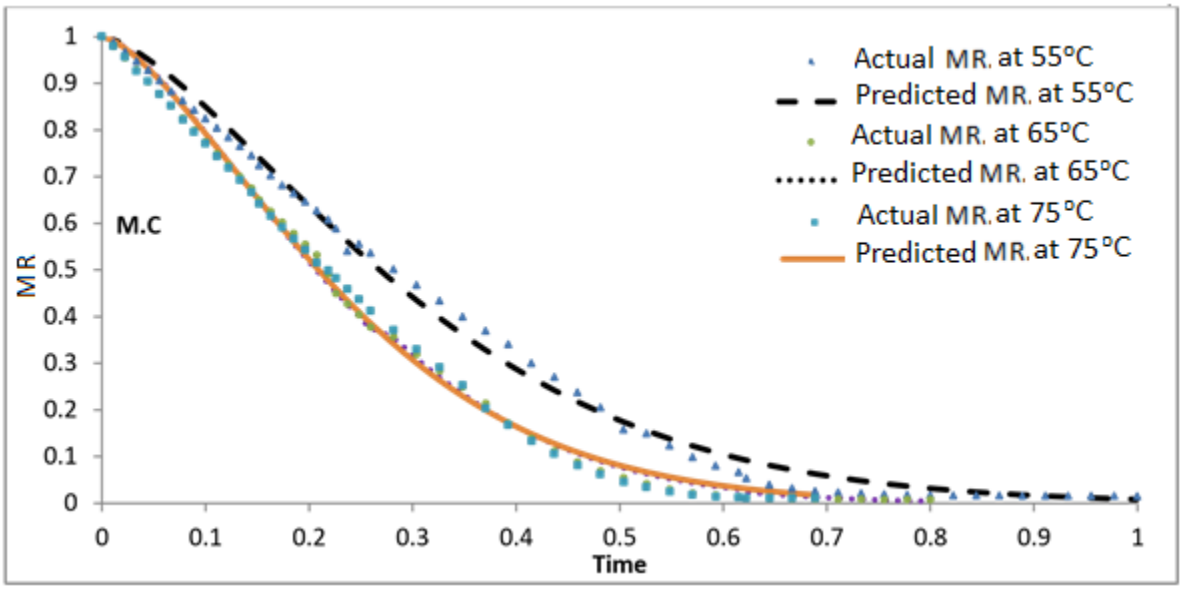

Figure 9. Effect of drying temperature on moisture ratio of cactus cladode blanched at 90 ^{o}C for 2 min after removing skin and with 1.0 cm slice thickness (**Time** is in minutes, and **MR** is in %)

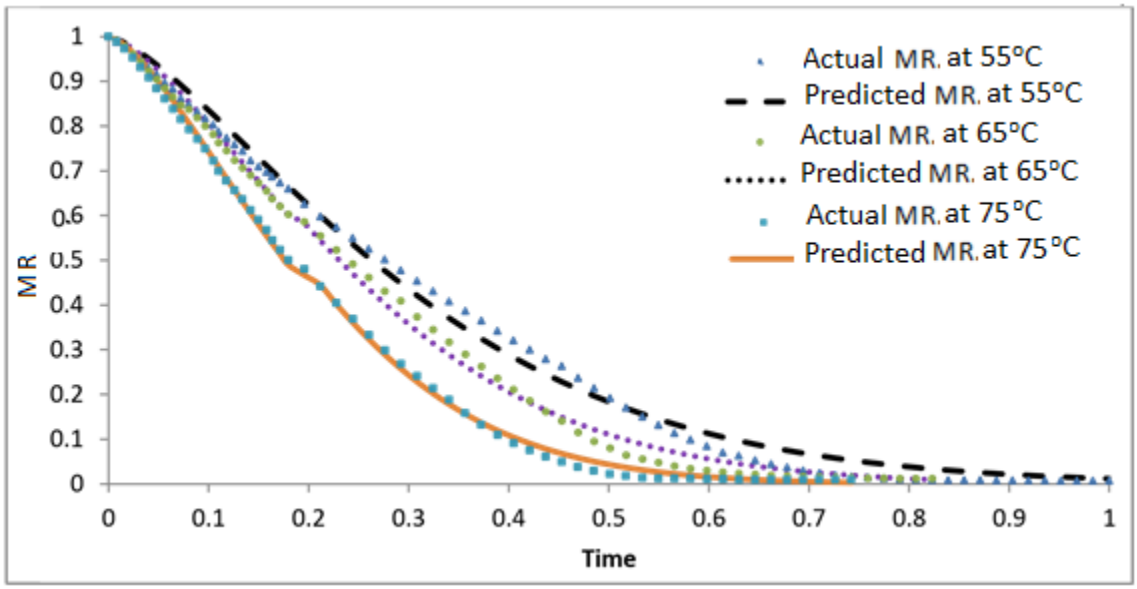

Figure 10. Effect of drying temperature on moisture ratio of cactus cladode blanched at 90 ^{o}C for 2 min after removing skin and with 1.5 cm slice thickness (**Time** is in minutes, and **MR** is in %)

4.1.2. Drying rate of cladodes

Drying rate was calculated using the recorded moisture data. Curve Experts 32 (version1.4) software was used to select the mathematical model that fitted the data. It was found that Hoerl equation, $Y=ab^{x}x^{c}$ gave better prediction for all pretreatment conditions. Coefficient of determination (R^2) varied from 0.9887 to 0.9992 and standard deviation ranged between 0.000010 and 0.000093. Drying rate graphs are shown in Figures 11-19. It is clear from the figures that the drying rate was low initially and continued to increase during the subsequent minutes and reached the peak point. This was due to the rise in temperature of the drying surface of the samples and that of the drying atmosphere in the drying environment. The rise in temperature of the air in the drying compartment continued with the buildup of heat until the air inside the drying room attains a wet bulb temperature. The heat supplied to the drying chamber was used to bring change of phase of the water thus no rise in air temperature was possible. As time went by, the quantity water flowing out from the interior of the samples to the drying surface was reduced leading to the fall of the drying rate. As more and more water was lost to the drying air by the sample, less and less water was available to move to the drying surface thus resulting in a continuous falling of the drying rate. This continued until equilibrium moisture content was reached by drying sample. This phenomenon occurred in all

the samples regardless of the drying temperature, presence or absence of the sample peel or the thickness of the drying samples. As the drying rate continuously fell some of the heat supplied to the drying chamber was available to raise the temperature of the drying sample and that of the air above the wet bulb value. In general drying rate increased for a short while, up to a certain level, and then continuously decreased. In relation to the drying temperature, the drying rate was highest at 75°C followed by that of the 65 and 55°C up to a certain time and then the trend was reversed, i.e, drying rate at 55°C was higher than that at 65 and 75°C. This was because at higher temperature large quantity of water was lost rapidly in the early periods because of ample water ready for evaporation and the higher heat supply. This resulted in higher water evaporation during early periods of the drying process leading to reduced supply of water coming to the surface and less and less water being evaporated in the later periods of the drying time.

Figures 11-19 showed that there were good agreements in the profiles between actual and predicted drying rate data. The statistical analysis results in terms of R^2, standard deviation and the coefficient of the Hoerl model are shown in Table 4 for the different combinations of drying temperature, slice thickness and pretreatments applied to the samples.

Table 3. Best fit mathematical modeling result for drying rate verses time ($y = ab^t t^c$)

Exp. No	Temp (^oC)	Thick (cm)	Treatment	R^2-value	S- value	Coefficients		
						a	b	c
1	55	0.5	UB	0.9962	0.000071	$1.373*10^{-2}$	$2.769*10^{-3}$	$5.436*10^{-1}$
2	65	0.5	UB	0.9960	0.000086	$2.105*10^{-2}$	$8.697*10^{-3}$	$6.700*10^{-1}$
3	75	0.5	UB	0.9947	0.00013	$4.379*10^{-2}$	$6.296*10^{-3}$	$8.674*10^{-1}$
4	55	1	UB	0.9979	0.000027	$2.318*10^{-3}$	$9.735*10^{-3}$	$2.383*10^{-1}$
5	65	1	UB	0.9964	0.000048	$1.140*10^{-2}$	$6.569*10^{-3}$	$6.433*10^{-1}$
6	75	1	UB	0.9941	0.000071	$9.662*10^{-3}$	$1.164*10^{-2}$	$5.375*10^{-1}$
7	55	1.5	UB	0.9992	0.000010	$1.885*10^{-3}$	$2.748*10^{-2}$	$2.370*10^{-1}$
8	65	1.5	UB	0.9969	0.000029	$4.829*10^{-3}$	$1.819*10^{-2}$	$4.712*10^{-1}$
9	75	1.5	UB	0.9961	0.000046	$7.137*10^{-3}$	$1.471*10^{-2}$	$5.029*10^{-1}$
10	55	0.5	BWORS	0.9971	0.000005	$8.817*10^{-3}$	$6.043*10^{-3}$	$5.172*10^{-1}$
11	65	0.5	BWORS	0.9969	0.000064	$1.325*10^{-2}$	$4.966*10^{-3}$	$5.262*10^{-1}$
12	75	0.5	BWORS	0.9958	0.000084	$2.150*10^{-2}$	$8.284*10^{-3}$	$7.069*10^{-1}$
13	55	1	BWORS	0.9980	0.000032	$6.269*10^{-3}$	$8.971*10^{-3}$	$4.413*10^{-1}$
14	65	1	BWORS	0.9967	0.000047	$1.040*10^{-2}$	$6.357*10^{-3}$	$5.824*10^{-1}$
15	75	1	BWORS	0.9962	0.000062	$1.353*10^{-2}$	$4.607*10^{-3}$	$6.052*10^{-1}$
16	55	1.5	BWORS	0.9969	0.000024	$2.727*10^{-3}$	$1.278*10^{-2}$	$3.255*10^{-1}$
17	65	1.5	BWORS	0.9983	0.000025	$4.737*10^{-3}$	$8.658*10^{-3}$	$3.911*10^{-1}$
18	75	1.5	BWORS	0.9979	0.000037	$6.980*10^{-3}$	$6.366*10^{-3}$	$4.352*10^{-1}$
19	55	0.5	BWRS	0.9953	0.000057	$1.156*10^{-2}$	$1.493*10^{-2}$	$6.638*10^{-1}$
20	65	0.5	BWRS	0.9962	0.000074	$1.803*10^{-2}$	$9.180*10^{-3}$	$6.570*10^{-1}$
21	75	0.5	BWRS	0.9949	0.000010	$2.395*10^{-2}$	$3.916*10^{-3}$	$6.683*10^{-1}$
22	55	1	BWRS	0.9954	0.000055	$1.547*10^{-2}$	$4.827*10^{-3}$	$7.731*10^{-1}$
23	65	1	BWRS	0.9928	0.000093	$2.930*10^{-2}$	$2.221*10^{-3}$	$9.054*10^{-1}$
24	75	1	BWRS	0.9934	0.000080	$1.616*10^{-2}$	$1.118*10^{-2}$	$7.406*10^{-1}$
25	55	1.5	BWRS	0.9912	0.000054	$6.822*10^{-3}$	$8.655*10^{-3}$	$5.881*10^{-1}$
26	65	1.5	BWRS	0.9887	0.000075	$1.060*10^{-2}$	$6.690*10^{-3}$	$7.007*10^{-1}$
27	75	1.5	BWRS	0.9926	0.000082	$2.388*10^{-2}$	$1.642*10^{-3}$	$8.687*10^{-1}$

***Where**: **Exp.No** = Experiment number, **Tem** = Temperature. **Thic** = Thickness, **Tre** = Treatment, **S-value** = Standard deviation value, **UB** = Unblanched, **BWORS** = Blanched without removing skin. **BWRS** = blanched after removing skin*

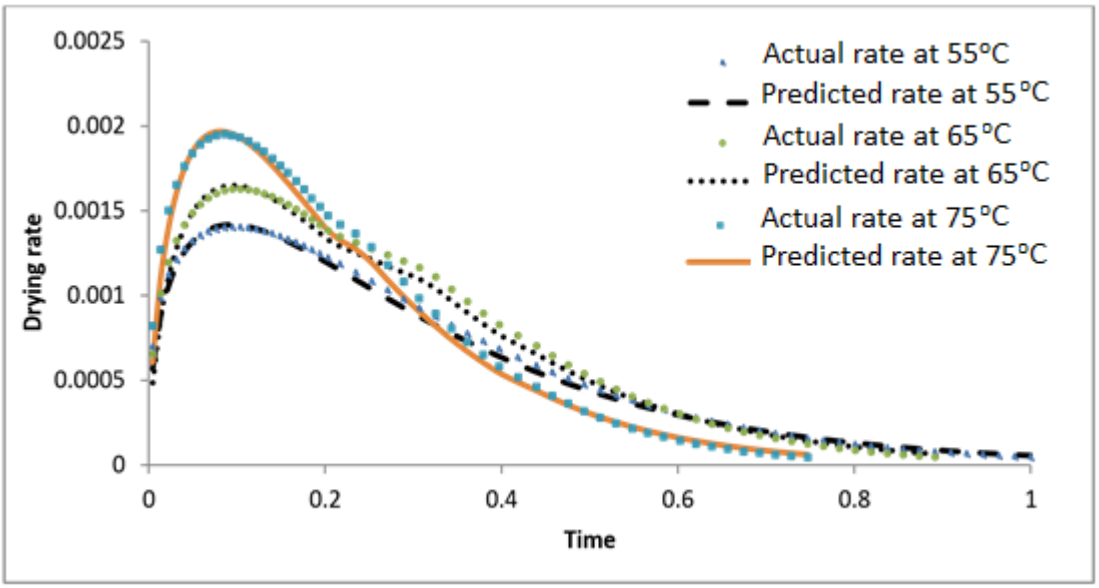

Figure 11. Effect of drying temperature on drying rate of un-blanched cactus cladode with 0.5 cm slice thickness (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

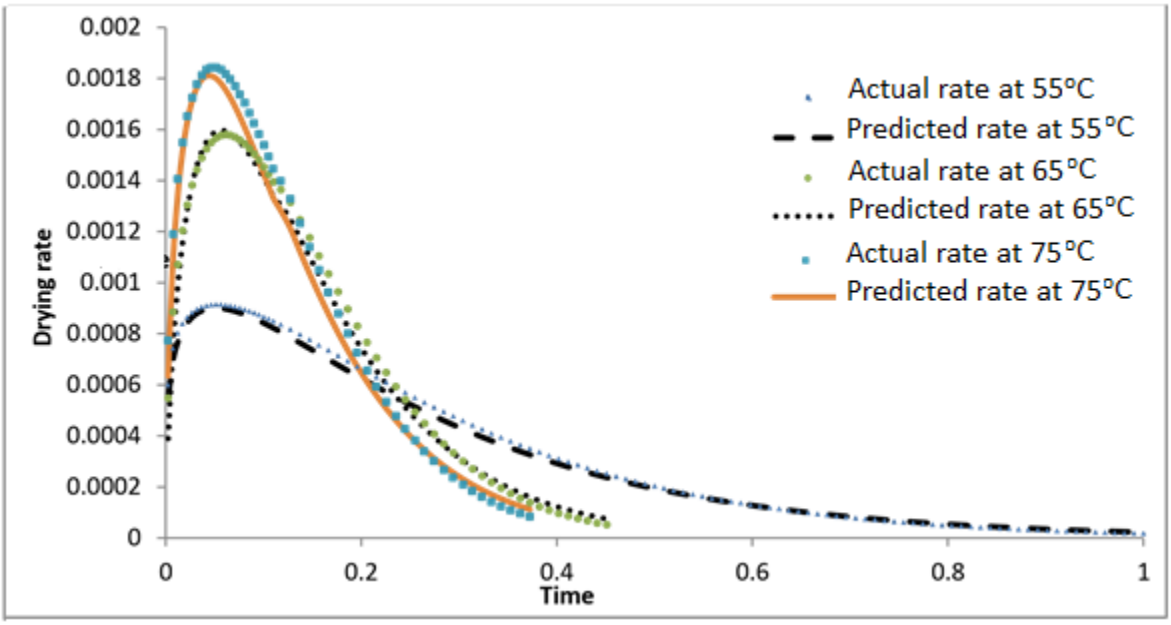

Figure 12. Effect of drying temperature on drying rate of un-blanched cactus cladode with the1.0 cm slice thickness (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

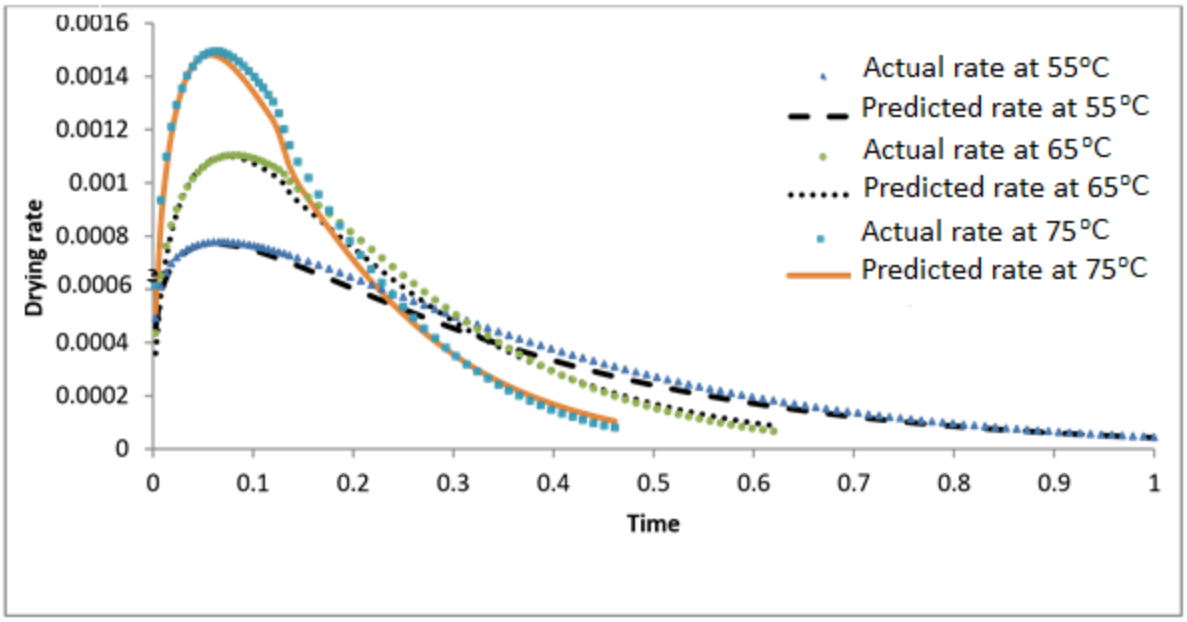

Figure 13. Effect of drying temperature on drying rate of unblanched cactus cladode with 1.5 cm slice thickness (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

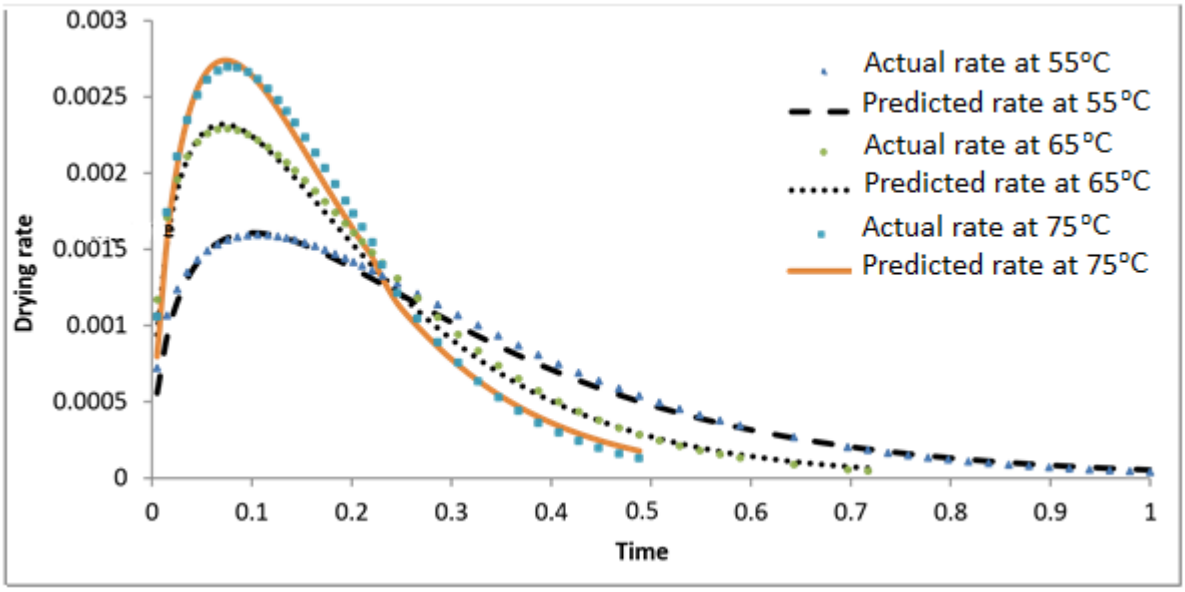

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Figure 14. Effect of drying temperature on drying rate of cactus cladode blanched without removing skin with slice thickness of 0.5 cm (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

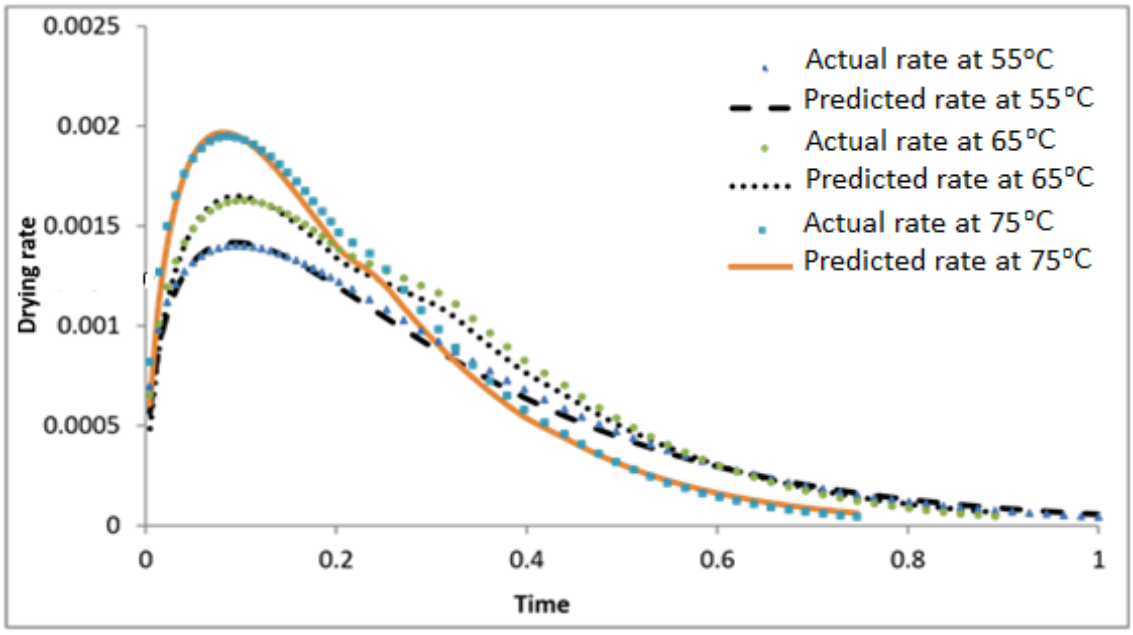

Figure 15. Effect of drying temperature on drying rate of cactus cladode blanched without removing skin with slice thickness of 1.0 cm (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

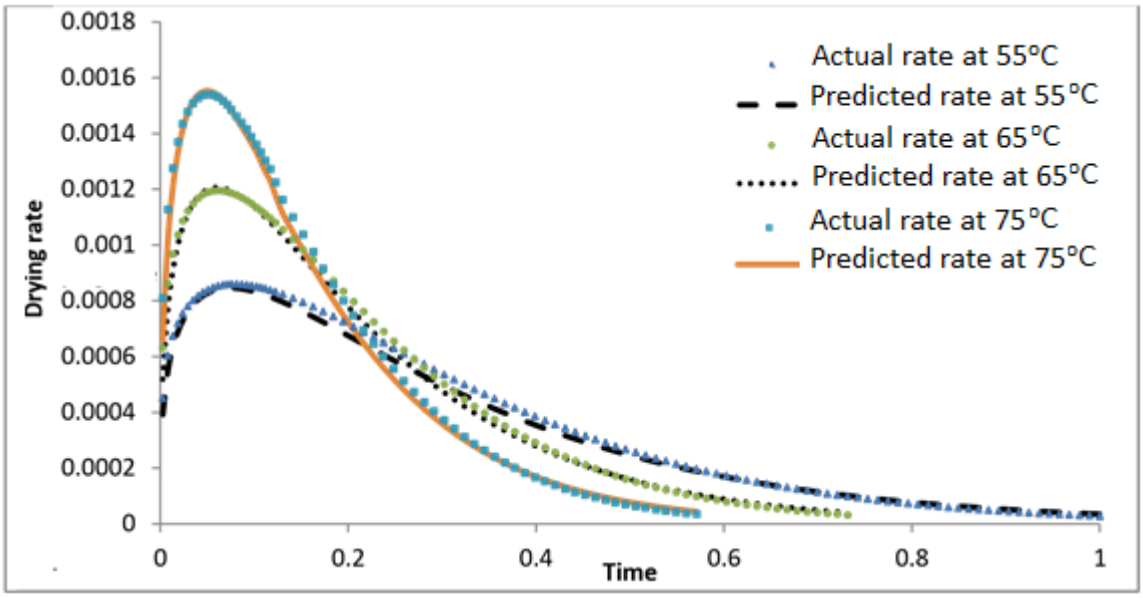

Figure 16. Effect of drying temperature on drying rate of cactus cladode blanched without removing skin with slice thickness of 1.5 cm (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

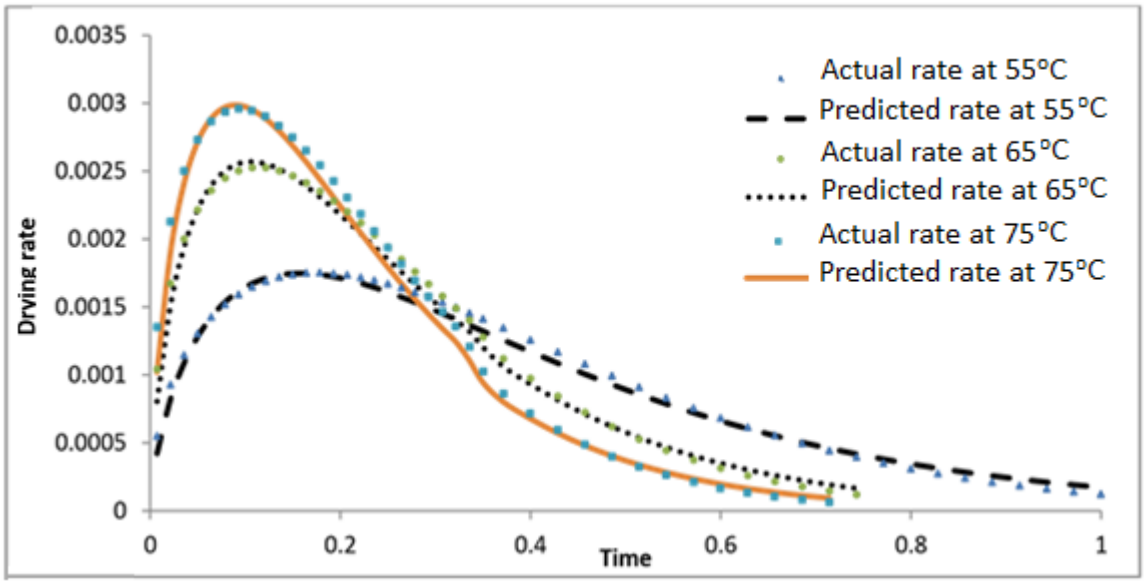

Figure 17. Effect of drying temperature on drying rate of cactus cladode blanched after removing skin with slice thickness of 0.5 cm (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

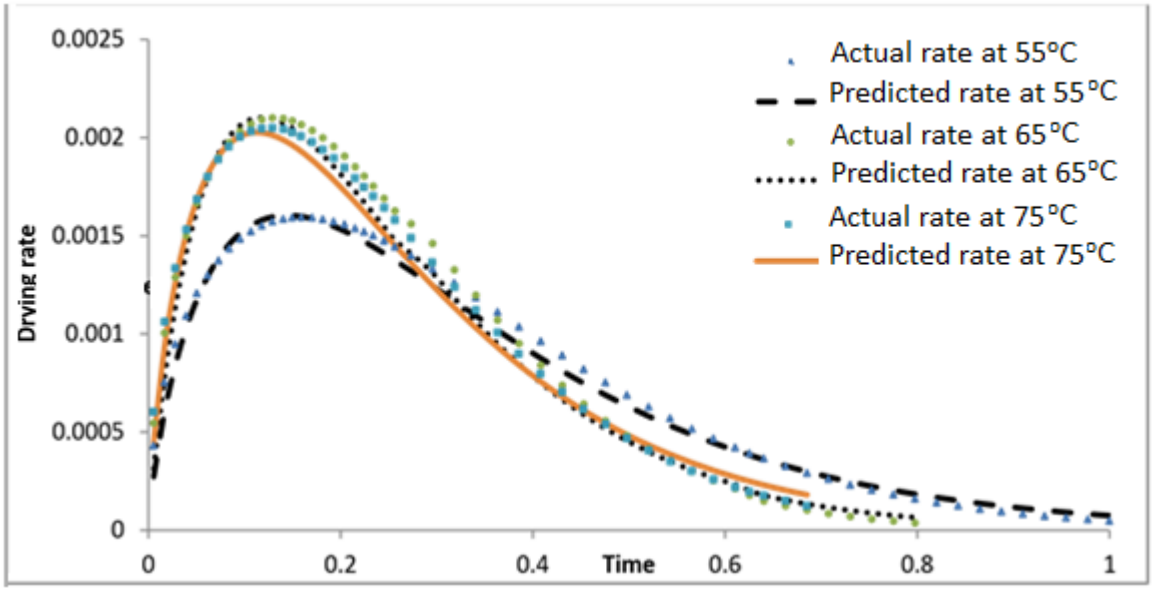

Figure 18. Effect of drying temperature on drying rate of cactus cladode blanched after removing skin with slice thickness of 1.0 cm (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

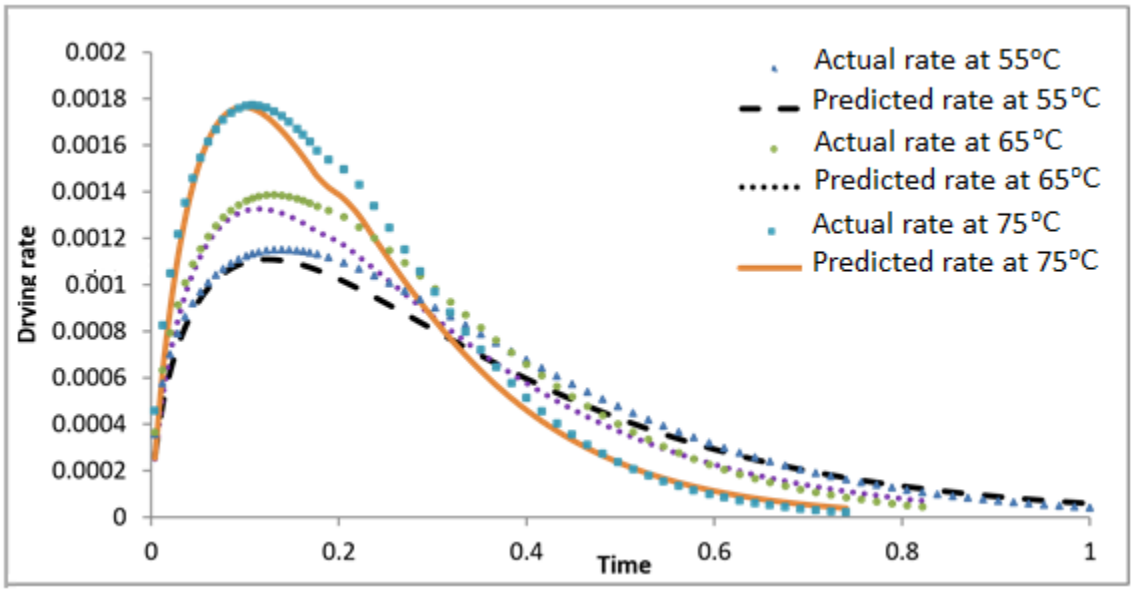

Figure 19. Effect of drying temperature on drying rate of cactus cladode blanched after removing skin with slice thickness of 1.5 cm (**Time** is in minutes, and **drying rate** is Kg of water/Kg of material.minute)

In regard to slice thickness, the drying rate was the highest for samples with 0.5 cm thickness which could be attributed to the short distance that the moisture travels from the interior of the samples to reach the drying surface. The drying rates in samples of this thickness remained relatively higher for longer duration during the drying process as compared to the thicker slices. This was true regardless of the difference in the drying temperatures because more and more water was evaporated continuously and the water in the tissue was moving to the surface for short distance. Thus the time needed for the drying rate to reach minimum value was relatively shorter. The two higher drying temperatures (65 and 75^{o}C) needed more than 75% of the time needed at 55^{o}C drying. The drying rates were lowest for those samples with the largest slice thickness for all three drying temperatures.

The blanched samples exhibited the highest rate of drying for the respective drying temperatures as compared to those un-blanched samples. This could be attributed to the additional water absorbed by the samples during the blanching process which could easily be lost by the tissue. Furthermore, the blanching could result in softening the tissue of the samples allowing fast loss of the additional water during drying. The removal of the skin before blanching exhibited big difference in the drying rate of slices. All samples blanched after removing the skin showed the highest rate of drying for all three drying temperatures. It

could be due to high water absorption of water by the tissue during blanching process and a correspondingly high loss of the water during drying as the tissue has no protective layer to slow down the water loss. So presence or absence of the peel had significant impact on the drying rate of the cladode leaves.

4.2. Functional and physical properties of cladodes powder

Data of the functional properties of cladode powder determined in experiments are given in Table 5. Design Expert (trial version) was used to analyze the data of different attributes as function of pretreatments which are considered categorical factors; and of drying temperature and slice thickness as numerical factors. The results and their analyses are reported in the following sections.

4.2.1. Water absorption capacity

The minimum water absorption capacity (WAC) was 5.63 g/g of the experiment number 18 (Table 4) with conditions of 75 ℃ of drying temperature, 1.5 cm slice thickness and pretreatment of blanching without removal of the skin. The maximum WAC was 26.73 g/g of experiment number 8 (Table 4) with un-blanched sample, dried at 65℃ and 1.5 cm thickness. Similar reports of past work such as WAC value of 14.27 g/g and 15.49 g/g reported by Ramírez-Moreno *et al.* (2013) in different cultivation areas. In addition, Aparicio-Ortuño *et al.* (2024) reported that he got a result of 34.67% WAC. So, the variations among the findings in this study and the reports just mentioned might be due to differences in variety, maturity, and processing conditions.

4.2.2 Water solubility index (WSI)

The water solubility index (WSI) data of the cladode powder had 24.17% as the minimum value of the experiment number 9 with condition of 75℃ drying temperature, 1.5 cm slice thickness and no blanching. The maximum WSI was 45% of experimental numbers 3 and 27 (Table 4) the conditions of which were un-blanched sample, dried at 65 ℃ and with slice thickness of 0.5 cm and a blanched sample after removing the skin with 1.5 cm slice thickness. Ayadi (2009) reported WSI value of 5.23% for spiny and 27.84% for spineless cladodes. The variation in the values might be due to differences in variety and processing conditions.

4.2.3. Swelling power

The swelling power data of the cladode powder ranged from 49.87% to 105.27%. The lowest value was of the experiment number 3 (Table 4) with conditions of 75°C drying temperature, 0.5 cm slice thicknesses and no-blanching. The maximum value was of experiment number 23 (Table 4) with conditions of blanching after removing skin, drying at 65°C and with slice thickness of 1cm. Elsafy-(2013) reported SP value of 60% while Ayadi *etal* (2009) expressed it as 7.37cm^3/g and 7.78cm^3/g for spiny and spineless cladodes, respectively. The variations between the findings in this study and the literature reports might be due to differences in variety and processing conditions.

4.2.4. Oil absorption capacity

The data of oil absorption capacity varied between 0.575 and 1.100 ml/g. The smallest value was of experimental number 27 (Table 4) with samples blanched after removing the skin with slice thickness of 1.5 cm and dried at 75^{o}C. On the other hand the largest value was of experiment number 1 (Table 4) with un-blanched samples of 0.5 cm slice thickness dried at 55^{o}C. El-safy-(2013) and Lopey-cervantes *etal.* (2011) reported that the OAC value of 2.80 ml/g and 3.7 g of oil per gram of dry matter respectively. The variation on OAC may be due to treatment condition.

4.2.5. Bulk density

The bulk density values of cladode powder ranged from 0.449 to 0.836 g/cm^3. The lowest value belonged to the experimental number 7 (Table 4) with conditions of 55°C drying temperature, 1.5 cm slice thickness and un-blanched sample. On the other hand the highest value was of samples of experimental number 16 (Table 4) with samples blanched without removing the skin and dried at 55°C and 1.5 cm slice thickness. As Nabil *et al.* (2020), and Aparicio-ortune *etal.* (2024) mentioned that the bulk density results 0.95 g/cm^3 and 0.77 g/100g respectively. The results reported by the two scholars were aligned with our results.

Table 4 . Average value of responses of the functional properties

Exp. N<u>o</u>	Temperature (^{o}C)	Thickness (cm)	Treatmt	**Functional Properties**				
				WAC	WSI	SP	OAC	BD
1	55	0.5	UB	15.35	30.00	60.33	1.100	0.458
2	65	0.5	UB	10.80	30.83	54.97	0.895	0.524
3	75	0.5	UB	18.05	45.00	49.87	0.870	0.552
4	55	1	UB	24.70	25.50	54.63	0.870	0.494
5	65	1	UB	21.23	30.77	60.00	0.885	0.473
6	75	1	UB	18.60	24.90	62.43	0.855	0.537
7	55	1.5	UB	26.53	25.00	69.80	0.980	0.449
8	65	1.5	UB	26.73	25.23	61.83	0.950	0.491
9	75	1.5	UB	12.15	24.17	85.17	0.850	0.486
10	55	0.5	BWORS	9.50	30.50	55.00	0.760	0.616
11	65	0.5	BWORS	10.45	30.50	55.60	0.705	0.644
12	75	0.5	BWORS	11.18	35.03	50.10	0.660	0.696
13	55	1	BWORS	10.45	35.03	55.03	0.695	0.643
14	65	1	BWORS	11.40	30.50	55.37	0.630	0.690
15	75	1	BWORS	9.48	30.50	60.00	0.695	0.667
16	55	1.5	BWORS	9.30	25.07	50.00	0.845	**0.**836
17	65	1.5	BWORS	6.93	36.37	55.73	0.770	0.606
18	75	1.5	BWORS	5.63	40.00	50.07	0.685	0.616
19	55	0.5	BWRS	12.03	25.00	55.45	0.710	0.691
20	65	0.5	BWRS	11.48	20.90	70.00	0.735	0.709
21	75	0.5	BWRS	9.70	40.00	60.00	0.875	0.702
22	55	1	BWRS	14.50	25.73	53.30	0.710	0.689
23	65	1	BWRS	10.53	30.50	105**.**27	0.830	0.654
24	75	1	BWRS	11.48	26.03	65.77	0.815	0.679
25	55	1.5	BWRS	10.53	40.00	50.00	0.630	0.654
26	65	1.5	BWRS	8.15	35.00	51.83	0.635	0.634
27	75	1.5	BWRS	6.05	45.00	50.00	0.575	0.636

*Where: **UB** = un-blanched, **BWORS** = blanched without removing skin (90℃, 2min), **BWRS** = blanched with removing skin (90℃, 2min) **WAC** = water absorption capacity, WSI = water solubility index, **SP** = swelling power, OAC = oil absorption capacity, BD = bulk density*

Table 5 presented probability data and the level of significance of the effect of the different factors and their interaction on the various functional properties of the cladode powder. Drying temperature had significant effect ($P \leq 0.05$) on the water absorption capacity (WAC) while pre-treatments had highly significant ($P \leq 0.01$) effect on same property. Likewise interaction

between drying temperature and slice thickness showed significant effect (P≤0.05) while the interaction between slice thickness and pretreatments exhibited highly significant (P≤0.01) effect on the same functional property.

Water solubility index was significantly (P<0.05) affected by drying temperature as well as the interaction of slice thickness and the pretreatments. The swelling power was not affected (P>0.05) by either of the factors and their interactions. The oil absorption capacity of the cladode powder was highly significantly (P≤ 0.0001) affected by the pretreatments. It was also significantly (P<0.05) influenced by interactions of the pretreatments with both the drying temperature and the slice thickness.

The bulk density of the cladode powder was highly significantly (P≤ 0.0001) affected by pretreatments and significantly (P≤0.05) affected by the interaction of drying temperature and slice thickness.

Generally coefficients of equations for calculating various responses are given in Table 7. Final equation of WAC, WSI, SP, OAC and BD as influenced by various treatments i.e raw, blanched with out and with removal of skin are also given in Table 8.

Table 5. Probability data of the effect of factors on functional properties

Factor	WAC	WSI	SP	OAC	BD
Model	0.0001sign	0.0953sign	0.5879 not sign	<0.0002 sign	<0.0001sign
X1	0.0210**	0.0565**	0.6037	0.1641	0.8101
X2	0.7766	0.7393	0.8063	0.1946	0.2969
X3	<0.0001****	0.3745	0.2892	<0.0001****	<0.0001****
X1X2	0.0228**	0.4388	0.5496	0.4557	0.0130**
X1X3	0.3420	0.9356	0.9332	0.0526**	0.1375
X2X3	0.0091***	0.0128**	0.1612	0.0400**	0.1407
R^2	0.8467	0.5216	0.3088	0.8042	0.8847
S.D	2.83	5.62	12.41	0.068*	0.040**

***Where**: sign = significant, **X1** = temperature, **X2** = thickens, **X3** = treatment, **X1X2** =the interaction temperature and thickens, **X1X3** =the interaction temperature and treatment, **X2X3** = the interaction thickens and treatment, **R^2** = coefficient of determination, **SD**= standard deviation, **WAC**= water absorption capacity, **WSI** =water solubility index, **SP** = swelling power, **OAC,** = oil absorption capacity, **BD**= bulky density*

Table 6. Coefficient estimates for models representing responses of various factors on

Model	WAC	WSI	SP	OAC	BD
Intercept	13.11	31.22	59.61	0.79	0.61
Temperature	-1.70	2.71	1.55	-0.023	$2.311*10^{-3}$
Thickness	0.19	0.45	0.73	-0.022	-0.010
Raw	6.24	-2.18	2.50	0.13	-0.12
Blanched with removing skin	-3.74	1.39	-5.51	-0.070	0.056
Temperature and thickness	-2.05	-1.29	2.19	-0.015	-0.032
Temperature and Raw	-1.27	-0.45	0.57	-0.039	0.027
Temperature and BWRS	1.21	-0.22	-1.53	-0.020	-0.022
Thickness and Raw	3.34	-5.69	7.88	$7.500*10^{-3}$	$-7.511*10^{-3}$
Thickness and BWRS	-1.74	0.45	-1.55	0.051	0.027

Where: - WAC= water absorption capacity, WSI =water solubility index, SP = swelling power, OAC, = oil absorption capacity, BD= bulky density

Table 7. The final equation in terms of actual factors on functional properties

Property	-1 (Raw)	0 (BWORS	1 (BWRS)
WAC			
Intercept	19.3500	9.37037	10.61481
A(temperature)	-2.96389	-0.49169	-1.63889
B(thickness)	3.53611	-1.54444	-1.41389
AB(temp & thick)	-2.04861	-2.04861	-2.04861
WSI			
Intercept	29.04444	32.61111	32.01852
A(temperature)	2.26111	2.48889	3.38333
B(thickness)	-5.23889	0.90000	5.68333
AB(temp & thick	-1.28611	-1.28611	-1.28611
SP			
Intercept	62.11481	54.1000	62.62407
A(temperature)	2.11667	0.022222	2.50278
B(thickness)	8.60556	-0.81667	-5.60278
AB(temp & thick	2.18750	2.18750	2.18750
OAC			
Intercept	0.91722	0.71611	0.72389
A(temperature)	-0.062500	-0.043333	0.035833
B(thickness)	-0.014167	0.029167	-0.080000
AB(temp & thick)	-0.015000	-0.015000	-0.015000
BD			
Intercept	0.49607	0.66818	0.67193
A(temperature)	0.028933	-0.019333	-2.6666*10-3
B(thickness)	-0.017700	0.017033	-0.029900
AB(temp & thick)	-0.032167	-0.032167	-0.032167

***Where:** - WAC= water absorption capacity, WSI =water solubility index, SP = swelling power, OAC, = oil absorption capacity, BD= bulky density*

4.3. The Effects of Drying Condition of Cladodes on Selected Phytochemicals

The phytochemicals (chlorophylls a and b, and carotenoid) of cladode powder determined in experiments are given in Table 8. Design expert (trial version) was used to analyze the data considering pretreatments as categorical factors and temperature and thickness as numerical factors. The results of analyses are reported in following sections.

4.3.1. Chlorophyll ^{a}

The minimum value of chlorophyll a was 0.032 mg/g of the experiment number 21 (Table 8) with condition of 75℃ drying temperature, 0.5 cm slice thickness and blanching after removal of the skin. The maximum value was 0.041 mg/g of experiment number 5 (Table 8) with un-blanched sample, 65℃ drying temperature and 1 cm slice thickness. These findings were in agreement with the those of El-safy-(2013) who reported Chl(a) value of 6.70 mg/100g and of Ayadi *etal.* (2009), who had earlier report of 9.93 mg/100g. The variations between the findings in this study and the literature reports might be due to differences in variety, maturity, and processing conditions.

4.3.2 Chlorophyll ^{b}

Similarly the minimum value of chlorophyll b was 0.055 mg/g of the experiment number 19 (Table 8) with conditions of 55℃ drying temperature, 0.5 cm slice thickness and blanching after removal of the skin. On the other hand, the maximum was 0.063 mg/g of experiment number 2 (table 8) with un-blanched sample of 0.5 cm thickness and a drying temperature of 65℃. The reports of El-safy (2013) with a value of 16.255 mg/100g and that of Ayadi *etal.* (2009) with a value of 17.6 mg/100g appeared to be slightly higher than the findings in this work. The variation might be due to differences in variety and processing conditions.

4.3.3. Carotenoids

Table 8 also shows that the minimum value of carotenoids was 0.018 mg/g of the experiment number 19 (Table 8) with conditions of 55℃ drying temperature, 0.5 cm slice thicknesses and blanching after removal of the skin. On the other hand the maximum value was 0.025 mg/g of experiment number 27 (Table 8) with un-blanched sample of 1.5 cm thickness dried at 75℃. Similarly Lahmidi et al. (2023) was reported 0.019 to 0.060 mg/g the sample. The variability

in carotenoid values reported in different studies may be due to maturity, species, growing, and processing condition.

Table 8. The average values (mg/g) of response phytochemicals

Expt.No	Factors			Parameters		
	Temperature	Thickness	Pre-treatment	Chl. ^{a}	Chl. ^{b}	Carotenoid
1	55	0.5	UB	0.039	0.062	0.021
2	65	0.5	UB	0.039	0.063	0.021
3	75	0.5	UB	0.037	0.060	0.020
4	55	1	UB	0.038	0.059	0.020
5	65	1	UB	0.041	0.061	0.021
6	75	1	UB	0.039	0.060	0.021
7	55	1.5	UB	0.035	0.056	0.019
8	65	1.5	UB	0.038	0.058	0.021
9	75	1.5	UB	0.038	0.057	0.022
10	55	0.5	BWORS	0.035	0.056	0.019
11	65	0.5	BWORS	0.035	0.058	0.020
12	75	0.5	BWORS	0.035	0.057	0.020
13	55	1	BWORS	0.035	0.056	0.020
14	65	1	BWORS	0.035	0.057	0.020
15	75	1	BWORS	0.036	0.057	0.021
16	55	1.5	BWORS	0.037	0.056	0.021
17	65	1.5	BWORS	0.036	0.057	0.021
18	75	1.5	BWORS	0.034	0.056	0.020
19	55	0.5	BWRS	0.033	0.055	0.018
20	65	0.5	BWRS	0.034	0.056	0.020
21	75	0.5	BWRS	***0.032***	0.056	0.019
22	55	1	BWRS	0.036	0.056	0.021
23	65	1	BWRS	0.035	0.056	0.021
24	75	1	BWRS	0.033	0.056	0.020
25	55	1.5	BWRS	0.033	0.059	0.024
26	65	1.5	BWRS	0.038	0.058	0.023
27	75	1.5	BWRS	0.035	0.056	0.025

***Where: UB** = un-blanched , **BWORS** = blanched without removing skin (90°C, 2 min), **BWRS** = blanched after removing skin (90°C, 2 min) , **Chl** ^{a} = chlorophyll and **Chl** ^{b} = chlorophyll b*

Table 9 presented the data of the probabilities of occurrence of significant effects of the three factors on the three parameters. It shows that Chlorophyll a was affected by slice thickness significantly at 5% while the pretreatments had effect at 1% level of significance. Effect of interaction between slice thickness and pretreatments on the same parameter was also highly significant ($P < 0.01$).

In regard to Chlorophyll b, the same table shows that pre-treatments had significant effect at 1% level and the interaction between thickness and pre- treatment was also highly ($P<0.01$) significant. Likewise, thickness had significant effect at 1% level.

Generally equations for calculating various responses are given in Table 10. Final equations of chlorophyll (a), chlorophyll (b) and carotenoid for various treatments i.e raw, blanched with out and with removal of skin are reported in Table 11.

Table 9. Probability of the effect of factors on phyto-chemicals

Factor	Chl. a	Chl. b	Carotenoid
Model	0.0005 sign	<0.0001sign	0.0002sign
X1	0.0615*	0.5379	0.3374
X2	0.0290**	0.0336**	<0.0001****
X3	0.0005****	<0.0001****	0.2340
X1X2	0.5908	0.7237	0.7082
X1X3	0.0692	0.2944	0.5541
X2X3	0.0020***	<0.0001****	<0.0001****
R^2	0.7774	0.8622	0.8059
S.D.	$1.290*10^{-3}$	$9.133*10^{-4}$	$8.23*10^{-4}$

Where: *- X1= temperature, X2= thickens, X3 = treatment, X1X2= the interaction temperature and thickens, X1X3= the interaction temperature and treatment, X2X3= the interaction thickens and treatment, R2 =coefficient of determination, SD = standard deviation*

Table 10. Response coefficient estimate for the phyto-chemicals

	Chl. [a]	Chl. [b]	Carotenoid
Intercept	0.036	0.058	0.021
A	$-6.088*10^{-4}$	$-1.353*10^{-4}$	$1.916*10^{-4}$
B	$7.25*10^{-4}$	$-4.975*10^{-4}$	$1.098*10^{-3}$
C1	$1.747*10^{-3}$	$1.862*10^{-3}$	$3.399*10^{-5}$
C2	$-9.301*10^{-4}$	$-7.959*10^{-4}$	$-3.611*10^{-4}$
AB	$-2.041*10^{-4}$	$-9.475*10^{-5}$	$9.048*10^{-5}$
AC1	$7.679*10^{-4}$	$-8.445*10^{-5}$	$2.981*10^{-4}$
AC2	$2.702*10^{-4}$	$4.635*10^{-4}$	$-9.953*10^{-5}$
BC1	$-1.46*10^{-3}$	$-1.771*10^{-3}$	$-1.135*10^{-3}$
BC2	$-2.344*10^{-4}$	$1.608*10^{-4}$	$-3.831*10^{-4}$

Where*: - The letter Represents, A= temperature, B= thickens, C1 =Raw, C2= blanched with removing skin, AC1 =the interaction b/n temperature &Raw, AC2 =the interaction b/n temperature &blanched with removing skin, BC1= the interaction b/n treatment &Raw, BC2 = the interaction with removing skin.*

Table 11. The final equations in terms of actual factors for phyto-chemicals

Factor	-1 (Raw)	0 (BWORS)	1 (BWRS)
Chlorophyll[a]			
Intercept	0.037882	0.035206	0.035319
A	$1.59183*10^{-4}$	$-3.38542*10^{-4}$	$-1.6469*10^{-3}$
B	$-7.39775*10^{-4}$	$4.90592*10^{-4}$	$2.42425*10^{-3}$
AB	$-2.04075*10^{-4}$	$-2.04075*10^{-4}$	$-2.04075*10^{-4}$
Chlorophyll[b]			
Intercept	0.059496	0.056838	0.056568
A	$-2.19800*10^{-4}$	$3.28200*10^{-4}$	$-5.14450*10^{-4}$
B	$-2.26865*10^{-4}$	$-3.36700*10^{-4}$	$1.11290*10^{-3}$
AB	$-9.47500*10^{-5}$	$-9.47500*10^{-5}$	$-9.47500*10^{-5}$
Carotenoid			
Intercept	0.020706	0.020311	0.020999
A	4.89663*10-4	9.20553*10-5	-6.94945*10-6
B	-3.71689*10-5	7.14589*10-4	2.61560*10-3
AB	9.04763*10-5	9.04763*10-5	9.04763*10-5

Where: *- The letters represent A=Temperature, B= thickens AB= the interaction b/n temperature and thickens, BWORS = blanched without removing the skin, BWRS =blanched with removing skin.*

4.4. Anti-nutritional factors of cladodes powder

4.4.1. Total phenolic content

Table 12 presented the data of anti-nutritional factors in the cactus cladode samples considered in the study. It shows that the minimum total phenolic content was 37856.06 mg/100g of the experiment number 4 (Table 12) with conditions of 55℃ drying temperature, 1.0 cm of slice thickness and un-blanched sample. On the other hand the maximum value was 41113.64 mg/100g of experiment number 18 (Table 12) with blanching of the cladode without removing the skin, drying the cladode at a temperature of 75℃. In the study by Avila-Nava *et al.* (2014), cladode samples with a slice thickness of 1.5 cm were reported to contain 92,980 mg/100g of total phenols, which is higher than the findings of our study. In contrast, Aparicio-Ortuño *et al.* (2024) reported a significantly lower total phenol content of 2050.20 mg GAE per 100g, which is considerably lower than our results. These variable results could be due to different factors such as sample preparation and geographical origin. These differences underscore the importance of standardizing methodologies and considering environmental influences in phenolic compound studies.

4.4.2. Condensed Tannins

The condensed tannin data determined in the different experiments are presented in Table 12. The minimum value was 707.69 mg/100g of the experiment number 5 (Table 12) with conditions of 65°C drying temperature, 1.0 cm thickness of the slices and no blanching of the samples. The maximum value was 725.2884 mg/100g of experiment number 11 (Table 12) which consisted of blanching the cladode sample without removing the skin, drying the sample at a temperature of 65°C and a slice thickness of 0.5 cm. Comparing with the reported result by Haile et al. (2016), significantly lower concentrations of tannins have been obtained in this study.

Table 12. Values of ant-nutritional contents (mg/100g) of cladode samples from different experimental conditions

Expt. No	Factors			Parameter	
	Temperature (^oC)	Thickness (cm)	Pre-treatment	Tannin	T. phenol
1	55	0.5	UB	724.7889	41037.88
2	65	0.5	UB	722.2682	39825.76
3	75	0.5	UB	721.7768	38765.15
4	55	1	UB	717.7637	***37856.06***
5	65	1	UB	***707.6900***	39636.36
6	75	1	UB	709.7011	39181.82
7	55	1.5	UB	716.7445	38765.15
8	65	1.5	UB	719.2606	39409.09
9	75	1.5	UB	721.2672	38992.42
10	55	0.5	BWORS	724.7934	40545.45
11	65	0.5	BWORS	**725.2884**	39712.12
12	75	0.5	BWORS	720.7621	40128.79
13	55	1	BWORS	711.7213	39939.39
14	65	1	BWORS	720.2663	39636.36
15	75	1	BWORS	717.2404	38689.39
16	55	1.5	BWORS	719.2652	38689.39
17	65	1.5	BWORS	713.7324	39409.09
18	75	1.5	BWORS	714.2283	**41113.64**
19	55	0.5	BWRS	718.2551	39522.73
20	65	0.5	BWRS	719.7611	38803.03
21	75	0.5	BWRS	719.7611	38159.09
22	55	1	BWRS	720.2616	38462.12
23	65	1	BWRS	722.2773	38537.88
24	75	1	BWRS	721.7722	38689.39
25	55	1.5	BWRS	713.2273	38815.66
26	65	1.5	BWRS	713.7324	39068.18
27	75	1.5	BWRS	722.7823	39560.61

Where: - UB- un-blanched, BWORS- blanched without removing skin (90°C, 2 min)

BWRS- blanched with removing skin (90°C, 2 min)

Table 13 showed that temperature had no significant (P>0.05) effect in all the conditions. Tannin and total phenolic content need further studying.

Generally equation for calculating various responses is given in Table 14. Final equation of tannin and total phenol for various treatments i.e raw, blanched with out and with removal of skin is reported in 15.

Table 13. Probability of the effect of factors on anti-nutritional factors

Factor	Tannin	**Total phenol**
Model	0.9276 not signi.	0.9619 not signi.
X1	0.9476	0.7554
X2	0.6227	0.7148
X3	0.8149	0.7707
X1X2	0.5133	0.5948
X1X3	0.5469	0.5184
X2X3	0.5934	0.8456
R^2	0.1684	0.1399
S.D	5.20	921.9

Where: *- the letters that represent **X1** = temperature, **X2** = thickens, **X3** =treatment, **X1X2** = the interaction b/n temperature &thickens, **X1X3** = the interaction b/n temperature& treatment, **X2X3** = the interaction b/n thickens &treatment, **R^2** = coefficient of determination*

SD *= standard deviation*

Table 14. Response coefficient estimates for the anti-nutritional factors

Model	**Tannin**	**Total phenol**
Intercept	718.3	39294.52
A	-0.082	-68.74
B	-0.61	80.67
C1	-0.84	160.87
C2	0.11	-6.08
AB	1.00	144.15
AC1	0.75	195.01
AC2	-0.93	-358.45
BC1	-1.65	-30.16
BC2	1.45	167.65

Where: *- the letters represent **A** = temperature, **B** = thickens, **C1** =Raw, **C2** = blanched with removing skin, **AB** = the interaction b/n temperature & thickens, **AC1** = the interaction temperature & Raw, **AC2** = the interaction b/n temperature & blanched with removing skin, **BC1** = the interaction b/n thickens & Raw, **BC2** = the interaction b/n thickens & blanched with removing the skin*

Table 15. Actual factors for anti-nutritional factors

	-1 (Raw)	0 (BWORS)	1 (BWRS)
Tannin content			
Intercept	717.69	718.65	719.26
A	0.67	-2.01	1.09
B	-2.26	0.84	-0.42
AB	1.00	1.00	1.00
Totaphenol			
Intercept	39455.38	39288.44	39139.73
A	126.26	-427.19	94.69
B	50.51	248.31650	-56.82
AB	-144.15	-144.14983	-144.15

Where: - the letters that represent, **A=** temperature**, B=**thickens**, AB** =the interaction b/n temperature &thickens

4.5. Optimization of the Drying Condition of Cladodes Flour

Table 16 showed the results of optimization considering some constraints like whether WAC is in range or maximum. Similarly WSI and chlorophyll (a) were put in range or maximum. Up on perusal of the various conditions obtained it was found that pretreatment of un-blanched is common while temperature is almost same in constraints 2, 5 and 7 (Table 16) i.e. 55℃, while thickness of 1.5 cm is approximately same in constraints 2, 3 and 7 (Table 16). Therefore optimum conditions of no blanching of samples, 55℃ cladode drying temperature and 1.5 cm slice thickness are recommended.

Table 16. Response of the constraint that were used for optimization

Constraint number	Parameter	Goal	Constraints			
			A	**B**	**C**	**Responses**
1	WAC	In range	1	1	-1	**18.00**
2	WAC	Maximum	**-0.93**	**0.93**	-1	27.14
3	WSI	In range	-0.38	0.87	-1	24.05
4	WSI	Maximum	1	1	1	39.80
5	WAC	In range	-1	-1	-1	19.07
	WSI	In range				29.19
6	WAC	Maximum	1	-1	-1	14.90
	WSI	Maximum				37.83
7	WAC	Maximum	-1	1	-1	**26.73**
	Chl a	Maximum				0.0373

Where: *- the letters (constraints) represent **A**= temperature, **B**= thickens, **C**= treatment, **WAC**= water observation capacity, WSI = water solubility index and Chla= chlorophyll* [a]

The effect of drying temperature and slice thickness on water absorption capacity is shown in Figure 20 for pretreatments of (a) un-blanching (b) blanching without removal of skin and (c) with removal of skin. Fig 20a show that the maximum WAC is obtained towards maximum thickness and minimum temperature while the minimum towards maximum temperature and minimum thickness. Figs 20 b and c show the saddle region in which there is maximum as well as minimum WAC.

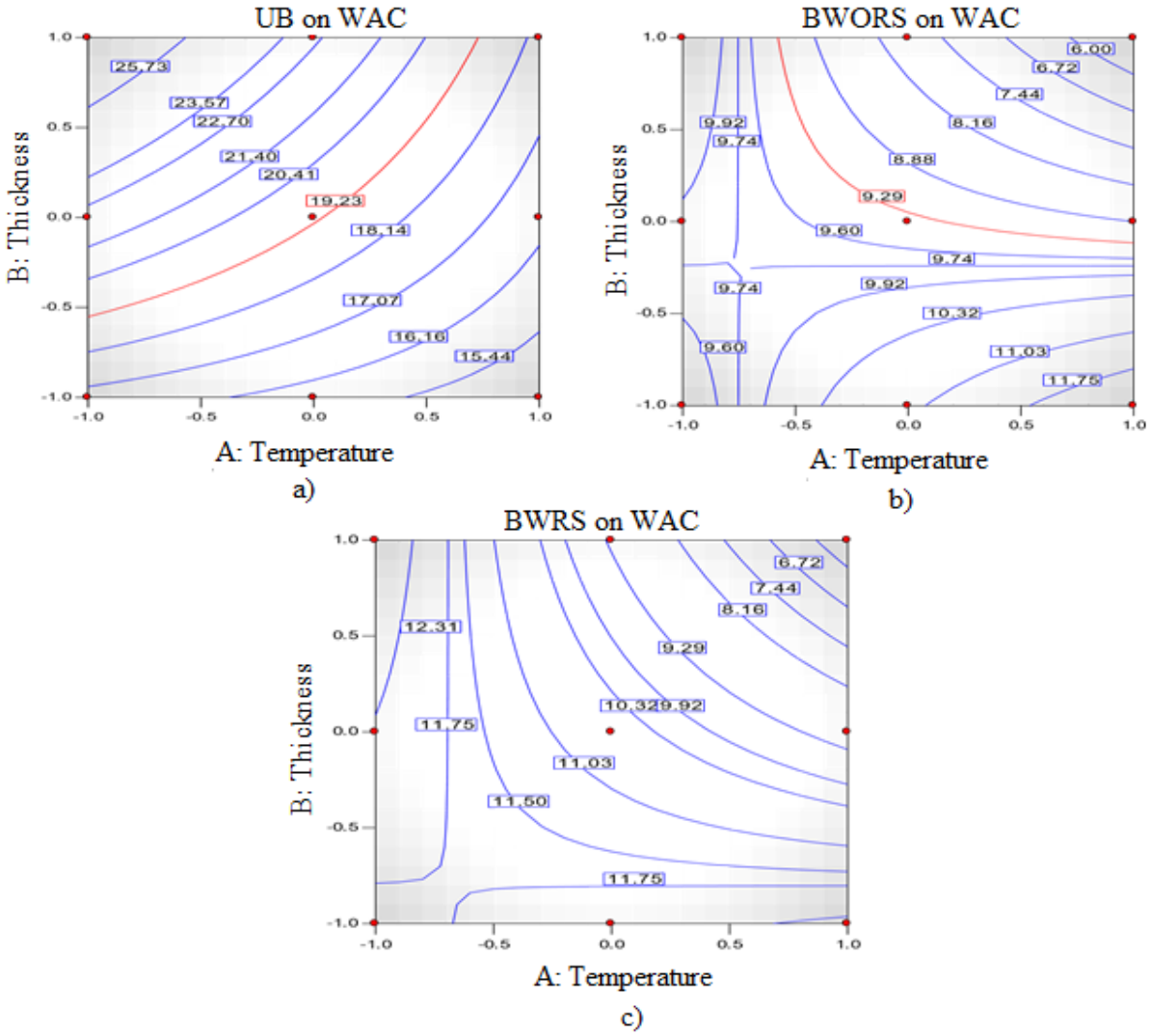

Figure 20. Responses surface counter plot for water absorption capacity regarding slice thickness and drying temperature on sample which were un-blanched, blanching with out and with removing skin

The effect of temperature and thickness on water solubility index is shown in Fig 21 for pretreatments of (a) un-blanching (b) blanching without removal of skin and(c) with removal of skin. Fig 21 (a) show that the maximum WSI is obtained towards maximum temperature

and minimum thickness while the minimum is obtained towards maximum thickness and minimum temperature. Fig 21 (b) shows that the WSI increased when thickness and temperature increase to same extent up to around 69℃ at which point there is no effect due to thickness. Fig (c) shows that the maximum WSI was at the maximum thickness and maximum temperature as well as that the minimum WSI is obtained toward the minimum thickness and minimum temperature.

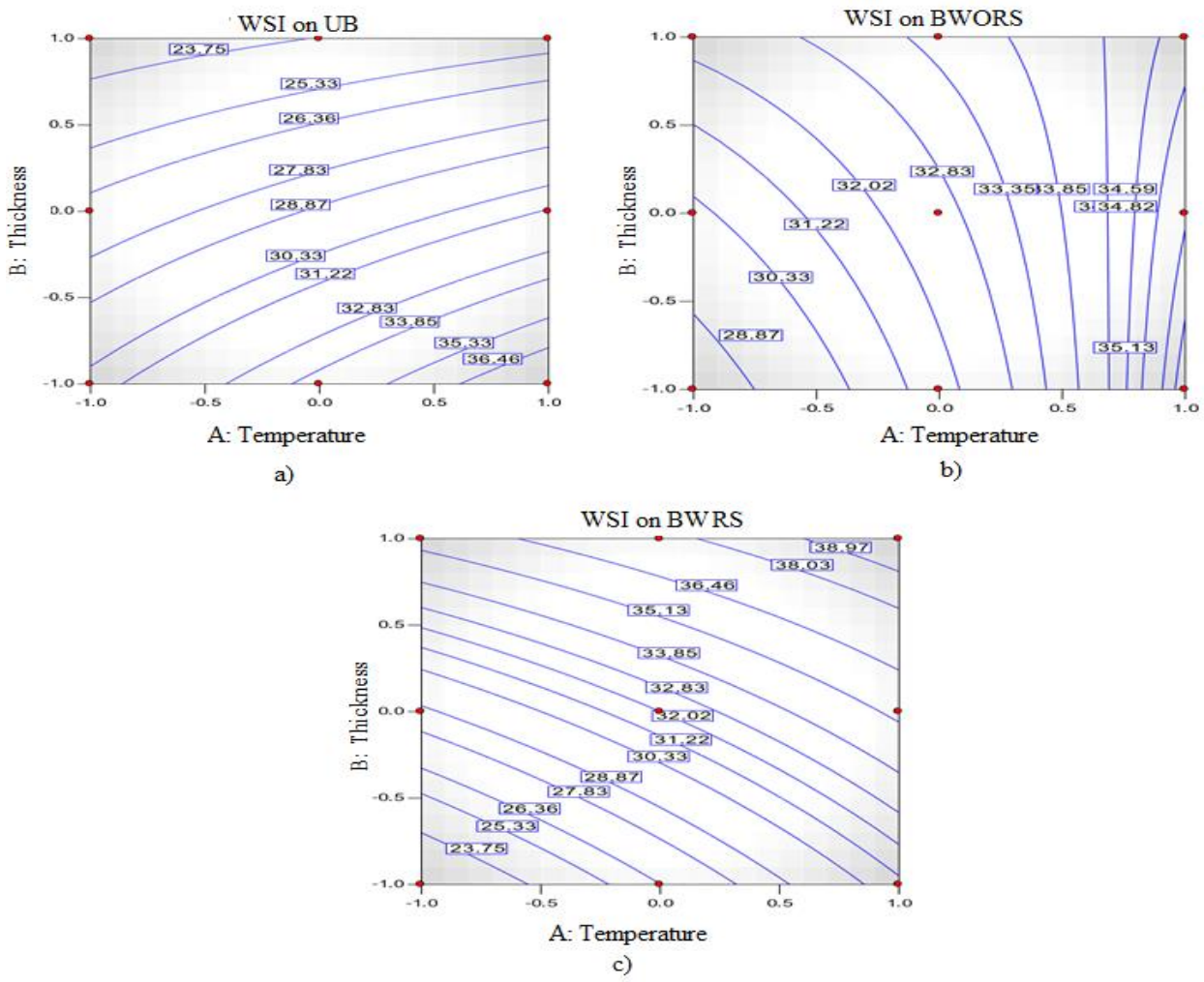

Figure 21. Responses surface contour plot for water solubility index regarding slice thickness and drying temperature on sample which were un blanched, blanche with out and with removing skin

The effect of thickness and temperature on swelling power is shown in Fig. 22 for pretreatments of (a) un-blanching, (b) blanched without removing and (c) with removal of skin. Fig 22 (a) shows that the maximum SP is obtained towards the highest thickness and temperature and the minimum values towards the minimum thickness and temperature. Fig 22(b) shows the saddle region in which there is maximum as well as minimum. Fig 22 (c) shows that the maximum SP is obtained towards the highest temperature and the lowest thickness.

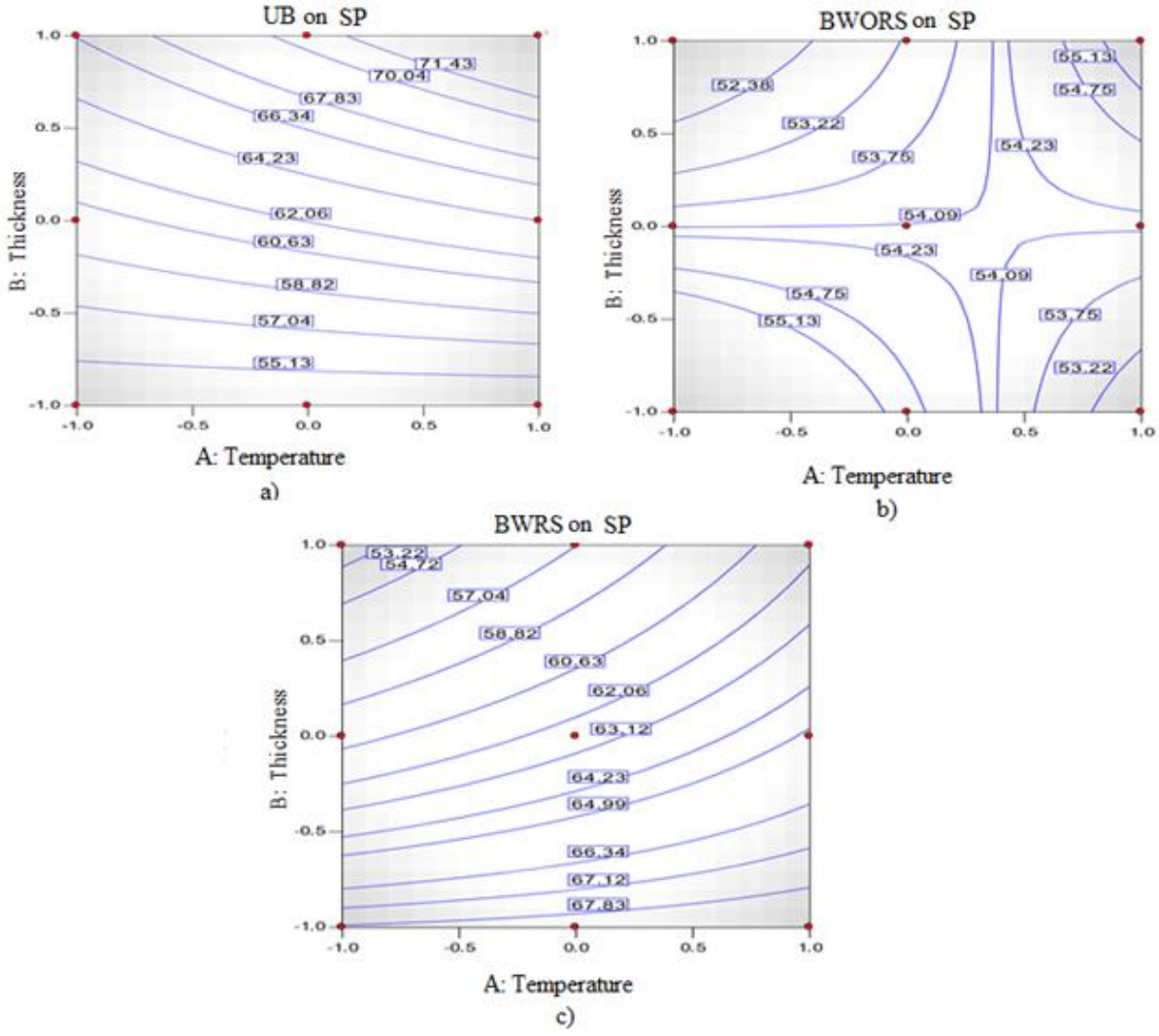

Figure 22. Responses surface counter plot for swelling power regarding slice thickness and drying temperature on sample which were un blanched, blanche with out and with removing skin.

The effect of thickness and temperature on oil absorption capacity is shown in Figure 23 for pretreatments of (a) un-blanching (b) blanching without removing and(c) with removing skin.

Fig 23 (a) shows that thickness had a little effect on oil absorption capacity while decrease in maximum temperature. Fig 23.(b) show that the oil absorption maximum towards maximum thickness and minimum temperature while in fig 23 (c) shows that the maximum oil absorption capacity was towards the maximum temperature and minimum thickness and the minimum oil absorption capacity was obtained in the maximum thickness and minimum temperature.

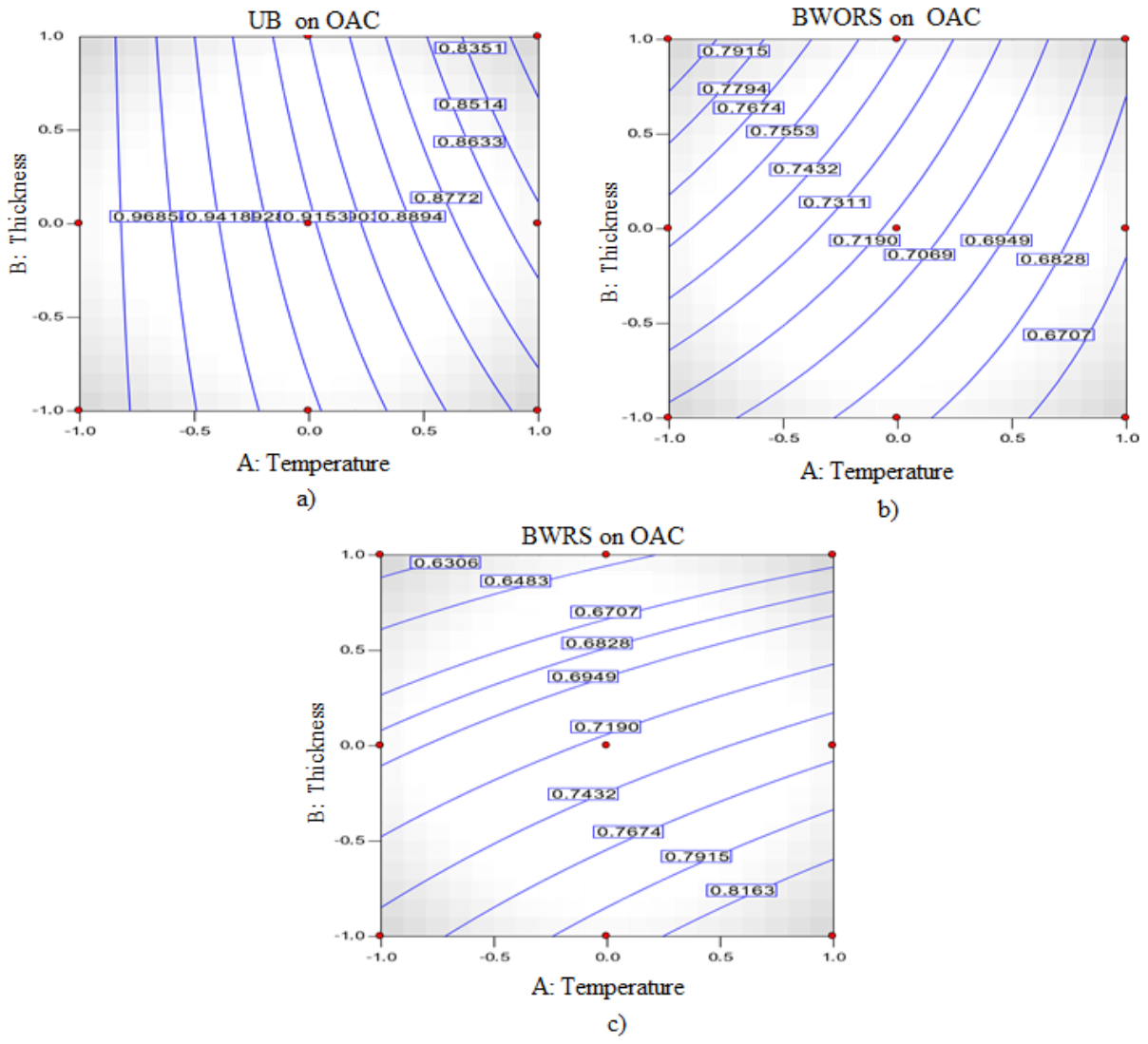

Figure 23. Responses surface counter plot for oil absorption capacity regarding slice thickness and drying temperature on sample which were un blanched, blanche with out and with removing skin.

The effect of thickness and temperature on bulk density is shown in fig 24 for pretreatments of (a) un-blanching (b) blanching without removing and(c) with removing skin. Figure 24 (a) showed that the maximum value of bulk density was obtained at higher temperature and lower thickness but also shows saddle region of maximum and minimum at the middle of thickness and at the highest point of thickness and lowest temperature.

Figure 24 (b) and (c) shows the saddle region in which there is maximum as well as minimum bulk density.

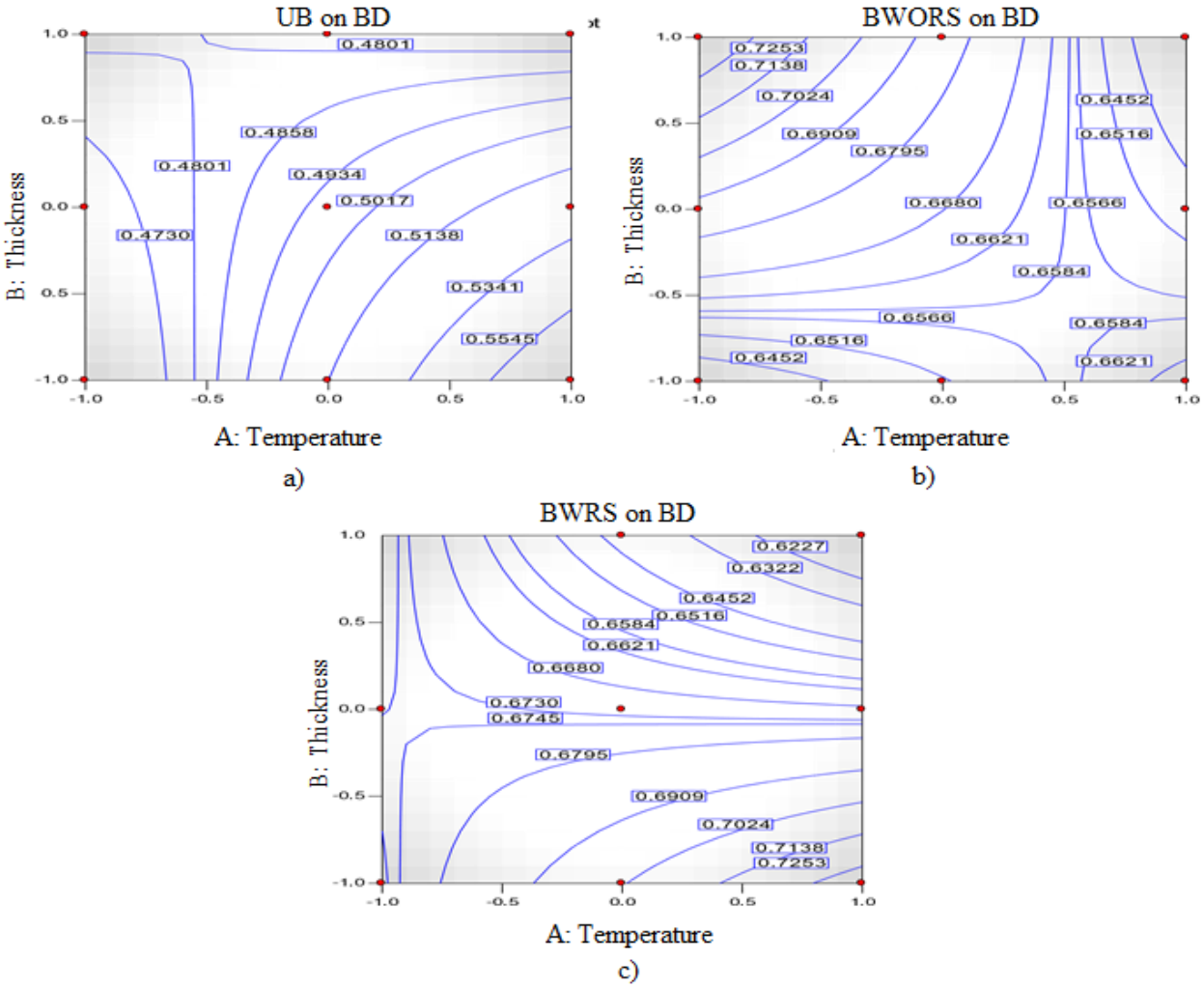

Figure 24. Responses surface counter plot for bulk density regarding slice thickness and temperature drying on sample which were un-blanched, blanched with out and with removing skin.

The effect of thickness and temperature on chlorophyll a is shown in Figure 25 for pretreatments of (a) un-blanching (b) blanching without removing and(c) with removing skin. Figure 25(a) shown that the maximum chlorophyll a was obtained at maximum temperature

and minimum thickness and the minimum chlorophyll a was obtained towards minimum temperature and maximum thickness. Figure 25 (b) and (c) shows that in both the maximum chlorophyll (a) were obtained towards maximum thickness and minimum temperature and the minimum chlorophyll a towards the maximum temperature and minimum thickness.

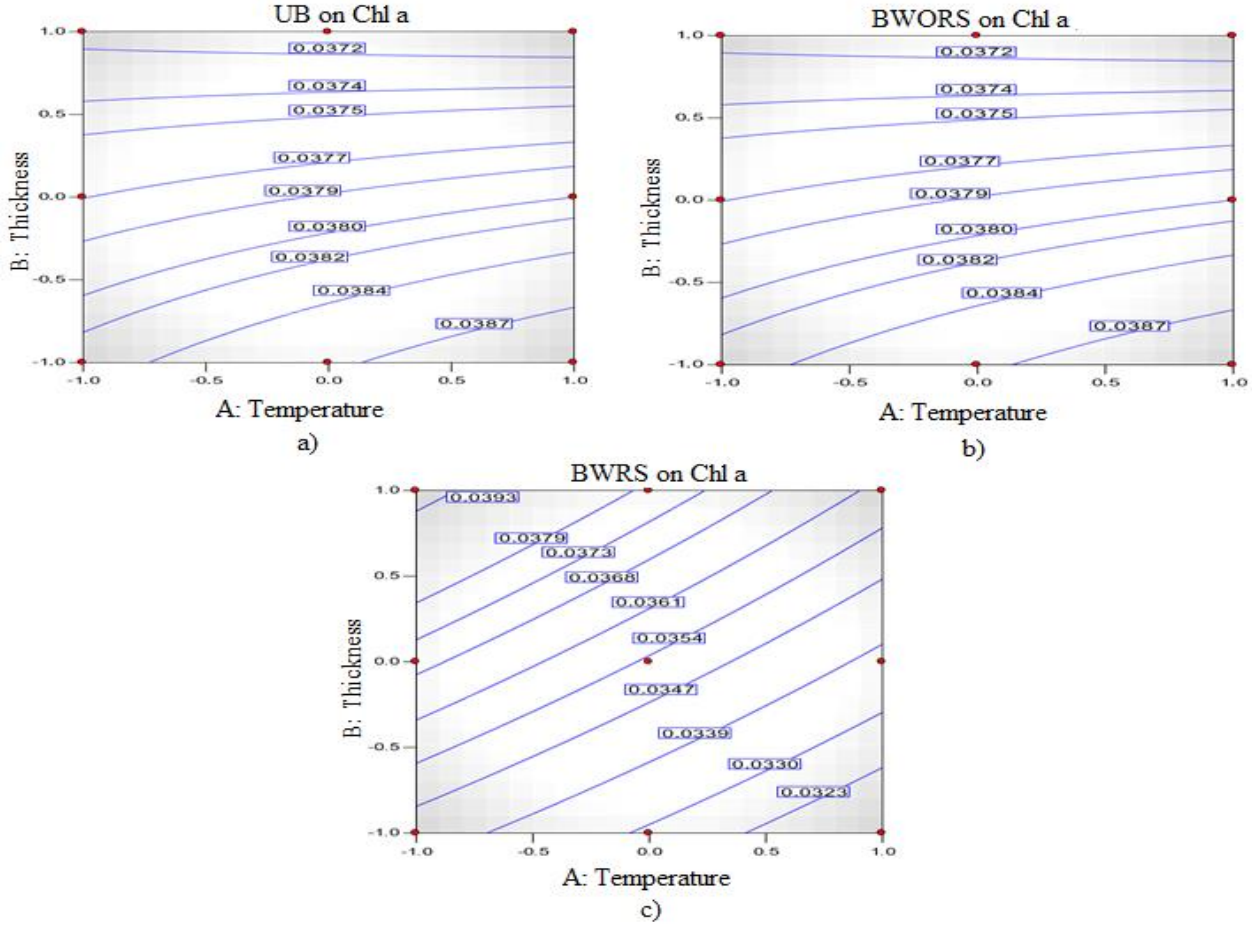

Figure 25. Responses surface counter plot for chlorophyll a regard slice thickness and drying temperature on sample which were un-blanched, blanched without and with removing skin.

The effect of thickness and temperature on chlorophyll b is shown in Figure 26 for pretreatments of (a) un-blanching (b) blanching without removing and(c) with removing skin. Figure 26 (a) shown that the maximum chlorophyll b was obtained at lowest thickness there is no more effect by temperature. Figure 26 (b) shows that the maximum chlorophyll b was obtained at lowest thickness and highest temperature while in Figure 26 (c) shows that the maximum value was get at maximum thickness and minimum temperature and the minimum value was obtained towards maximum temperature and minimum thickness.

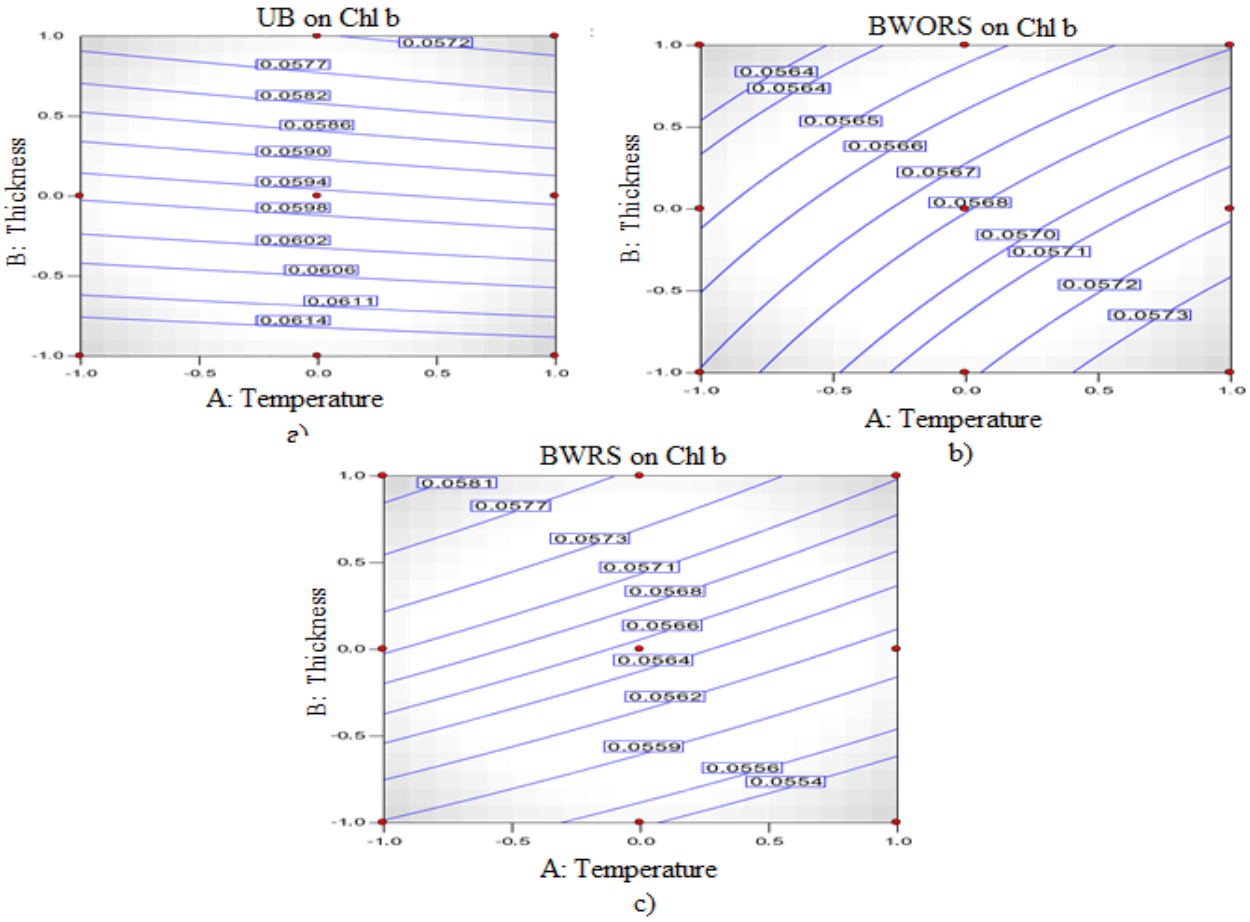

Figure 26. Responses surface counter plot for chlorophyll b regarding slice thickness and drying temperature on sample which were un-blanched, blanched with out and with removing skin.

The effect of thickness and temperature on carotenoid is shown in Figure 27 for pretreatments of (a) un-blanching (b) blanching without removing and(c) with removing skin. Figure 27(a) shows that at the maximum temperature was obtained the maximum carotenoid but no effect on the thickness. Figure 27(b) shown that maximum carotenoid was at the maximum thickness had no effect on the temperature. Figure 27 (c) shows that maximum was obtained towards in the maximum temperature and maximum thickness.

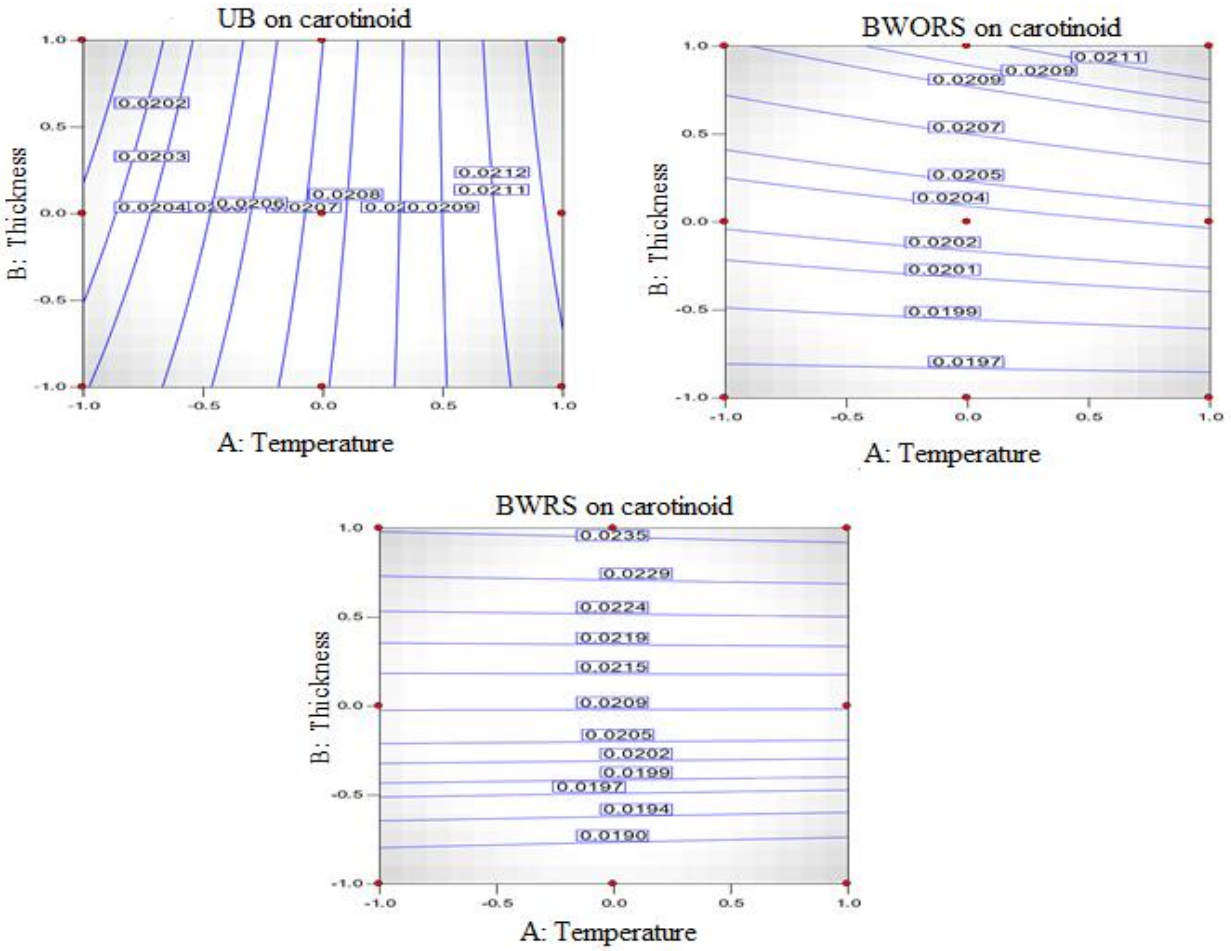

Figure 27. Responses surface counter plot for carotinoid regarding slice thickness and drying temperature on samples which were un-blanched, blanched without and with removing skin

The effect of thickness and temperature on tannin is shown in Figure 28 for pretreatments of (a) unblanching (b) blanching without removing and(c) with removing skin. Figure 28 (a) showed that at the minimum tannin was obtained towards the maximum thickness and temperature. The maximum was obtained towards the minimum thickness and maximum temperature. Figure 28 (b) show that little effect of thickness and maximum value was obtained at maximum temperature. Figure 28 (c) show the saddle region in which there is maximum and minimum tannin.

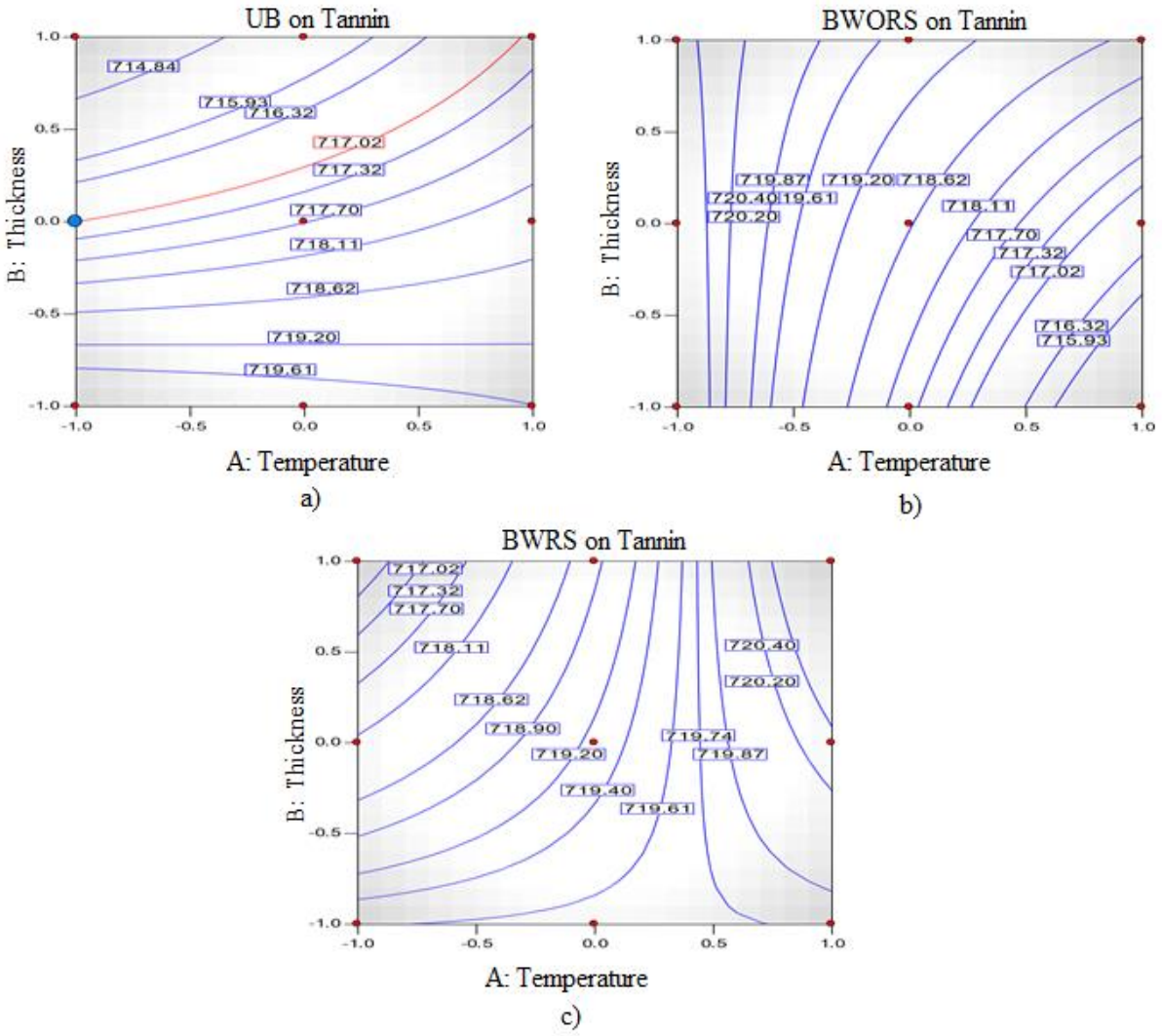

Figure 28. Responses surface counter plot for tannin content regarding slice thickness and drying temperature on samples which were un-blanched, blanched with out and with removing skin.

The effect of thickness and temperature on total phenol is shown in Figure 29 for pretreatments of (a) un-blanching (b) blanching without removing and(c) with removing skin. Figure 29 (a) and (c) show the saddle region in which there is maximum as well as minimum total phenol.Figure 29 shown that the maximum was obtained towards the maximum thickness and minimum temperature and the minimum was obtained towards the minimum thickness and maximum temperature.

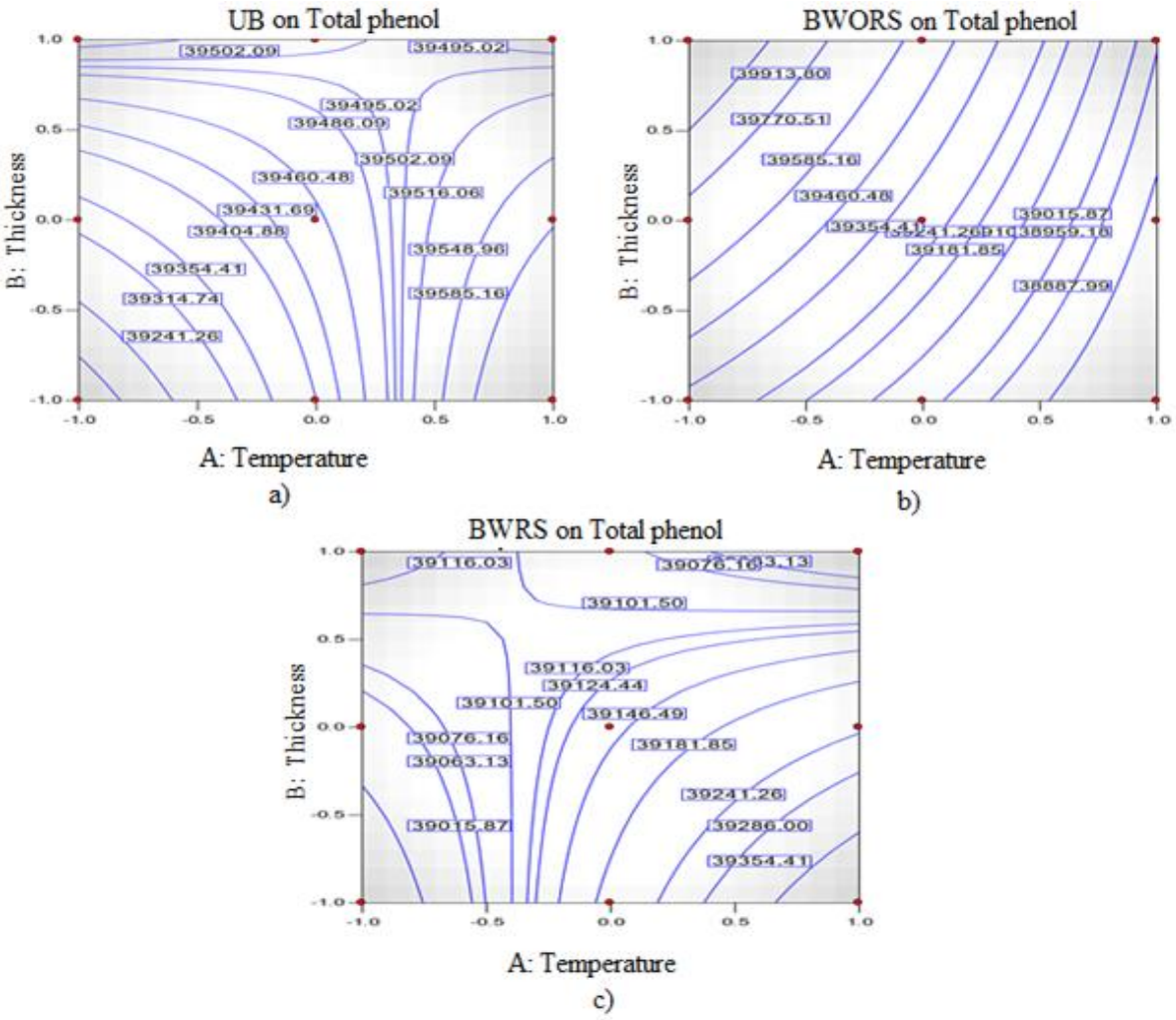

Figure 29. Responses surface counter plot for total phenol regarding slice thickness and drying temperature on sample which were un- blanched, blanched with out and with removing skin
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4.6. Determination of chemical composition of cladodes flour

4.6.1. Proximate composition

The proximate composition and energy content of the powders produced from dried cladodes of cactus as influenced by the drying temperature and slice thickness are presented in Table 18.

Table 17. Effect of drying temperature and slice thickness on proximate composition of cactus cladodes flour

Factors		Proximate Compositions						
		M.C (%)	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	CHO (%)	Energy (Kcal/100g)
Temperature (^{o}C)	55	7.89^{a} ±0.33	5.43^{a} ±0.84	1.29^{a} ± 0.62	3.89^{b} ± 0.54	22.69^{a} ± 0.91	58.80^{a} ±1.74	268.48^{b} ±4.13
	65	7.35^{a} ± 0.50	5.07^{a} ± 0.10	1.28^{a} ±0.62	4.06^{ba} ±0.49	22.06^{a} ± 0.94	60.17^{a} ±1.40	272.52^{a} ±5.60
	75	7.21^{a} ±1.08	5.20^{a} ±0.50	1.71^{a} ±0.25	4.40^{a} ±0.42	21.94^{a} ±1.39	59.80^{a} ±1.60	272.32^{ba} ± 2.20
Thickness (cm)	0.5	7.52^{a} ±0.97	5.43^{a} ±0.50	0.65^{b} ±0.24	3.99^{b} ±0.50	22.14^{a} ±0.86	60.26^{a} ±0.90	268.62^{b} ±3.10
	1.0	7.61a±0.49	5.33^{a} ±0.60	1.61^{a} ±0.20	3.89^{b} ±0.50	21.78^{a} ±1.30	59.77^{a} ±2.40	274.93^{a} ±4.10
	1.5	7.33^{a} ±0.77	4.93^{a} ±0.50	1.61^{a} ±0.20	4.46^{a} ±0.38	22.78^{a} ±1.01	58.88^{a} ±1.00	269.76^{b} ±6.30
LSD		**0.86**	**0.97**	**0.36**	**0.40**	**4.76**	**2.64**	**3.60**
CV		**0.7218**	**0.5615**	**0.223**	**0.419**	**1.036**	**1.544**	**3.845**

Where: M.C = moisture content, CHO = carbohydrate, LSD = list of significant Difference, CV= coefficient variance

4.6.1.1. Moisture content

Main effect of drying temperature on the moisture content of cladodes powder is shown in Table 17. The values ranged from 7.21 to 7.89% Similarly, EL-safy (2013) reported 6.785% moisture content of the cladodes. That was because the drying was conducted until the moisture content reached a target value (7%). The same is true regarding the effect of slice thickness on moisture content of the cladode powder for same reason.

4.5.1.2. Crude protein

The protein content of the cladode powder ranged from 4.93 to 5.43% with no statistical difference attributed to either drying temperature or slice thickness (Table 17). This is expected as there is no internal factor involved in the drying process. Both factors did not have any significant ($P>0.05$) impact on the values of the protein content of the dried samples. The data showed that cactus cladode is poor in protein content as are leaves of many higher plants. Young cladodes grown under commercial fruit production in Spain had protein content of 10.6 – 15.0% while the mature cladodes varied from 4.4 to 11.3% (Retamal, *et al.*. 1987). This showed that age has significant impact on the protein content of the cactus cladodes and those used in the study were mature ones as described in the materials and methods. As mentioned by EL-Safy (2013) and Razzak et al. (2024) the crude protein content of 7.26% and 7.54% for cactus cladode respectively. The variation on the result may be due to nitrogen fertility, cultivation, and environmental factors Dubeux et al. (2021).

4.5.1.3. Crude fat

Fats and oils are one of the major constituents of food and are important in our diet for a number of reasons. They are a major source of energy and provide essential lipids nutrient. In many foods, the lipids component plays a major roles role in determine the overall physical characteristics such as flavor, texture and appearance. The fat content of cladode powder produced in the experiments ranged from 0.65 to 1.71% (Table 17). Drying temperature didn't have significant effect ($P>0.05$) on fat content of the powders. However, samples produced from dried slices with 0.5 cm thickness resulted in significantly ($P < 0.05$) the lower value as compared to those determined in samples of 1.0 and 1.5 cm thickness. EL-Safy (2013) and

Razzak et al. (2024) reported the crude fat content of 2.21% and 2.30 % respectively. This variation may be due to maturity.

4.5.1.4. Crude fibre

The fiber contents of powder produced from cactus cladodes are significantly ($P<0.05$) affected by drying temperature. The values ranged from 3.89 to 4.40% with statistical difference ($P<0.05$) between the two extreme values the highest value being of samples subjected to the highest temperature (Table 17). AL-MARAZEEQ *et al.* (2023) and Razzak et al. (2024) reported that the crude fiber content of 22.3% and 20.52% respectively. The variation on the results may be due to age difference, genetic composition, geographical location, and agro climatic variable.

4.5.1.5. Ash

The ash content is an inorganic residue remaining after the removal of water and organic matter by heating in presence of oxidizing agent which provides measuring means of the total amount of mineral in a food. The ash content of cladode powder produced in this study varied between 21.78 and 22.78% with no statistical difference ($P>0.05$) among all values (Table 17). Drying temperature as well as slice thickness didn't affect the values significantly. As Razzak et al. (2024) reported that the ash content were 24.40%. So, from this result the slight difference is may be due to age of the plant and processing condition.

4.5.1.6. Utilizable carbohydrate

The utilizable carbohydrate content values of the cladode powder produced in this study exhibited no statistical difference ($P>0.05$) attributable to the different experimental conditions (Table 17). Neither the drying temperature nor the slice thickness affected the results. The values ranged from 58.80 to 60.26%, all of which appeared to be with little differences among them. As EL-Safy (2013) and Razzak et al. (2024) reported a carbohydrate level of 45.06% and 55.90% respectively. The variation on the result may be due to the age of plant, season, environmental factor, physiological adjustment of the plant, variety, and processing condition.

4.5.1.7. Energy content

The energy data of the cladode powder recorded in Kcal/100 g in Table 17 exhibited significant ($P<0.05$) differences among the values attributable to differences in both drying temperature and slice thickness. The values ranged from 268.48 to 274.93 Kcal/100g. Higher drying temperature led to higher energy contents and vice versa whereas values in relation to slice thickness varied randomly without a trend. Nabil et al. (2020) reported that the energy content were 377.72 Kcal/100g. The variation on the result may be due to Varity, maturity, and processing condition.

4.5.2. Mineral content of cladodes flour

Mineral content data of cactus cladode powder are presented in Table 18. No significant difference ($P>0.05$) in calcium content was noted attributable to drying temperature. The values were in the range of 469.0 to 533.7 mg/100g. However, the values showed significant differences ($P<0.05$) due to slice thickness. The Values were 545.6, 452.5, and 522.2 mg/100g for samples of 0.5, 1.0 and 1.5 cm thickness. The differences were random showing no trend with slice thickness. Razzak *et al.* (2024) reported that the Ca content of cladodes were 503.8 mg/100g. The variation on the results may be due to season, plant age, cladodes order, cultivation, fertilization, and processing condition.

Table 18. Effects of drying temperature and slice thickness on mineral content of cladode powder

Factors		Mineral (mg/100g)		
		Ca	Fe	Zn
Temperature (^oC)	55	533.7 ± 53.36^a	$2.65^b \pm 0.16$	$9.65^b \pm 0.16$
	65	$469.0^a \pm 11.81$	$3.32^a \pm 0.95$	$9.74^b \pm 0.98$
	75	$517.6^a \pm 48.73$	$2.24^{c\pm} 0.50$	$9.69^b \pm 0.95$
Thickness (cm)	0.5	$545.6^a \pm 35.85$	$3.38^a \pm 0.86$	$10.83^a \pm 1.00$
	1.0	$452.5^b \pm 11.78$	$2.49^b \pm 0.32$	$10.96^a \pm 2.34$
	1.5	$522.2^a \pm 46.94$	$2.34^b \pm 0.53$	$10.55^a \pm 2.08$

Whereas: the same letters shows no significant where different letters have significant

The Iron content of cladodes flour produced at experimental conditions of drying temperatures of 55, 65 and 75℃ and thicknesses of 0.5, 1 and 1.5 cm are presented in Table 18 which ranged from 2.24to 3.3201 mg/100g of the cladodes flour. Similarly there was significant difference ($P<0.05$) in Fe due to slice thickness which ranged from 2.34 to 3.38 mg/100g.

Razzak *et al.* (2024) reported that the Fe content of cladodes were 15.60 mg/100g. The variation on the results may be due to season, plant age, cladodes order, cultivation, fertilization, and processing condition.

The zinc content data of cladodes flour produced at experimental combinations of drying temperatures of 55, 65 and 75℃ and thicknesses 0.5, 1 and 1.5cm are presented in Table 18. Data associated with drying temperature ranged from 9.65 to 9.74 mg/100g of the cladode flour with no statistical difference among them whereas those associated with thickness were from 10.55 and 10.96 mg/100 g, again with no statistical difference among them. Razzak *et al.* (2024) reported that the Zn content of cladodes were 4.78 mg/100g. The variation on the results may be due to season, plant age, cladodes order, cultivation, fertilization, and processing condition.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

This study was carried out to determine the drying characteristics (moisture ratio and drying rate) and optimize the drying condition of temperatures (55, 65 and 75°C); thicknesses (0.5, 1.0 and 1.5cm) and pre-treatments (un-blanched blanched without and with removing skin) of the cladodes *(opuntia ficus-indica*) based on the functional properties, phyto-chemicals, anti-nutritional factors. The drying characteristics, moisture ratio (MR) and drying rate data, were plotted graphically using mathematical modeling curve Expert 32 (version 1.4) software. The software considered non-linear models and gave the result models with ranking based on the coefficients determination of R^2. The moisture ratio was calculated from the actual data of the recorded weight. Then the predicting data was calculated using the page model equation ($Y= e^{-atb}$) and its graph was plotted. The actual drying rate was calculated from the moisture content and the predicting drying rate was calculated from predicting moisture ratio by selecting the best fit hoerl model ($y = ab^x x^c$) and its grapg was plotted. To optimize the drying condition of the functional properties, phytochemicals and ant- nutrition factors were analyzed using design Experts (version 6.0.8). The proximate compositions and mineral content of cladodes flour were analyzed by factorial experiments performed on un-blanched samples. The maximum and minimum values of the response functional properties were found to be 26.73g/g to 5.63g/g for water absorption capacity, 45.00 % to 24.17 % for water solubility index, 105.27 to 49.87 % for swelling power, 1.100 to 0.575 ml/g for oil absorption capacity and 0.836 to 0.449 g/cm^3 for the bulk density. Water absorption capacity was significantly affected ($P<0.05$) by drying temperature, pretreatments with significant ($P<0.01$) effect and their interaction. Water solubility index was significantly ($P<0.05$) affected by the temperature and the interaction between thickness and pretreatment while swelling power was not significantly ($P>0.05$) affected in any of the conditions. The values of Chlorophyll a and b were found to be 0.041 mg/g to 0.032 mg/g and 0.063 mg/g to 0.055 mg/g, respectively, while that of carotenoid was 0.025 mg/g to 0.018 mg/g. Chlorophyll a was significantly affected by temperature ($P<0.0005$) and thickness ($p<0.0001$), whereas the Chlorophyll b was significantly ($P<0.0001$) affected by the thickness as well as by the interaction between thickness and treatment ($P<0.0001$). Similarly, the carotenoid was significantly ($P<0.0001$)

affected by the thickness and interaction between thickness and treatments ($P<0.0001$). The ant-nutritional factors, tannin and total phenol, had not significant ($p>0.0005$) effect on the conditions.

5.2. Conclusions

Optimum combinations of the pretreatments, drying methods and slice thicknesses were determined for the phytochemicals, anti-nutrients, and functional properties of cladode flours. For the drying rate of cladodes, Hoerl equation, $Y = ab^x x^c$ gave better prediction for all pretreatment conditions with coefficient of determination (R^2) varying from 0.9887 to 0.9992 and the standard deviations between 0.000010 and 0.000093. Drying temperature had significant effect on drying rate with higher values for higher temperatures in the early stages of the drying process and lower values for the lower drying temperatures. For all temperatures, drying rate increased in the early periods until it reached the peak at some point and then it reduced continuously until it reached the lowest target moisture content. Slice thickness affected the drying rate with highest rate being for the thinnest slice and reducing as thickness increased. Thicker slices needed longer time to attain the target moisture content. Highest drying rate was recorded for blanched samples in general and particularly for those blanched after skin removal and with lowest slice thickness. In general skin removal lead to high drying rate. The majority of the proximate compositions and mineral contents were not significantly affected by drying temperature and slice thickness. The tannin and total phenol contents were not affected at all by the indicated factors. The different combinations of pretreatments considered in the study had caused significant differences among the values of functional properties such as water absorption capacity, oil absorption capacity, water solubility index, swelling power and bulk density. Furthermore, these properties were also significantly affected by drying temperature and slice thick and their interactions. The phytochemicals such as chlorophyll a and b as well as carotenoids were also significantly affected by the combinations of pretreatments, drying temperatures and slice thickness. Accordingly equations were established with appropriate coefficients of the factors involved and their interactions.

5.3. Recommendations

As this study focused on a Cactus variety with spines on the cladode, it is advisable to conduct similar studies on those different species of cladodes which are important in solving the problem of malnutrition.

As the purpose of making cladode powder was for using it to enrich food items to exploit its health and nutritional benefits, researches on alternative utilization of cladode powder as food in the communities need to be conducted.

Study on packaging methods and effect of storage conditions and time on the quality of the cladode powder is also important. It also needs to study the effect of velocity of cladodes on the drying time.

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7. APPENDIX

Appendix 7.1. Appendix figures

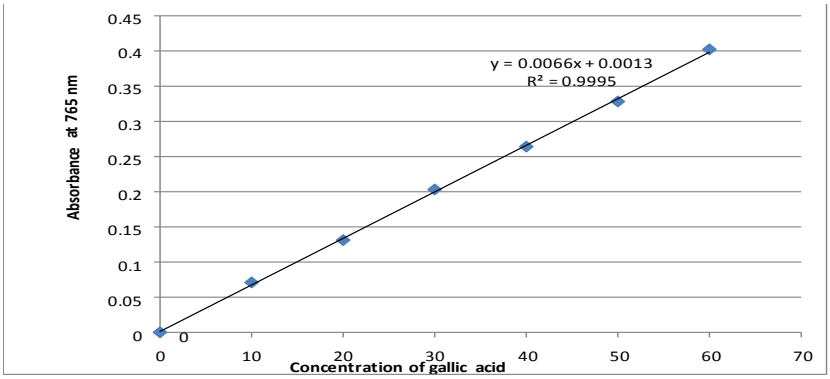

Figure 1.Calibration curve for total phenolic content determination

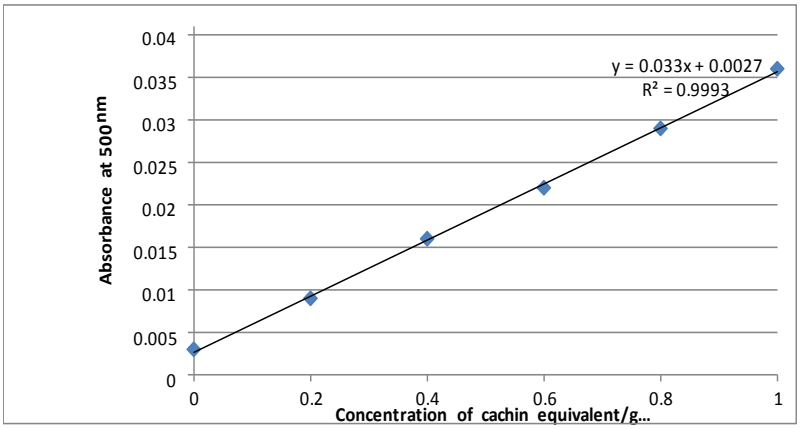

Figure 2.Calibration curve for tannin determination

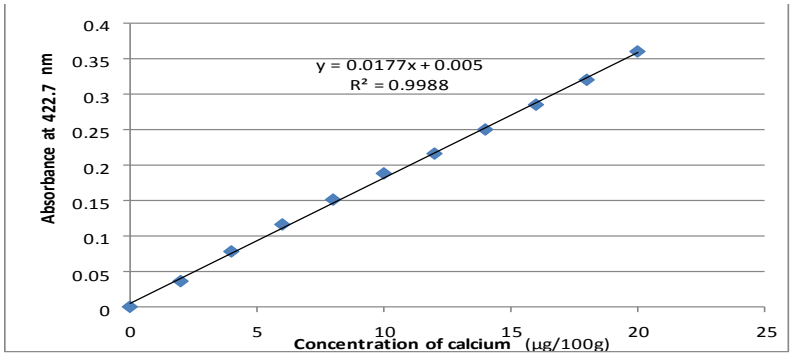

Figure 3.Calibration curve for calcium determination

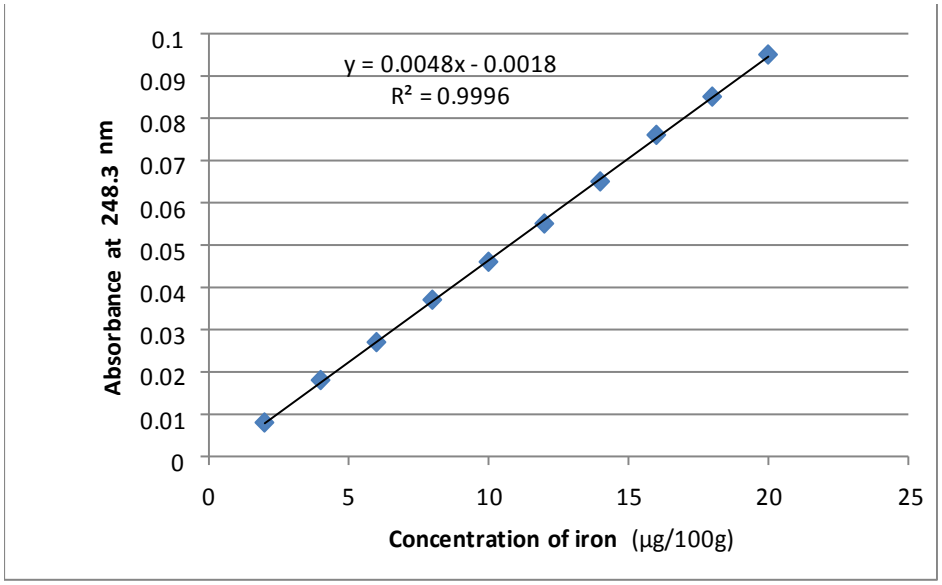

Figure 4.Calibration curve for iron determination

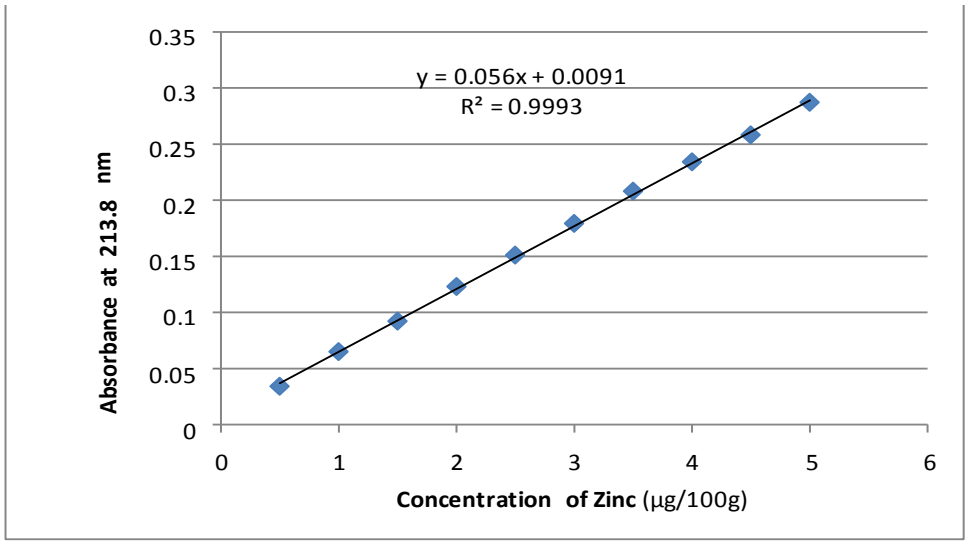

Figure 5.Calibration curve for zinc determination

Figure 6.This picture indicates that the preliminary trial runs to selected level of different factors

.

Figure 7.Conducted the harvest processing, removed the spin using a knife, washed with tap water, sliced, peeled, and weighed the cladodes sample.







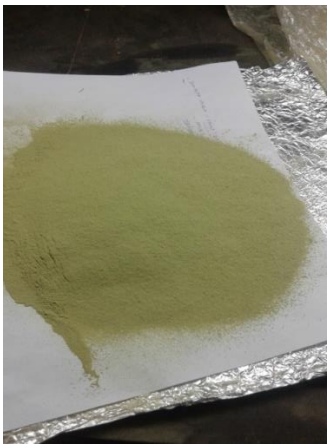

Figure 8.Drying the sample using an oven dryer, milling it, and sieving it were indicated .

Figure 9.Indicated the prepared sample of cladodes powder for each dried temperature, slice thickness, and treatment.

Figure 10. Displays the demonstration of functional properties in the lab room

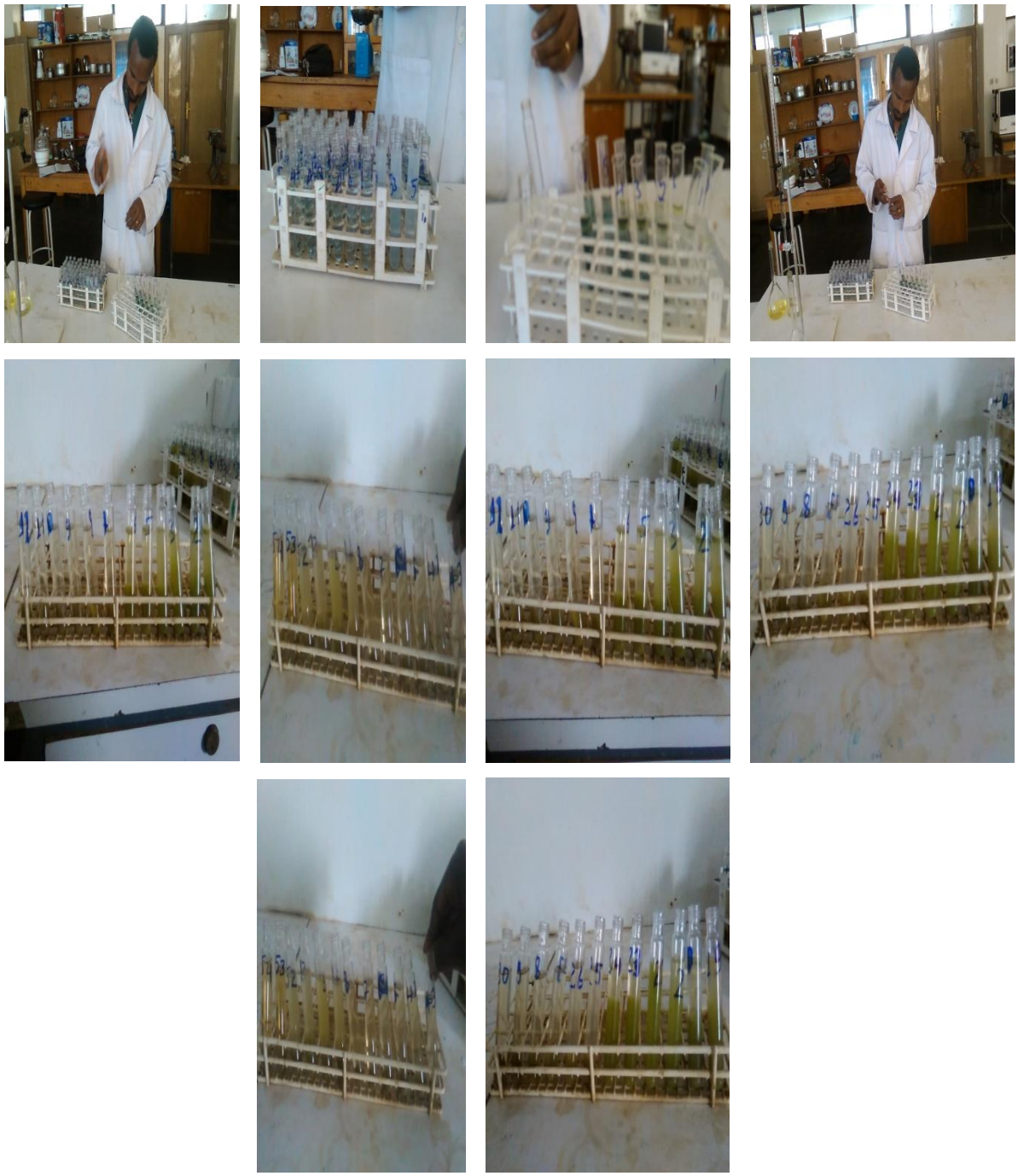

Figure 11.Display the process of preparing a sample solution for reading the parameters

.

Figure 12.Indicated the demonstration of phytochemicals and anti-nutritional factors used in UV

.