



Addis Ababa University
Addis Ababa Institute of Technology
School of Chemical and Bio Engineering

Optimization of Drying Parameters for “*Moisture Reduced Teff Injera Making*” Using Response Surface Methodology

By:
Dessalegn Abit

Advisor: Prof. Eduardo Ojito Cespedes

A thesis submitted to the School of Chemical and Bio Engineering of Addis Ababa Institute of Technology in Partial Fulfillment of the Requirement for the Degree of Master of Science in Biochemical Engineering.

June, 2019
Addis Ababa, Ethiopia



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Declaration

I, the undersigned, declare that this thesis work is my original work and that all sources of materials used for the thesis have been fully acknowledged.

Name: **Dessaegn Abit**

Signature - _____ Date: - _____

Dedication

This work is dedicated to my beloved family!!

Abstract

Teff Injera is the staple Ethiopian fermented bread processed from fermented tef [Eragrostis tef (Zucc.) Trotter] grain flour. "Dirkosh" is the Amharic name given to the dried /moisture reduced injera. The current potential need of the super food, Teff and its products like injera and its dried form, Dirkosh needs a scientific research that will increase its quality, healthy and market demand. Therefore, the objective of the study was to prepare and optimize the drying parameters of Dirkosh using computer controlled tray dryer. The selected drying parameters were (drying air temperature, air velocity and sample loading density) in response of the most quality parameters of the final dried injera/Dirkosh. The response variables were the final moisture content, drying time, color, texture, overall acceptability, water activity and drying rate. The optimization process done by using Box-Behnken Design, response surface methodology (RSM). Drying process factors (drying air temperature(55-65°C), air velocity(0.5-1.5m/s) and sample loading density(1-2kg/m²)) were considered and made 15 experimental runs of Dirkosh drying including 3 replicates using RSM. The investigated responses were final moisture content(5.43), color(6.02), texture(6.23), overall acceptability(6.05), water activity(0.274) but drying time and drying rate were not significant model terms but it was possible to estimate the drying kinetics using the better drying process parameters. RSM with Box-Behnken Design was used to develop and optimize drying process factors in response of the dried injera. Moreover, both numerical and graphical optimizations were carried out to determine the optimum values of Dirkosh in terms significant model terms. The optimum process factors of drying process parameters were drying air temperature of 55 °C, air velocity of 1.4m/s and sample loading density of 1kg/m² with a desirability of 0.65. The study showed that all the drying process factors were important parameters influencing the physicochemical and sensory qualities of Dirkosh.

Key words: Box-Behnken Design, Moisture-reduced injera, Optimization, Response Surface Methodology, Water Activity

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List of symbols and abbreviations

a*	CIE red(+)/green(-) color attribute
b*	CIE yellow(+)/blue(-) color attribute
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
BBD	Box -Behnken Design
CHO	Carbohydrate
CIE	Commission Internationale d'Eclairage
CCTD	Computer Controlled Tray Dryer
DCC	Digital Color Camera
DM	Dry matter
DZARI	Debrezeit Agricultural Research Institute
EPHI	Ethiopian Public Health Institute
FAO	Food and Agriculture Organization
JPEG	Joint Photographic Experts Group
L*	CIE lightness coordinate
LAB	Lactic Acid Bacteria
RSM	Response Surface Methodology
SD	Standard deviation
SPSS	Statistical Package and Social Service
WHO	World Health Organization
RSM	Response surface methodology

CHAPTER ONE

1. Introduction

1.1. Background

Teff Injera is the staple Ethiopian fermented bread processed from grain Teff [*Eragrostis Teff* (Zucc.) Trotter] flour. Teff is known to have better nutritional value than common cereal grains (wheat, barley, sorghum, maize and rice) because grain Teff is always consumed as whole grain (Bultosa & Taylor, 2004). Grain tef bears about 11% protein, 73% carbohydrate (virtually all starch), 3% crude fiber (CF), 2.5% fat and 2.8% ash (Bultosa & Taylor, 2004). The very small size grain Teff starch granules (2–6 μ m) are implicated to have a fat mimetic, flavor and aroma carrier functionalities as that of small starch granules (Bultosa & Taylor, 2004).

The shelf life of injera after baking does not commonly go beyond three days at ambient temperature under the traditional storage conditions essentially due to mold spoilage (Ashagrie and Dawit, 2012). Drying of fresh injera to low moisture content and low water activity while retaining its functional quality is essential for long-term storage.

Drying of baked teff injera is nowadays a common practice, since dried injera (**Dirkosh** in Amharic) can be stayed long and can be handled and transported easily. Dirkosh Crunch has been prepared and sold in markets. Dirkosh Crunch prepared from teff injera is vegan, gluten-free, and oil-free as that of Teff injera.

Drying is a process of preserving food by reducing water or other liquid from the solid material until an adequate low moisture content is reached, thus preserving foods by avoiding microbial growth and deteriorative chemical reactions. The Drying Process leads to reduction of the moisture content in solids, to maintain their consistency in storage and transport. To achieve the desired moisture content, the material should be dried. Dried products are very good source of nutrients but the dehydration process may alter the quality of the products. This can be limited by having proper pre-treatment of the materials and also by controlling the drying process. Some of the quality parameters considered are colour, visual appeal, flavour, retention of nutrients, free from contaminant

Therefore, this research was done by using computer controlled tray dryer (CCTD) and finally reaching the optimum drying process parameters by using the box-behnken design (BBD) as a response surface methodology (RSM).

1.2. Problem statement

Teff Injera has been consumed in Ethiopia as a major staple food and becoming very known and wanted globally. Dried Teff injera, which is very known by its **Amharic name” Dirkosh”** is the other most important version of the fresh teff injera becoming popular in the market. It is easy to handle and can be stored for long time.in a research report (Quilligan, 2018) there are about six business group individuals who are studying and designing to assist Dirkosh in entering international markets. Unfortunately, there were not any study related to how it is produced maximum product, its physicochemical and sensory quality of Dirkosh. due to this reason dried Injera has been used in Ethiopia and exported abroad for long by using sun or griddle(mitad in Amharic) to dry the baked Injera. Using sun light energy to dry injera is not efficient and time consuming as well as it is impossible to control the temperature to keep the quality of the Dirkosh and mitad is not also controlled due this the product may be over dried or burnt. In order to alleviate such kind of problems in dried Injera production in home and in industrial scale for a better quality Dirkosh and economically profited this research finding was done by using CCTD and optimized the drying process factors(drying Temperature, air velocity and sample loading density) of CCTD in responses of the physicochemical and sensory quality of Dirkosh. The research was done by using the Box-Behnken design response surface methodology (RSM).

1.3. Significance of the study

The findings of this new research, optimization of drying conditions for quality dried teff injera contributed as a baseline data for developing effective drying of Dirkosh using Tray dryer and to have good information about how to produce dried teff injera using tray dryer. Tray dryers can be used to produce dried injera in homemade and in industrial scale so that we can add our economy and health benefits.

1.4. Objectives of the Study

1.4.1. General objective

The general objective of this study was to prepare and optimize the drying conditions for quality moisture reduced/dried Teff Injera ('Dirkosh') using response surface methodology".

1.4.2. Specific objectives

- ✓ Evaluate the effects of drying conditions (air temperature, air velocity and sample load) of tray dryer for dried Injera
- ✓ Evaluating and optimizing the responses by using desirability index technique of the dried Injera
- ✓ Assess the quality criteria (physical, chemical, microbiological/water activity and sensory quality) of dried injera

CHAPTER TWO

2. Literature Review

2.1. Teff

The cereal grain teff (*Eragrostis tef* [Zucc.] Trotter) is one of the major cereal crops of Ethiopia, where it is believed to have originated (Urga K and HV Narasimha, 1997). It is the most popular cereal grain for making injera, which forms the traditional basic diet in Ethiopia, although other grains such as sorghum, maize, barley, wheat and finger millet are sometimes used (Bultosa G. 2004). Teff has the largest share of area (23.42%, 2.6 million hectares) under cereal cultivation and third (after maize and wheat) in terms of grain production (18.57%, 29.9 million quintals) in Ethiopia (Central Statistical Agency of Ethiopia, 2008).

The principal use of teff grain for human food is the Ethiopian bread injera, a soft porous thin pancake with a sour taste (Yigzaw Y, et al .2001). Injera is made from flour, water and starter ersho (Ashenafi, 2006). Ersho is a fluid saved from previously fermented dough. Teff provides over two-thirds of the human nutrition in Ethiopia, with grain protein content (10-12%) similar to other cereals. Teff proteins have non-gluten nature and owing to prevailing portion of prolamins belong to easily digestible ones, which make it a suitable alternative to wheat in the case of celiac disease and gluten-free diet. Besides providing protein and calories, it has high nutritional content, including better amino acid composition, especially lysine, more mineral content (mainly iron, calcium, phosphorus and copper) than other cereal grains, contain B1 vitamin and is rich in fibre.

Fermentation is one of the oldest and most economical methods of producing and preserving food. It is found to destroy undesirable components, to enhance the nutritive value, flavour and taste of the food, and to make the product safe from pathogenic microorganisms. In indigenous fermented foods, the microorganisms responsible for the fermentation are usually the microflora naturally present on the raw substrate. Back slopping, that is, inoculation of the raw substrate with a small quantity of a previously performed successful fermentation is used to optimize spontaneous fermentation. This kind of a starter, which is a previously fermented product, is used not only to initiate the fermentation but also to accelerate the initial phase of fermentation and keep a uniform quality from batch to another. Foods that, in addition to their basic nutrients, contain biologically active components that can have a positive impact on the health of the consumer are defined as

functional foods (Nyanzi R *et al*, 2012) associated with fermentation are useful microorganisms, referred to as probiotics, most of which belong to the genera *Lactobacillus* and *Bifidobacterium*. These health enhancing microorganisms bring about fermentation resulting in production of lactic acid and hence commonly referred to as lactic acid bacteria (LAB). The term LAB is used to describe a broad group of Gram-positive, catalase-negative, non-sporing rods and cocci, usually non-motile, that utilize carbohydrates fermentative and form lactic acid as the sole or major end product. Prebiotics, on the other hand, are non-digestible food ingredients that affect the host by selectively targeting the growth and/or activity of one or a limited number of beneficial bacteria in the colon, and thus have the potential to improve health (Desai AR, *et al*, 2004). Teff *injera* is the most common and the main staple food in much of the central, western and northern highlands of Ethiopia as well as among the urban community.

2.2. Fermentation Process of Injera

The preparation of teff *Injera* consists of two stages of natural fermentation, which last for about 24 to 72 hours, depending on ambient temperatures (Steinkraus KH, 1983) Temperature in the highlands of Ethiopia is generally between 17 and 25°C. The only required ingredients are the teff flour and water. This is kneaded thoroughly to produce a thick paste. Inoculation is accomplished by consistently using partially cleaned fermentation container (back slopping) and by adding some *ersho*, a clear, yellow liquid that accumulates on the surface of the dough towards the final stage of a previous fermentation (Desiye A and K Abegaz. 2013). The initial 18 hours of fermentation are characterized by vigorous evolution of gas and maximum dough-rising (Gashe BA.1983). This is followed by the appearance of an acidic yellowish liquid on the surface of the dough at about 30-33 hours of fermentation. Gas evolution decreases after the pH has fallen below 5.8 (31 hours). The liquid layer is discarded at the end of the first stage of fermentation. As soon as the liquid layer is poured off, about 10% of the fermenting dough is mixed with three parts of water and boiled for 2 to 5 minutes.



Figure 2.1: Fermented teff batter ready to bake during the work

This is called *absit*, a dough enhancer, and it is mixed with the rest in the fermentation vat. *Absit* ensures that *Injera* will have the proper texture and consistency and the dough rising and gas formation processes are enhanced so they occur in a short time. This process signals the initiation of the second stage of fermentation.

Enjerra baked without *absit* or with less *absit* than the required will have fewer amounts of eyes (pits) on the upper surface. A higher number of larger eyes are a very desirable attribute of an attractive enjerra. Enjerra baked at 24 hours or less is called *aflegna enjerra* and has sweet taste. It is recommended for people suffering from gastritis and those who do not tolerate acidic foods.

Maximum dough-rising, which normally takes 30 minutes to 2 hours, signals the termination of fermentation. At this stage the fermenting dough is thin enough to pour onto the hot flat pan, locally known as *mitad* for steam-baking into *enjerra*. The total baking time for one enjerra is 2 ½ - 3 ½ minutes (Ashenafi M. 2006). Enjerra storage period does not usually exceed three days at ambient temperature (temperature in the highlands of Ethiopia is between 17 and 25o C) under the traditional storage conditions essentially due to mold spoilage.

2.3. Nutritional and Health Benefits of Teff *Enjera*

Importance of Fermentation: Fermentation leads to synthesis and availability of nutrients, reduction in ant nutritional factors and also leads to a general improvement in the shelf life, texture, taste and aroma of the final product (Blandino, Al-aseeri, Pandiella, Cantero, & Webb, 2003). Lactic acid fermentation contributes towards the safety, nutritional value, shelf life and acceptability of a wide range of cereal-based foods.

Nutritional Importance of Teff Fermentation

Teff grain contains less than 1% (528-842mg/100g) phytic acid and other inositol phosphates, which are strong inhibitors of Fe and Zn absorption (Umeta M, West CE and H Fufa. 2005) Fermentation gives *enjerra* its sensorial characteristics, as flavour, aroma and colour. But the more important effect of teff fermentation is the increase in the nutritional content, because of the decreasing relationships of iron with phytates and of iron and tannins. One study on content of zinc, iron, calcium and their absorption inhibitors in foods commonly consumed in Ethiopia reported that amount of phytates in *enjerra* is considerably reduced to 35-76 mg/100 g (91-93% destruction) due to fermentation and the acidity nature of *enjerra*. Microorganisms are able to produce various metabolites during the fermentation through their enzymatic action on the substrate and ant-nutritional factors are also reduced. Indeed, the lactic acid and volatile fatty acids (C2 - C6) were reported as the major organic acids produced during fermentation and contributing to good aroma and sour taste of *enjerra* (Umeta M and RM Faulks, 1988).

Different authors have demonstrated that during the teff paste fermentation, the phytate: iron molar ratio decreases. That is why, Ethiopian scientists and nutritionist agree about the need to improve the practice to ferment teff before use in *enjerra* production. Given the high iron content and the relatively favorable phytate: iron molar ratio, teff *enjerra* was the best source of bioavailable iron of all foods analyzed by researchers, between the Ethiopian foods.

**Table 2.1. Nutritional value of teff injera adopted from ESA ES 3786
2013 injera Specification.**

S.No	Types of nutrients	Nutrient composition per 100g of teff injera
1	Energy, Cal	145.0 – 155.9
2	Protein, g	3.0 – 3.8
2.1	Gluten	ND*
3	Total carbohydrate, g	31.9 – 34.0
3.1	Crude fiber, g	1.0 – 1.8
4	Fat, g	0.6 – 0.7
5	Minerals (Total ash), g	0.7 – 1.7
5.1	Calcium (Ca), mg	50.0 – 68.0
5.2	Phosphorus (P), mg	100.0 – 115.0
5.3	Iron (Fe), mg	7.0 – 14.7
5.4	Zinc (Zn), mg	1.5 – 1.7

2.4. Teff injera Health Benefits

Teff Injera, particularly from red teff, has high iron content. In areas of the country where consumption of injera from red teff is prevalent, people tend to have higher levels of hemoglobin and, thus, a decreased risk of anemia related to parasitic infection. (Since the teff grain is too small to separate into germ, bran and endosperm, the flour has much higher fibre content than other cereals. This is particularly important in dealing with diabetes in assisting with blood sugar control (Gebremariam, Zarnkow, & Becker, 2012).

Interest in teff has increased noticeably due to its very attractive nutritional profile and gluten-free nature of the grain, making it a suitable substitute for wheat and other cereals in their food applications as well as foods for people with celiac disease. Research on celiac disease patients who are using teff reported a significant reduction in symptoms. Hence, teff *injera* can be a valuable addition to the gluten free diet of celiac disease patients.

2.5. Physical Characteristics and Quality Attributes of Injera

Injera is a fermented and naturally-leavened flatbread indigenous to Ethiopia, ~50 cm in diameter with a honeycomb-like texture, rather like a giant crumpet (Belton & Taylor, 2004).

It constitutes 70% of the diet of Ethiopians (Gamboa and Ekris, 2008) and is preferably made from the teff grain which is indigenous to Ethiopia. Other grains such as sorghum, millet, maize, wheat and mixtures thereof have also been used in making injera. Sorghum is the second most preferred flour for injera preparation in Ethiopia; however, teff injera is the most preferred because it can be stored for 3 days without losing its pliability (Steinkraus, 1995).

Quality characteristics of injera are directly related to its appearance, texture and taste. According to Gebrekidan and Gebre Hiwot (1982), a normal and typical injera is round, soft, spongy and resilient, about 6 mm thick and ~60 cm in diameter with uniformly spaced honeycomb-like “eyes” on the top. Injera is unique in that despite the fact that it is not made from gluten-containing wheat, it is leavened.

Injera with large unevenly spaced eyes or those with tiny eyes are both considered poor quality. While the former signifies insufficient fermentation, the latter signifies too much asit in the dough. The backside of injera is normally smooth and devoid of eyes. A good injera is also spongy and can be folded without cracking. A non-powdery, soft appearance is also characteristic of a good quality injera. Poor quality injera is brittle, crumbles easily when handled, and looks powdery and dry, or sticky and rusty brown on the back.

The color of injera could generally be whitish, cream, reddish brown, or brown depending on the color of the Teff flour used. The most preferred kind of injera is whitish or cream in color, has a soft and pliable texture for as long as 3 days after its preparation, is relatively thin, and has uniformly spaced medium sized eyes. The backside of injera must be smooth, not sticky and should not look rusty or brown with burns. Good quality injera does not fluff off and stick to the fingers when it is handled. In taste, good injera must be slightly sour to have the desired taste combination with the spicy wot. Injera made from dough that has not been sufficiently fermented has sweetish taste and is not considered good for eating with wot. This type of injera is called aflegna. When there is an urgent need for injera and the house wife cannot wait until sufficient fermentation has taken place,

she would normally make Aflegna injera. Injera made from over fermented dough is too sour and is undesirable for food.

The texture of injera should be spongy as well. Texture is the overall experience of how a substance feels in the hand and mouth. It contributes to the overall eating experience and can impact flavor release of a food product. *Injera* is used as an eating utensil and this makes its texture an important quality attributes.

The quality of injera is influenced to a large extent by the fermentation process and the length of time for fermentation. In teff, the primary agent of fermentation of the injera dough has been identified as the yeast *Candida guilliermondii* (Cast) Langeron and Guerra (Stewart and Getachew 1962).

2.5.1. Number of eyes

The number of eyes and the distribution on the surface of injera has always been taken as a good indicator of injera quality. Ideally, eyes should neither be too few nor too numerous, they must be rather deep, interlocked with thin cross walls between them and be evenly distributed. Eyes need not be of uniform size, but variation in dimension should not be large.

Carbon dioxide produced during fermentation is known to play a fundamental role in the formation of cellular structure of leavened breads. Thus the absence of eyes or limited number of eyes in the prepared injera is indicative of very little carbon dioxide being produced during fermentation. So if the activities of microorganisms and enzymes are limited, the fermentation process will be inhibited (Yetneberk *et al.*, 2004).

2.5.2. Color

Visual appearance or the color of a food is the first quality parameter that the consumer perceives and uses as a tool to either accept or reject it. Color is one of the physical properties often used by food customers and manufacturers to qualitatively assess the quality of feed and food materials. Color is a perceptual phenomenon that depends on the observer and the conditions in which the color is observed. Color is one of the most important physical attributes in the assessment of flour quality in injera preparation. According to Gebrekidan and GebreHiwot, (1982), the color of injera could generally be whitish, cream, reddish-brown, or brown depending on the color of the flour

used. The most preferred kind of injera is whitish or cream in color, has a soft and pliable texture for as long as 3 days after its preparation, is relatively thin, and has uniformly spaced medium sized eyes.

The color of food products can be evaluated using sensory panelists or instrumental analysis. Instrumental color analysis can be specified by three co-ordinates in the color space which can be obtained directly with a tristimulus colorimeter. In his study “A comparison of two different instruments for measuring venison CIELAB values and color assessment by a trained panel” on meat products, Stevenson et al. (2015) identified that there is close relationship between perceived color and CIE (1976) $L^*a^*b^*$ values and suggests that both instruments can be used as a satisfactory substitute for a trained panel, provided they are calibrated appropriately. Literature is scarce with respect to the effect of blending ratios on color quality (L^* values) of injera.

CIELab color space

$L^*a^*b^*$ color space (Figure 2.2) is an international standard for color measurements, adopted by the Commission Internationale d’Eclairage (CIE) in 1976 (Leon *et al.*, 2006; Pathare *et al.*, 2013). L^* is the luminance or lightness component, which ranges from 0 to 100, and parameters a^* (from green to red) and b^* (from blue to yellow) are the two chromatic components, which range from -120 to 120 (Leon *et al.*, 2006). The Lab color is device independent, providing consistent color regardless of the input or output device such as digital camera, scanner, monitor, and printer. The $L^*a^*b^*$ values are most frequently used in food research studies to measure the color of food products. Unlike the RGB and CMYK color models which are mostly used for screen display and printing respectively (Yam & Papadakis, 2004), $L^*a^*b^*$ color is designed to approximate human vision.

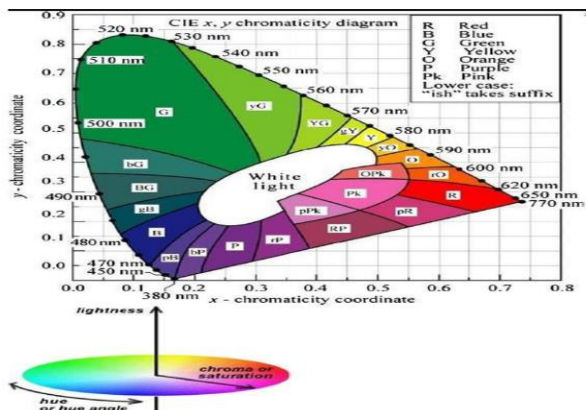


Figure 2.2: Illustration of the CIE, 1931 color space.

It aspires to perceptual uniformity, and it is L^* component closely matches human perception of lightness. It can thus be used to make accurate color balance corrections by modifying output curves in a^* and b^* components, or to adjust the lightness contrast using the L^* component (Vyawahare *et al.*, 2013)

Adobe Photo ShopTM

PhotoshopTM is standard software used primarily by graphics producers and photographers for photo re-touching and image editing (Adobe Photoshop, 2002). However, the software also has several features that maybe adopted for analyzing color of food samples. Its richness in image editing features and its color analysis capability comparable to the more expensive color analysis software make the Adobe PhotoshopTM more preferable (Yam, 2004). The software provides more sophisticated capability for man-aging color and producing consistent color than other graphics software. The software is also available in many laboratories, and it is strongly supported by the manufacturer and user (Yam and Papadakis, 2004).

Image Analysis of Injera

The digital imaging method allows measurements and analyses of the color of food surfaces that are adequate for food engineering research. PhotoshopTM is shown to be able to analyze the color for food samples, although the software was not originally designed for this purpose. However, it is already one of the most powerful software for color analysis, and the manufacturer and users are regularly making enhancements (Yam and Papadakis, 2004).

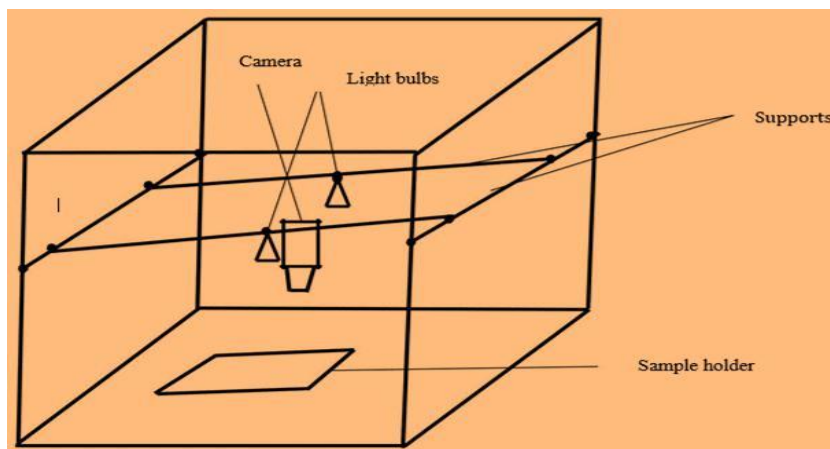


Figure 2.3: Image processing acquisition systems.

2.5.3. Taste

A good injera must be slightly sour to have the desired taste combination with the spicy wot. Injera made from dough that has not been sufficiently fermented has sweetish taste and is not considered good for eating with wot. This type of injera is called aflegna. Injera made from over fermented dough is too sour and is undesirable for food (Mezemir, 2015; Boka *et al.*, 2013). The quality of injera is influenced to a large extent by the fermentation process and the length of time for fermentation.

2.5.4. Appearance

The shape is properly round and the top surface has uniformly distributed eyes and closely located to one another. There should be no blind spots on the surface. The general appearance should be rich and not powdery. The backside should be smooth and not browned. Rough circumference, powdery and cracked top surface, too large or tiny and irregularly placed eyes and if the backside is browned are considered as poor quality injera (Gebrekidan and Gebrehiwot, 1982; Yetneberk *et al.*, 2004)

2.5.5. Texture

The injera should be soft enough to cut a piece easily with the fingers but resistant enough so that it does not crack or crumble when folded or used to wrap around wot portions when eating. The texture should not be gluey or stick to the fingers when handled. It should not be too thin, dry, brittle, or leathery (Gebrekidan and Gebrehiwot, 1982).

2.5.6. Proteins

Since tef flour does not contain gluten, its elasticity is not due to gluten. However, proteins in tef may have a function similar to that of gluten in wheat flour (Rosell *et al.*, 2002). The gluten proteins in wheat contain gliadin and glutenin subunits. The fractions have functional significances as the glutenins are largely responsible for gluten elasticity and gliadins for viscosity (Shewry *et al.*, 1995). This view is supported by the fact that when reductants such as cysteine, or sulfhydryl-blocking agents, such as N-ethylmaleimide, are added to the dough, viscoelasticity decreases greatly. Interactions other than disulfide crosslinks, such as hydrogen bonding and hydrophobic

interactions may also play a vital role in viscoelasticity of wheat dough. Belitz *et al.* (1986) stated that partial or total reduction of intermolecular disulfide bonds lowers both molecular weight and elasticity of gluten. Adebowale *et al.* (2011) observed in their study of tef proteins that polypeptide bonds in prolamins are disulphide bonds and that a large proportion of the storage proteins in cereals are bonded into large polymeric networks. Tef prolamins were however found to be less cross-linked by disulfide bonds than sorghum prolamins. A study by Vallons *et al.* (2011) showed that protein polymerization by thiol/disulfide-interchange reactions occurred in white rice and tef batters using capillary gel electrophoresis but there was no such cross-link mechanism in buckwheat proteins due to the absence of free sulfhydryl groups. Even though Adebowale *et al.* (2011) showed that there is crosslinking of disulfide bonds of prolamins in tef, it is still unknown to what extent this interaction may be responsible for elasticity of *injera*. Other studies (Renzetti and Arendt, 2009; Moore *et al.*, 2006) have used enzymatic manipulation to crosslink proteins in gluten-free flours in order to obtain similar textural characteristics of gluten-containing cereal flours. Different strategies have been used in the absence of gluten in order to mimic its viscoelastic properties. In a study on roti, unleavened bread made from sorghum, the authors stated that although sorghum grains do not contain gluten, when sorghum flour is mixed with water and kneaded it produces sticky dough. They further stated that good quality dough should be sticky and easily rollable without breaking. Renzetti and Arendt (2009) improved the bread making performance of gluten-free flours from corn and sorghum that they attributed to protein polymerization, which can enhance elastic-like behavior of batters. Making the dough properties more similar to those of wheat flour and rice flour which were improved by addition of soy protein isolates and hydroxypropylmethylcellulose (HPMC) in a study by Marco and Rosell (2008). Traditionally in Ethiopia, tef dough is kneaded and this forms a dense sticky mass. It is however unknown whether this dense mass is as a result of network formation by tef proteins. The various proteolytic activities induced by fermentation hydrolyze cereal proteins to produce free amino acids (Spicher and Nierle, 1988; Thiele *et al.*, 2002). Cereal flour, yeasts, and lactic acid bacteria contain proteases and peptidases that can contribute in different ways to these proteolytic events. According to Renzetti and Arendt (2009), lower molecular weight proteins resulting from hydrolysis by proteases affected the resistance of brown rice flour batters during proofing, and increased batter elasticity and paste stability. Higher proteolytic activities are encountered for brans and whole grain flour compared to white flour (Loponen *et al.*, 2004), and this is likely to

have an effect on *injera* prepared from tef flour since it contains bran. In a study conducted by Salmenkallio-Marttila *et al.* (2001) on wheat bran, they found that the positive effect of fermentation of bran on bread quality was evident when comparing the well-developed protein network structure of the breads baked with fermented bran and the control bread containing unfermented bran. Protein degradation in sourdough fermentation is among the key phenomena that affect overall quality of sourdough breads according to Ganzle *et al.* (2008). The functionality of the cross-linking enzymes such as transglutaminases and tyrosinases in gluten-free breadmaking is also comparable to that in wheat breadmaking. According to Renzetti and Arendt (2009), in the absence of other hydrocolloids, protein structures are important to ensure the textural quality of gluten-free breads. It has however not been proven that proteins contribute to the elastic texture in *injera*.

In a study on the proteins found in sorghum and millet, Belton and Taylor (2004) stated that full analysis and sequencing of the main storage proteins is yet to be carried out and very little work exists on their functional properties. The results from a study by Schober *et al.* (2007) suggested that proteases mainly degrade proteins that are already soluble at the beginning of fermentation, and degradation of those proteins soluble in the dough liquid (supernatant after centrifugation) to smaller peptides may well explain why they can no longer cross-link and therefore do not aggregate upon baking. According to Schober *et al.* (2007), it remains unclear whether and according to which physicochemical mechanism protein degradation and bread quality are related in a gluten-free system. Parker *et al.* (1989) observed that tef storage proteins played no part in the structural integrity of cooked *injera*, although they may add to the texture. This statement is however not clear as structural integrity of a material is related to its texture. Parker *et al.* (1989) also found out that total protein levels decreased slightly during the preparation of *injera*. It is therefore necessary to understand the contribution of proteins to the quality of *injera*.

2.5.7. Starch

A study by Parker *et al.* (1989) on *injera* showed that during cooking, the starch within the *injera* is totally gelatinized to form a steam-leavened, spongy starch matrix, in which fragments of bran and embryo, micro-organisms and organelles are embedded. Petrofsky and Hoseney (1995) indicated that increased starch-gluten interaction increased the viscoelasticity of gluten dough.

Petrofsky and Hosenev (1995) further stated that starch had an active role in determining dough rheological characteristics. Hamada *et al.* (2013) also reported that the rheological properties of rice batter facilitated adequate gas retention during yeast fermentation, which was caused by protein-starch interaction that resulted from the partial degradation of storage proteins surrounding the starch granules. Umeta and Faulks (1988) stated that tef starch has a smaller granule size of 2-6 μm compared to sorghum starch (approximately 20 μm) and according to Yetneberk *et al.* (2004), the relative softness of tef *injera* compared to sorghum *injera* could be related to starch granule size. They further stated that the cell walls and aleurone components of tef could affect the texture of *injera* positively. It is proposed that tef starch forms networks which might have a significant role to play in the elasticity of *injera*. The pasting properties of tef starch have an effect on the texture of *injera*. The breakdown viscosity is the decrease in viscosity of the paste as a result of the rupturing of starch granules at high temperatures (Sciarini *et al.*, 2008). This gives an indication of the shear-thinning behavior of the pastes. Yetneberk *et al.* (2004) stated that the difference in pasting properties of sorghum and tef flours could also be related to inherent morphological differences in their starches. More syneresis is likely to be seen in a viscous fluid with a high setback viscosity. The study on tef starch by Bultosa *et al.* (2002) reported a low setback viscosity and slow syneresis. (Yetneberk, Kock, Rooney, & Taylor, 2004) hence stated that this finding by Bultosa *et al.* (2002) is probably related to the softer texture of tef *injera* compared with sorghum *injera*. According to Bultosa (2007), tef starch and its flour pasting are shear tolerant and thus have a potential for use in foods processed under high shear conditions. The *absit* (pre-gelatinized starch) added to the tef batter after primary fermentation is known to enhance the texture of *injera*. According to Taylor and Emmambux (2008), the increased viscosity of the tef batter resulting from cooking the *absit* seems to enable it to better hold the carbon dioxide produced during fermentation. Zannini *et al.* (2012) stated in their paper that starch gelatinization could play an important role in gluten-free formulation because of the ability of starch pastes to trap air bubbles that aid the gas-holding capacity of batter. According to Abdel-Aal (2009), modified starches such as partially cross-linked and pre-gelatinized starches could play an important role in gluten-free bakery formulations due to their ability to form highly viscous slurries and pastes. Native and modified starches are added to batter formulations in order to soften crumb texture, improve batter consistency and control starch gelatinization during baking (Abdel-Aal, 2009). The *absit* therefore plays an important role in the formulation of good quality *injera*.

2.5.8. Hemicelluloses

Since the grains of tef are extremely small, less than 1.5 mm in length (Parker *et al.*, 1989), the whole tef grain is milled into flour. Hemicelluloses are found in the bran or outer layer of grains. Hemicelluloses are generally classified according to the main sugar residue in the backbone, e.g., xylans, mannans, and glucans, with xylans and mannans being the most prevalent in plant tissues (Wyman *et al.*, 2005). Izydorczyk *et al.* (2001) stated that both beta-glucans and arabinoxylans may influence barley dough properties by affecting water distribution in the dough and may form elastic networks and contribute to overall elasticity and strength of the dough under conditions of restricted water availability. However, a study by Hung *et al.* (2005) showed that dietary fibers in baked products increase water absorption and decreased dough elasticity. According to Parker *et al.* (1989), the thin bran layers and endosperm cell walls in tef probably account for the lower levels of dietary fiber of less than 5% compared with 14% in wheat, however, these components appear to be unaffected by fermentation.

2.5.9. Exopolysaccharides

Lactic acid bacteria are responsible for the sour taste in sourdough fermentations like that of *injera*. Many lactic acid bacteria (LAB) can produce a wide variety of long-chain sugar polymers called exopolysaccharides (EPS), which are varied in their chemical composition, structure and physical properties (Moroni *et al.*, 2011). According to Arendt *et al.* (2007), polymers produced from lactobacilli may be expected to beneficially affect a number of technological properties of bread, including water absorption of the dough, dough machinability, increased loaf volume, and retarded bread staling.

2.6. The effect of other components in fermented tef on *injera* quality

2.6.1. Fermentable sugars

The level of sugar in tef flour is known to decrease during fermentation as lactic acid bacteria acts on it to produce lactate. Sugar has been shown to have an effect on *injera* quality as most Ethiopians prefer the characteristic sour taste of *injera*. The *aflegna injera* (baked at 24 hours) is sweet and is preferred by some Ethiopians, but is not as pliable as fully fermented *injera*. During fermentation, amylase breaks down starch into dextrin, which increases levels of fermentable

sugars in the wheat dough (Goesaert *et al.*, 2006) and hence, increases bread volume. Umeta and Faulks (1988) studied two varieties of tef and observed that both varieties contained free sugars that were predominantly sucrose (95%) with fructose being the principal free sugar in the fermenting batter and cooked product Baye *et al.* (2013) showed glucose to be the main fermentable sugar in a tef-white sorghum composite *injera*. Free sugars may also have an effect on the texture of *injera* as Rühmkorf *et al.* (2012) showed in their study that the higher the sucrose concentration at the beginning of fermentation, the higher the amount of exopolysaccharides produced. The free sugars in fermented tef may also have an effect on the glass transition temperature (Tg) of *injera*. Tg defines a transition from brittle, metastable amorphous solid to a rubbery, unstable, amorphous liquid (Kaletunc and Breslauer, 1993). There is limited study on the Tg of tef, however, a study by Adebowale *et al.* (2011) reported that tef prolamins have a relatively low thermal stability compared to kafirin and this may be related to the good bread making functionality of tef flour. According to Welti-Chanes *et al.* (2008), a polymer is brittle (a glassy solid state) below its Tg but above Tg, it is flexible and malleable. The flexibility of *injera* is an important attribute as it relates to its elasticity. As mentioned in previous paragraphs, the pliability of *injera* enables it to be used as a utensil to scoop up *wot*. It is however unknown whether Tg of the protamines, starches or sugars in tef have a significant effect on the texture of *injera*.

2.6.2. Polyphenols

Antioxidant activity is a fundamental property important for life (Velioglu *et al.*, 1998). Polyphenols are known to have nutritional properties because of their antioxidant characteristics. Phenolic compounds such as flavonoids, phenolic acids, and tannins are considered to be major contributors to the antioxidant capacity of plants. Tannins are known to cause bitterness in foods prepared from some cereals. A comparison of white tef, brown tef and red tef by Boka *et al.* (2013) reported that red Teff contained the highest polyphenolic content while white tef contained the lowest. In a study conducted by Yetneberk *et al.* (2005), tannins were observed to have an inhibiting effect on fermentation. Due to this phenomenon they decorticated sorghum by removing the bran, germ and testa (which contained tannins in some varieties of sorghum) in order to improve the color, taste and appearance of the *injera*. McManus *et al.* (1981) also described a tendency of polyphenols to cross-link protein molecules at higher protein concentrations in his study. He stated that where the protein concentration is high the relatively hydrophobic surface

layer is formed by complexation of the polyphenol onto the protein and by cross-linking of different protein molecules by the polyphenols. There has not been any research on tef, *let alone* gluten-free grains to show whether this phenomenon occurs during fermentation or whether this contributes to the elasticity in *injera*.

2.7. Moisture

In a study by Ashagrie and Abate (2012), the moisture content of their *injera* samples ranged between 63 to 65%. Moisture in foods is known to have an effect on quality both positively and negatively. Parker *et al.* (1989) likened cooking of *injera* to wafer production and stated that for rapid gelatinization of starch and entrapment of gas bubbles, the batter-like dough should have a high water content, that a steamy atmosphere should be maintained throughout the cooking period, and that heat should be efficiently transferred from the cooking surface. The glass transition is strongly dependent on water content, which often causes large differences in reported glass transition temperatures (Roos, 2010). Gelatinization of starch is strongly affected by water content (Pyle, 2005). Pyle (2005) observed that the structure of baked crumpets depended on a number of factors including water content of the batter. The moisture content of *injera* will therefore have an effect on its texture.

2.8. Tef fermentation and the contribution of ‘absit’ to injera quality

The fermentation of *injera* begins with adding water to tef flour and mixing or kneading it with a starter (back-slopped culture) called *irsho*. There is little information on mixing and its effect on the texture of *injera*. In the traditional preparation of *injera*, the tef flour, water and *irsho* are kneaded into a thick paste or dough (Zegeye, 1997; Girma *et al.*, 2013; Abraha *et al.*, 2013; Ashagrie and Abate, 2012). Kneading in breadmaking is known to aerate the dough and according to Maloney and Foy (2003), gas retention depends on the development of the proper dough structure which requires adequate dough mixing. According to Keiffer (2006), during kneading, the wheat dough will wind up the hook when the kneading optimum approaches. He described this as the ‘so-called Weissenberg effect’ and stated that it is a sign of elasticity. It is not known whether the Weissenberg effect (rod-climbing phenomenon) occurs in gluten-free dough or whether kneading enhances this phenomenon and hence has a significant effect on the quality of the final baked *injera*. Some studies conducted on *injera* reported varying amounts of tef flour to water

ratio in tef fermentation. The tef flour, water and *irsho* are usually mixed in different proportions. The flour to water ratio varies in literature from 1:1 to 2:3, 1:1.6 was used by Girma *et al.* (1989), 1:2 was used by Ashagrie and Abate (2012), Girma *et al.* (2013) and Abiyu *et al.*, (2013), while a ratio of 2:3 was used by Zegeye (1997) and (Parker *et al.*, 1989). According to Stewart and Getachew (1962), the time of fermentation depends on the altitude of the area, the concentration of the *irsho*, and the container used. Stewart and Getachew (1962) stated that the time for optimum fermentation, *i.e.* when gas production ceases and the dough and liquid phase separate, varies depending on how the fermentation is initiated, the numbers and type of organisms present in the *irsho* or flour, ambient temperature, and the type and bacterial cleanliness of the container used. After about 48 to 72 hours of primary fermentation, part of the fermented batter is gelatinized by cooking to form the *absit* which is then added back to the fermented batter. This step initiates the ‘secondary fermentation’.

The role of the *absit* in *injera* making is not clear. Zannini *et al.* (2012) stated that the functionality of *absit* in the *injera* flatbread can be described as that of hydrocolloids in gluten-free breads, providing the batter with a better gas-holding capacity because of increased viscosity. Ashenafi (2006) also reports that the *absit* is a dough enhancer (improves the texture of the dough) and Girma *et al.* (2013) also mentioned that the *absit* is a dough binder, but did not define these terms or suggest a mechanism for the effect. It is believed that the main function of a dough enhancer and dough binder is to enhance the viscosity of batters. Other possible functions of the *absit* are that it activates yeasts responsible for CO₂ production (Abiyu *et al.*, 2013) and the development of eyes during baking of *injera*. Ashenafi (2006) mentioned that *injera* baked without *absit* or with less *absit* than required will have a lesser amount of eyes on the upper surface. Also according to Stewart and Getachew (1962), *injera* made from batter lacking *absit* has a powdery look and lacks the air spaces or the so-called eyes of the *injera* which give it an “inviting look”. Yetneberk *et al.* (2004) stated that the objective of gelatinization is primarily to bring about cohesiveness of the batter and secondly to provide easily fermentable carbohydrate to leaven the *injera*.

Yetneberk (2004) reported that by cooking part of the fermented batter to gelatinize the starch, the carbon dioxide produced by the fermentation is trapped and leavens the *injera* on baking. Umeta and Parker (1996) stated that an objective of cooking part of the batter is to increase the amount of gluey material between the batter particles to form more cohesive starch matrix in the *injera*. It

is still not known whether the *absit* has all these functions or whether other processes during fermentation are responsible for eye formation and elasticity of *injera* during baking. However, from all the different functions of the *absit* it is very clear that it helps to improve the quality of *injera*. From studies on *injera*, the amount of *absit* to use for secondary fermentation varies. Ten percent (10%) (Ashenafi, 2006; Girma *et al.*, 2013; Umeta and Faulks, 1988; Zegeye, 1997) of the weight of the fermented batter is commonly used to make *absit*. However other amounts such as 5%, 15% and 20% (Zannini *et al.*, 2012) of the fermented batter are sometimes used. There are no studies on *injera* elasticity or any research to show whether *absit* contributes to this elasticity. Parker *et al.* (1989) stated in their study that the major contributor to the *injera* matrix is gelatinized starch.

2.9. Viscosity of Teff batter

The overall effect of batter viscosity on the quality of baked *injera* has not been studied. Zannini *et al.* (2012) stated that the *absit* added back to the fermented batter increases the viscosity of the batter and provides the batter with a better gas-holding capacity. According to Shelke *et al.* (1992), the minimum viscosity maintained by a wheat flour batter during heating is considered important because it reflects the ability of the batter to retain gas bubbles and to resist settling of starch. A study conducted by Schober *et al.* (2007) on sorghum flour, showed that during fermentation the sourdough becomes thinner. They observed that the extrusion force between a fresh (2 h) and ripe (24 h) sourdough differed significantly by 48% (4.6 N for fresh vs 2.4 N for ripe sourdough), and described the drop in consistency of the batters as being due to degradation of mechanically damaged starch by amylases from sorghum and the degradation of proteins. Degradation of starch and proteins of tef flour occurs during fermentation. It is however, unknown whether a similar effect observed in the sorghum flour is likely to be seen in tef flour, as both cereals are gluten-free. Hamada *et al.* (2013) related kneading of rice flour dough to the viscosity of batter. They observed that if rice flour is kneaded with water, the dough has greater fluidity than wheat dough and its viscosity resembles that of cake batter. Gebrekidan and GebreHiwot (1982) in their study on sorghum *injera* reported that normal *injera* should be thin, about 6 mm, the same thickness reported by KamalEldin and Chiwona-Karlton (2008). The viscosity ranges of 200-1500 cP appears to be a wide range as tef batter used in preparing *injera* usually has a thin pancake-like consistency. Tef batter is expected to exhibit shear thinning or non-Newtonian behavior at

increasing shear rates. A study by Bhattacharya and Bhat (1997) on rice-blackgram suspensions used to make ‘dosa’, a popular Indian dish similar to *injera*, showed that it exhibited shear-thinning behavior and the Herschel-Bulkley model fit the shear rate and shear stress data of the suspensions better than the power law model or the Casson model. The behavior of materials is described by three Herschel–Bulkley parameters (Mullineux, 2008): the consistency coefficient (k), flow behavior index (n) and yield stress (σ_0). This is represented by the equation:

$$\sigma = \sigma_0 + k\gamma^n$$

Considering the effect that the consistency of batters has on air bubble migration, it is believed that determining the viscosity of tef batter before baking is very crucial in ensuring that good quality *injera* is produced.

2.10. Impact of pH and temperature on *injera* quality

The pH, fermentation temperature and baking temperature of fermented tef batter may also have an effect on the quality of *injera*. Cereal mashes with a pH of 5-6.2, which are rich in fermentable carbohydrates, will be preferentially fermented by LAB, at least to a pH below 4, and below this point, acid-tolerant yeasts dominate the fermentation (Stolz, 2003). Ashagrie and Abate (2012) determined the pH of *injera* to be 3.4. Rühmkorf *et al.* (2012) analyzed pH and titratable acidity (TA) in fermented rice, buckwheat and quinoa and stated that these parameters are an important control for contaminations. Also in their study, Rühmkorf *et al.* (2012) observed that the higher the inoculated cell counts, the faster the pH decreased and TA and lactate amounts increased. Fermentation temperature has been found to affect the pH of spontaneous tef fermentations and quality of *injera*.

According to Valjakka *et al.* (2003), temperature control is critical in sourdough production as changes in fermentation temperature may cause variation in microflora of sourdough and thus variation in sourdough and final bread quality and flavor.

The optimum temperature range for yeasts is 20-30 °C. Most lactic acid bacteria work best at temperatures of 18 to 22 °C but temperatures above 22 °C favor lactobacillus species .

Ashagrie and Abate (2012) stated that temperature in the highlands of Ethiopia is generally between 17 and 25 °C, hence, *injera* made at these temperatures should still have the desirable quality characteristics. During the baking process, heat is transferred from the hot pan to the surface of the food material, while moisture is transferred from the interior to the surface of the product and then evaporates. As a result, changes in temperature and moisture conditions develop as cooking proceeds, and bring about the desirable characteristics (color, texture, and flavor) of the food (Getenet, 2011). Pyle (2005) stated that a typical temperature range for baking crumpets is 200-230°C, and observed that baking temperature increased the elasticity of the crumpets. While most studies conducted on *injera* do not state the temperature at which *injera* was baked, a study by Tsegay (2011) observed that the baking of *injera* starts after the baking pan surface temperature reached 215 °C and dropped to about 92 °C when the batter was poured onto the pan surface. They measured the baking pan surface temperature in the experiment and registered a temperature of about 215 °C on the pan surface in order to make it possible to bake ‘nice *injera*’.

According to Ashenafi (2006), the temperature in the middle of the *injera* during the baking process would reach around 90 °C. Because baking temperature of *injera* varies in the literature it will be necessary to obtain a standard temperature at which *injera* can be baked in order to obtain proper eye formation and elastic texture of *injera*.

2.11. Drying characteristics and mathematical models

Drying is an ancient technique of food preservation & for extension of shelf life of foods; and it minimizes the transportation cost as well as the storage cost per unit product weight. Sun drying is the most common method to preserve the foods in rural area whereas in industries mechanical drying is in practice. Preservation of fruits and vegetables, meat, fish and food plants by drying in the sun or in the naturally dry air of the deserts and mountains has been practiced and is still a vital operation in the life of many rural communities. For the faster drying (i.e. time saving) and more versatility in commercial scale mechanical drying is the common technique to preserve the foodstuff.

Drying or dehydration is, by definition, the heat and mass transfer process for removal of water by application of heat, from a solid or liquid food, with the purpose of obtaining a solid product sufficiently low in water content. Where removal of water takes place by virtue of a

difference in osmotic pressure and not by evaporation. The main objectives of food dehydration is: Preservation because of lowering of water activity; low transport and storage cost as a reduction in weight and volume;

According to a study by (Guiné, 2018),the traditional solar drying with direct exposure to the sun had many disadvantages and presently more modern methods are used, such as hot air drying, spray drying, lyophilization, infrared, microwave or radiofrequency drying, osmotic dehydration or many combined processes. Many foods can be preserved through drying, but their organoleptic and nutritional properties are greatly changed as compared to the fresh equivalents.

There are hundreds of types of dryers, based on different principles of operation, among this hot air convective drying by using tray dryer is the most important for foods, which are wet solids. The convective drying of porous media, including foods, has a pivotal role in several food industries. The methods in which hot air is used for drying foods are very versatile and have a considerable importance. These include drying in chambers with trays.

The direct (convective), drying medium directly contacts material to be dried and carries evaporated moisture. According to a study by (Perera, 2007) quality of dried food products involves many factors, such as :

- Microbiological stability of the dried product
- The processing environment—dirty floors, ceilings, and equipment surfaces can lead to product contamination and high microbiological load
- The production and packaging process—wet and dry areas should be separated so that no cross-contamination of the processing environments can take place. For most dried products, the packaging area should be climate controlled to prevent moisture reabsorbing back into the product.
- The finished product should be stored in a cool dry place

(Xiao, Gao, Lin, & Yang, 2010) studied the air impingement drying characteristics and quality of carrot cubes. The effects of air temperature (40, 50 and 60°C), air velocity (3.0, 8.0 and 13.0 m/s) and air relative humidity (10, 20 and 40%) on air impingement drying characteristics of carrot cubes and the quality of dried carrots were investigated. The drying experiments were carried out

according to orthogonal design method on the air impingement dryer. Results indicated that drying time of carrot cubes was more affected by drying air temperature, followed by air relative humidity and air velocity.

The color values L (white/dark), a (red/green) and b (yellow/blue) of the samples decreased from 50.02 to 32.71, 32.49 to 14.34 and 35.52 to 16.38 separately when the drying temperature increased from 40 to 60°C.

The surface microstructures of dried carrot cubes were observed using a scanning electron microscope, which showed that the outer layers of the samples dried at 60°C drying temperature and 10% air relative humidity had more consolidated rigid and denser structure than the samples dried at 40°C drying temperature and 40% air relative humidity.

2.12. Effect of drying on colour

To assess the colour values L, a and b of banana pulp and peel flour prepared from green and ripe Cavendish banana. It was reported that a substantial colour difference existed between the pulp and peel flour. The dehydration processes not only affect the colour and other pigments but also the sensory attributes like colour, appearance, texture, aroma and overall quality to a varying degree.

2.13. Response Surface Methodology and Experimental Design

An experiment is a series of tests, called runs, in which changes are prepared in the input variables in order to recognize the reasons for changes in the output response (Montgomery). Design of Experiments (DOE) is a powerful technique used for exploring new processes; gaining increased knowledge of the existing processes and optimizing these processes for achieving world class performance (Jiju Antony, 2003). Engineering experimenters wish to find the conditions under which a certain process attains the optimal results. That is, by careful design of experiments, they want to determine the levels of the design parameters at which the response reaches its optimum. The optimum could be either a maximum or a minimum of a response (output variable) which is influenced by several independent variables (input variables). One of the methodologies for obtaining the optimum results is response surface methodology.

Response Surface Methodology (RSM), invented by Box and Wilson, is defined as a collection of mathematical and statistical tools or techniques useful for modeling, analyzing and simultaneously solving problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Giovanni, 1983). Response surface methodology also quantifies the relationship between the controllable input parameters and the obtained response surfaces. It is a well-known up to date approach for constructing approximation models based on physical experimented observations (Box *et al.*, Montgomery). The main advantage of RSM is the reduced number of experimental runs needed to provide sufficient information for statistically acceptable results (Montgomery, 2000).

- ✓ Designing of a series of experiments for adequate and reliable measurement of the response of interest.
- ✓ Finding the optimal set of experimental parameters that produce a maximum or minimum value of response.

RSM can be defined as a statistical method that uses quantitative data from appropriate experimental designs to determine and simultaneously solve multivariate equations, which specify the optimum product for a specified set of factors through mathematical models.

CHAPTER THREE

3. Methodology

This chapter deals with the experimental plan, sample preparation, physical characteristics, different analytical techniques used, and modeling studies on drying data and product quality analysis methodologies.

3.1. Location of study area

The baking process of injera, physicochemical and sensory analysis of fresh Injera were done at Ethiopian Public Health Institute (EPHI). The other experiments, drying of injera and the analysis (moisture content, color, texture) of the dried injera were conducted at Addis Ababa Science and Technology University department of Food process Engineering (Food Process Engineering Laboratory).

3.2. Raw material collection and sample preparation

The raw material Quncho-white Teff (DZ-Cr-387) grain variety was collected from Debre Zeit Agricultural Research Center (DZARC). Quncho teff variety is the first popular variety in Ethiopia (Assefa et al., 2011). The teff sample was harvested in the year 2017/2018. The collected raw material was stored carefully until the appropriate and respective laboratory analysis were conducted.

3.3. Raw Material Preparation

Tef grain was cleaned, sorted, sieved in a fine sieve and stored in polyethylene bags. Then it was milled to whole flour to fineness level traditionally used for injera making. Samples for laboratory analysis was kept in an airtight, sealed plastic bag at room temperature until preparation of baking injera.

3.4. Experimental framework of the research

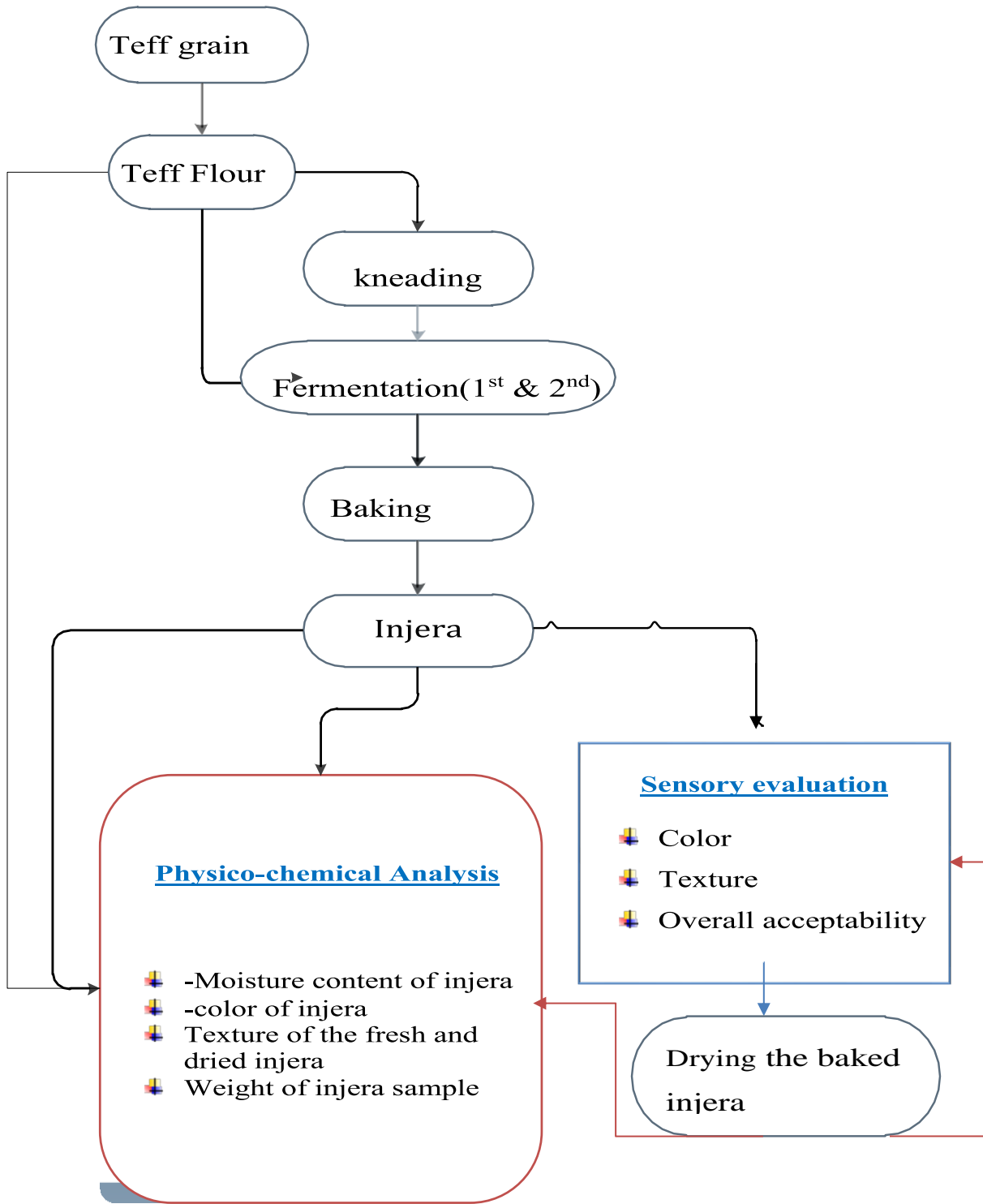


Figure 3.1: Experimental framework of the research work

3.5. Raw Materials Preparation

Teff grain were first cleaned and milled to whole flour to fineness level traditionally used for injera making. Samples for laboratory analysis were kept in an airtight, sealed plastic bag at room temperature until it is used.

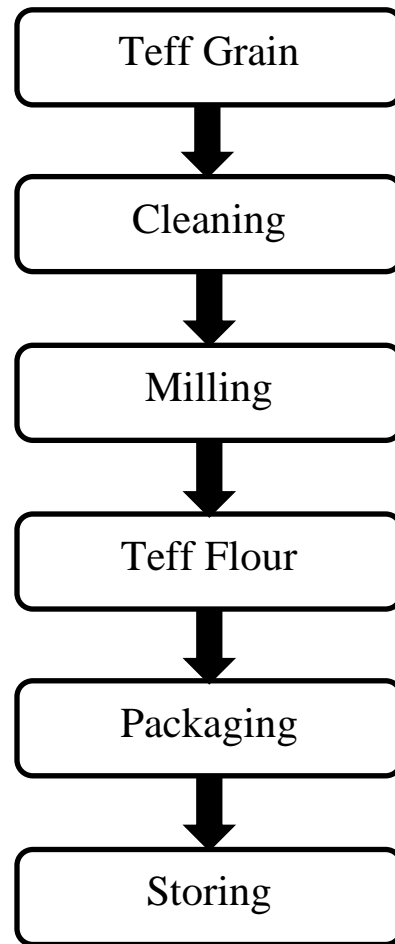


Figure 3.2: Process flow diagram for the preparation of Teff flour

3.6. Preparation of dough fermentation

Teff flour sample was prepared by mixing Teff flour (1 kg) with about 2 L of water and about 160 mL of irsho (starter culture saved from preliminary trail of the work) made into dough by hand kneading as is done traditionally.

The kneaded dough was kept covered in bowl having coded at room temperature. Fermentation for injera making involves two phases (first for 72 hours and second after absit addition). The first phase starts spontaneously when flour is wetted and/or owing to the addition of flour, water and irsho. At about 72 hrs.



Figure. 3.3: kneading process of the dough

After 72 hrs. of first fermentation of the dough, the yellowish liquid was slightly discarded and absit preparation was followed and kept until the bubble comes out.

3.7. Injera baking process

Injera baking was conducted by following traditional way of procedure as presented in the following figure.

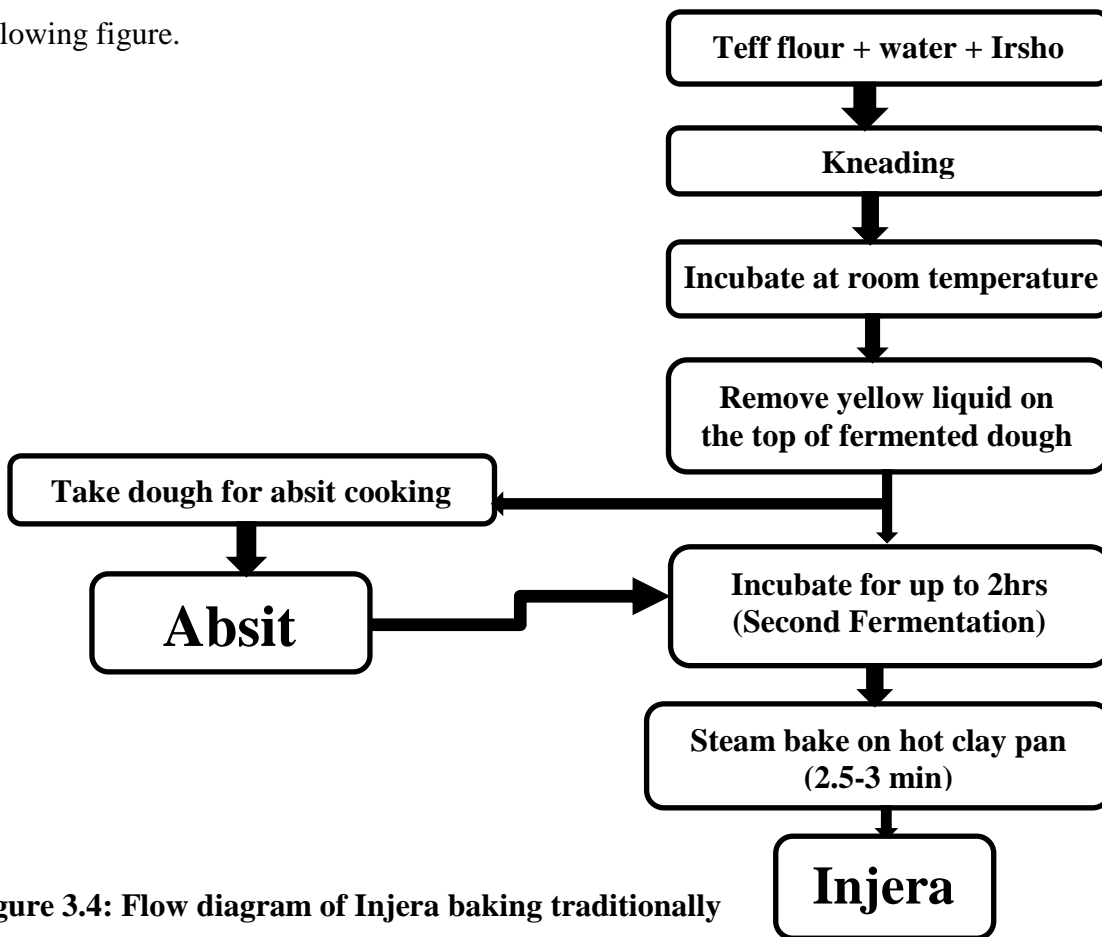


Figure 3.4: Flow diagram of Injera baking traditionally

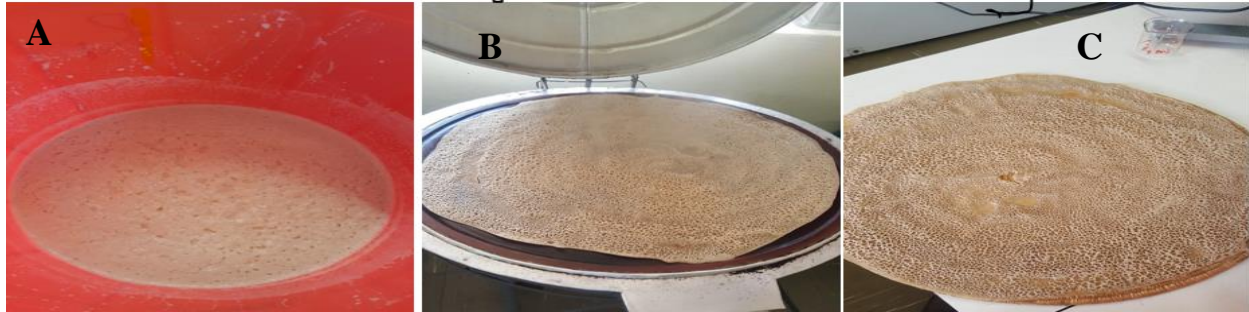


Figure 3.5: Dough preparation: A) Dough fermentation, B) Baking process and C) Injera

Note:

- i. The same irsho were prepared previously as the starter culture for the main dough and was used for all experiments to avoid any variation due to the microorganisms present.
- ii. One woman was doing the preparation of dough making and baking injera.
- iii. All other processing factors and type of teff was the same.

3.8. Experimental set-up for the drying process of baked injera

3.8.1 Computer controlled tray dryer

The drying process consists of the removal of moisture from a food sample, involving the heat and mass transfer at the same time. Mass transfer occurs when the substance losses moisture and heat transfer occurs when the air transfers heat to the food sample, which is used to evaporate the water added to the air as the drying process takes place. The Computer Controlled Tray Drier uses one of the most usual drying methods. It consists in making an air current circulate towards the food to be dried. It consists of a tunnel, four trays where the product to be dried is placed and a nozzle. There is an axial fan (computer controlled), located at the inlet of the tunnel, to introduce the air required to dry the product.

The unit has three strategically located hygrometers to determine the optimum humidity and temperature values required for the drying process. These hygrometers are formed by two temperature sensors: one of them is wrapped in an absorbing cover (wet bulb) and the other is directly located in the tunnel (dry bulb). The degree of humidity, enthalpy, etc. can be calculated by their measurements and the use of a psychometric chart.

The weight of the product to be dried is measured with a load cell (force sensor) during the drying process. The humidity air next to the product is measured with a humidity sensor.

Table: 3.1. Specification of computer controlled tray dryer

Particulars	Dimensions
Axial fan :speed range	0-2500 r.p.m
Flow range	0-2200m ³ /h(0-0.650 l/s)
Trays dimension each	270 x 170 x 40 mm
Number of trays	four
Power	3000W
Heating element with thermostat	70°C
Load sensor to measure weight of sample	0-5kg

The sample of the baked injera that was dried was cut into 50x50 cm and weighing then put in the computer-controlled tray dryer.



Fig.3.6 computer controlled tray dryer

3.9. Response Surface Methodology (RSM)

RSM is a collection of statistical and mathematical methods that are useful for the modeling and analyzing engineering problems. In this technique, the main objective is to optimize the response surface that is influenced by various computer controlled tray dryer process parameters for drying of fresh injera to make dried injera (Dirkosh).

RSM also quantifies the relationship between the controllable input parameters and the obtained response surfaces.

The design procedure of RSM is as follows:

For adopting RSM, selection of contributing parameters, their levels and proper experimental design are essential. RSM consists of a group of techniques used in establishing empirical study of the relationship between a response and several input variables. The main advantage of using RSM is to understand and evaluate the effect of multiple parameters and their interactions with each other in bringing out the response(s). Response surface methodology also quantifies the relationship between the controllable input parameters and the obtained response surfaces. It is a well-known up to date approach for constructing approximation models based on physical experimented observations.

The main advantage of RSM is the reduced number of experimental runs needed to provide sufficient information for statistically acceptable results (Montgomery, 2000).

- ✓ Designing of a series of experiments for adequate and reliable measurement of the response of interest.
- ✓ Finding the optimal set of experimental parameters that produce a maximum or minimum value of response.
- ✓ Representing the direct and interactive effects of process parameters through two and three-dimensional plots.

RSM can be defined as a statistical method that uses quantitative data from appropriate experimental designs to determine and simultaneously solve multivariate equations, which specify the optimum product for a specified set of factors through mathematical

models. These equations can be graphically represented as response surfaces, which can be used in three ways:

- To describe how the test variables, affect the response;
- To determine the interrelationships among the test variables; and
- To describe the combined effect of all test variables on the response

The optimization of drying conditions(air temperature, air velocity and sample loading) of a computer controlled tray dryer in response of drying rate, drying time, moisture content, color, texture and overall acceptability of dried Teff Injera using response surface methodology was investigated. Box-Behnken Design (BBD) based the conditions applied in the experimental setups used for the drying of Dirikosh.

3.9.1. Design of Experiments for RSM

RSM designs allow us to estimate interaction and even quadratic effects, and therefore give us an idea of the (local) shape of the response surface under investigation. Box-Behnken designs and central composite designs are efficient designs for fitting second order polynomials to response surfaces, because they use relatively small number of observations to estimate the parameters. Reliability is a reasonable basis for the selection of a response surface design. The purpose of RSM is optimization and the location of optimum is unknown prior to running the experiment, it makes sense to use a design that provides equal precision of estimation in all directions. For such purposes, Box – Behnken design is the commonly used experimental design models for three level three-factor experiments.

3.9.2. Box-Behnken Design

Box and Behnken proposed three level designs for fitting response surfaces. These designs are formed by combining $2k$ factorials with incomplete block designs. Table 3.2 illustrates the three variable Box – Behnken design. It can be noticed that the Box-Behnken design is a spherical design with all points lying on a sphere of radius $\sqrt{2}$. Also the Box –Behnken design does not contain any point at the vertices of the cubic region created by the upper and lower limits for each variable.

This could be advantageous when the points on the corners of the cube represent factor level combinations that are impossible to test due to physical process constraints or prohibitively expensive. Its "missing corners" may be useful when the researcher should avoid combined factor extremes. This property prevents a potential loss of data in those cases.

Box-Behnken designs require fewer treatment combinations than a CCD, in problems involving 3 or 4 factors. The Box-Behnken design is rotatable (or nearly so) but it contains regions of poor prediction quality like the CCD.

In this study, the experiments were planned and conducted according to a Box-Behnken type response surface design.

Table 3.2: Three factor coded Box-Behnken Design

Runs	X1	X2	X3
1	-1	0	1
2	0	0	0
3	1	0	1
4	0	-1	-1
5	1	0	-1
6	0	-1	1
7	-1	0	-1
8	-1	-1	0
9	0	0	0
10	0	1	1
11	0	0	0
12	1	1	0
13	1	-1	0
14	-1	1	0
15	0	1	-1

Where: **X1, X2 and X3** are drying air temperature, drying air velocity and sample loading density respectively

3.9.3. Mathematical Modeling

The second order response surface representing the surface drying rate, drying time, moisture content, color, texture and overall acceptability of the dried injera can be expressed as a function

of drying process conditions(Drying air temperature, velocity and loading sample) factors. A regression model can also be employed for this purpose.

Design expert software (minitab18) was used to design the experiment and randomize the runs. Randomization ensures that the conditions in one run neither depend on the conditions of the previous runs nor predict the conditions in the subsequent runs. Randomization is essential for drawing conclusions from the experiment, in correct, unambiguous and defensible manner.

Most importantly, parameters corresponding to the central point (0, 0, and 0) are repeated twice to establish that the experimental data is within the normal dispersion and repeatability is ensured.

3.9.4 Analysis of variance (ANOVA)

Analysis of variance, ANOVA, is a statistical decision making tool used for detecting any differences in average performances of tested parameters. It employs sum of squares and F statistics to find out relative importance of the analyzed Dirkossh drying processing parameters, measurement errors and uncontrolled parameters. Analysis of variance (ANOVA) was used to check the adequacy of the model for the responses in the experimentation.

3.10. Experimental Designs

Selection of Process Parameters

The drying process conditions of Dirkossh by using tray dryer had three levels as given bellow in Table 3.3. The levels were fixed based on the preliminary experiment-trials and the available literatures.

Table 3.3: drying process parameters of dried teff injera (Dirkosh) with their values at 3 levels

Level	Drying Temperature (°C)	Air velocity(m/s)	Injera sample(kg/m ²)
1	55	0.5	1
2	60	1	1.5
3	65	1.5	2

RSM designs allow us to estimate interaction and even quadratic effects, and hence give us the idea of the (local) shape of the response surface under investigation. Box-Behnken design is having the maximum efficiency for an RSM problem involving three factors and three levels. In addition, the number of runs required is less compared to a central composite design.

Table 3.4: Experimental design of Dirkosh drying under drying conditions of a tray dryer using Box-Behnken Design

Treatments	X1:Temperat ure (°C)	X2:Velocity (m/s)	X3:Loading density(kg/m ²)	Responses					
				Drying time(min)	M.C(g/100 g sample)	Drying rate (g/100g min.)	Colo r	Tex ture	Over all acc.
1	65	1.5	1.5						
2	55	0.5	1.5						
3	60	1.5	1						
4	60	1	1.5						
5	60	0.5	2						
6	55	1	1						
7	60	0.5	1						
8	65	1	2						
9	60	1	1.5						
10	55	1	2						
11	65	0.5	1.5						
12	60	1	1.5						
13	60	1.5	2						
14	65	1	1						
15	55	1.5	1.5						

Runs 12 and 9 are repeat of run-4

The experimental data for each response variable were fitted to the quadratic model as:

$$Y = \beta + X1 + X2 + X3 + X12 + X22 + X32 + X1X2 + X1X3 + X2X3 + \epsilon \quad \text{.. (3.1)}$$

Where:

Y denotes the responses; β constant; **X1** is air Temperature (oC), **X2** is air velocity (m/s) and **X3** is loading sample; X12, X22, X32 quadratic regression X1X2, X1X3, X2X3 = interaction regression; X1, X2, X3 = linear regression and ϵ is random error.

3.11. Injera drying process by computer controlled tray dryer

The dryer was run under no load condition for about half an hour for thermal stabilization of the dryer prior to start of drying experiments. Then the samples were weighed and uniformly put on each tray. Then observation of, weight loss were taken at time interval of 30 min until no change of weight loss depending upon the moisture depletion rate.

3.11.1. Drying Kinetic and Drying Rate Analysis

3.11.1.1. Moisture Content (M.C)

The moisture content of injera samples (2gm) were determined by drying at a temperature of 115°C using instant moisture analyzer (AND model ML-50, made in Japan). The percentage of the moisture content were displayed on the LCD screen as the whole moisture released off with a beep sound at the end of the process. The sample was analyzed in triplicate and recorded.

The percentage moisture was then calculated as below:

$$\text{Moisture \%} = \frac{\text{Difference in weight (g)}}{\text{original weight of sample}} \times 100 \quad \text{3.11.1}$$



Figure 3.7: Instant moisture analyzer



Figure 3.8: Pieces of Injera for drying

The moisture content of the sample is usually expressed in percentage by weight on wet basis. However, the moisture content on dry basis is simpler to use in calculation, as the quantity of moisture present at any time is directly proportional to moisture content on dry basis.

On dry basis (%), it can be calculated as follows:-

$$MCdb(\%) = \left(\frac{W_w}{W_d} \right) * 100 = \frac{m}{100 - m} * 100 \quad 3.11.2$$

In addition, on wet basis (%) by the formula:-

$$MCwb(\%) = \frac{W_w}{W_w + W_d} * 100 \quad 3.11.3$$

The two ways of expressing moisture content are related by:

$$MCdb(\%) = \frac{MCwb}{W_w + W_d} * 100 \quad 3.11.4$$

Where, **Wd** = weight of dry matter (g) , **Ww** = weight of water (g), **MCdb** = moisture content dry basis(%) and **MCwb** = moisture content wet basis (%).

3.11.1.2. Moisture Ratio (MR)

Moisture ratio is the ratio of the moisture content at any given time to the initial moisture content (both relative to the equilibrium moisture content). It can be calculated as:-

$$MR = \frac{M - Me}{Mo - Me} \quad 3.11.5$$

Where,

M = instantaneous moisture content (%db)

Mo = initial moisture content (%db)

Me = equilibrium moisture content (EMC) of material (%db)

3.12. Microbiological Analysis of Fresh and Dirkos Injera

3.12.1. Water Activity (*aw*)

The amount of water in food and agricultural products affects the quality and perishability of these products. However, perishability is not directly related to moisture content. In fact, perishability varies greatly among products with the same moisture content. A much better indicator of perishability is the availability of water in the product to support degradation activities such as microbial action. The term water activity is widely used in the food industry as an indicator of water available in a product.



Figure 3.9: Water activity meter used in the research work.

Water activity, unlike water content, can determine a food's shelf stability. It can predict which microorganisms will be potential sources of spoilage and infection (the difference between bacterial pathogens and fungal physiology, or, a_w of 0.91 versus that of 0.70). The water activity of a food is instrumental in maintaining its chemical stability.

Water activity (a_w) is defined as:

$$a_w = \frac{P_w}{P_{ws}} \text{ or } a_w = \phi \text{ since } \phi = \frac{P_w}{P_{ws}} \quad 3.11.8$$

Where: ϕ = the relative humidity, decimal

P_w = the partial pressure of water vapor at the specified conditions

P_{ws} = the partial pressure of water vapor at saturation and the temperature specified

Thus, water activity is the equilibrium relative humidity (ERH) in decimal form for a product at a given temperature and moisture content

3.13. Drying Rate

Drying rate is defined as the average value of moisture changes during the drying process, calculated using Eq. (3.11.6) below, and expressed as g water/100 g dry solids per min.

$$\text{Drying Rate} = \frac{(MC_0 - MC_1) * 100}{\text{Drying Time}} \quad 3.11.6$$

Where:

MC_0 and MC_1 were the moisture content of the fresh sample and the dehydrated sample on dry basis, respectively.

Similarly, the drying rate was approximately proportional to the difference in moisture content between the product being dried and EMC at the drying air state:

$$DR = \frac{Mt + dt - Mt}{dt} \quad 3.11.7$$

Where:

DR = drying rate(g/g min)

Mt = moisture content at time t (%db)

Mt+dt = moisture content at time t+dt (%db)

dt = time of successive measurements (min)

3.14. Sensory Evaluation of the Fresh and Dried Injera

Panelists were chosen from staff and students of the Food Process Engineering Department, Addis Ababa Science and Technology University. The fresh Injera prepared and the different dried Injera were evaluated for its sensory acceptability and preference by using 30 consumer participants. Evaluation of the fresh injera sample was carried at 6 hours after the injera was baked. The attributes assessed included: visual color, moisture content, texture, and over all acceptance.

The nine point hedonic scale rated from 1(extremely dislike), 5 (neither like nor dislike) to 9(extremely like) for evaluating the degree of liking and disliking were employed. All the panelists were frequent consumers of Injera. The age ranges of the participants were 23-40 years old, so that they could fill the scorecard properly. Six (6) of the participants were female while eighteen (18) of the participants were male. At the beginning of the test, panelists were instructed about the objective of the research and how to fill the scorecard based on their evaluation

3.15. Statistical analyses and Experimental Design

All experimental measurements were made in triplicate and analyzed using either regression, one-way, two-way or repeated measures (general linear model) analyses in Minitab 18 Statistical Analysis Package (State College, PA). Multiple comparisons of mean values was done using the Tukey's family error rate with a significance level of 0.05.

Coefficient of Determination (R^2):

In statistics, the coefficient of determination R^2 is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information. It is the proportion of variability in a data set that is accounted for by the statistical model. It provides a measure of how well future outcomes are likely to be predicted by the model. This is equivalent to the ratio of the regression sum of squares (SSR) to the total sum of squares (SST), which explains the proportion of variance accounted for in the dependent variable by the model. It evaluates how well the model fits the data.

3.16. Experimental design and optimization

The experiment was designed and done to get the optimum drying process parameters of computer controlled tray dryer for Dirikosh production and set the minimum and maximum factors (drying temperature, air velocity and loading sample) and conducted in Box-Behnken Design(BBD)) with response surface methodology . The design of experiment was drying conditions of a computer controlled tray dryer which were drying temperature (55-65°C), air velocity (0.5-1.5m/s) and sample loading(1-2kg/m²) for proper drying of Dirikosh. Operating drying process factors and levels were modified during preliminary studies and literatures of each variable.

CHAPTER FOUR

4. Results and Discussion

This chapter deals with results obtained during the course of experimentation on relevant physicochemical and sensory characteristics of dried injera (Dirkosh), drying of Dirkosh and empirical modeling of drying process undergoing in drying conditions.

4.1. Proximate composition of the fresh and dried injera

4.1.1. Moisture content of fresh injera and dried injera

The moisture content of fresh injera were measured and found to be ranged 58.24 % to 63.70%. In some literatures the moisture content is reported to be 65.23% for injera and on the other literature it was found in the range 62-65% (Ashagrie and Dawit, 2012; Attuquayefio, 2014). Studies by (Yetneberk et al., 2004) reported that the moisture content of injera made from different cereals is above 50%. The moisture content of injera should be in the range of 58% to 63% (ESA, 2013) is set.

The initial moisture content of fresh injera were measured in triplicate and mean was 60.97%wb, with standard deviation ± 2.73 . The moisture content of dried injera under different drying parameters were found to be ranged from 3.31 to 6.15 % wb. There was a significant difference between the fresh and dried injera.

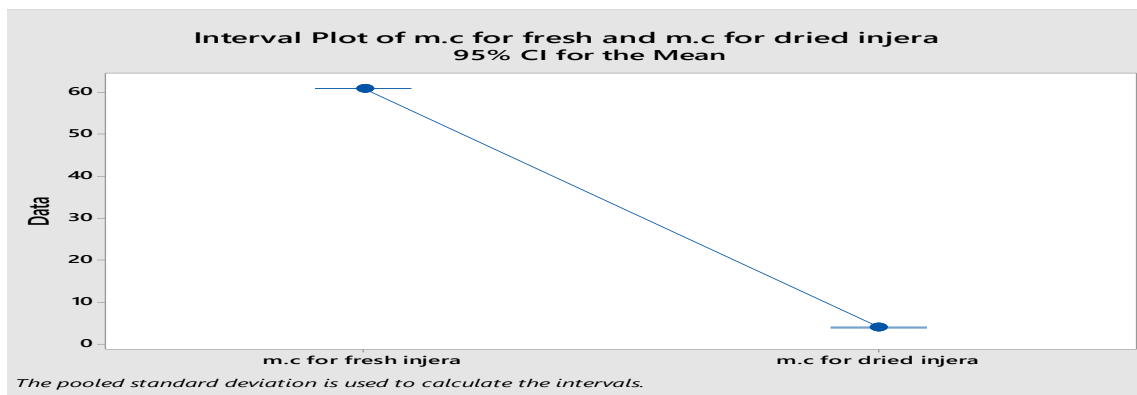


Fig. 4.1 Interval Plot of moisture content (m.c) for fresh and for dried injera

The final moisture content of dried injera (Dirkosh) ranged from 3.31-6.15%wb and there is a significant difference in ($p>0.005$) moisture content due to drying conditions parameters. The model for moisture content of dried injera data was significant ($p= 0.0246$) and the lack of fit test ($p= 0.3117$) showed that the model could occur due to noise.

R11(Dirkosh made from processing parameters combination(55°C , 1m/s and 2kg/m^2) was the minimum moisture content with relatively long time duration(305 minutes). The maximum moisture content was obtained in R14 ((65°C , 1.5 m/s and 1.5 kg/m^2) of air temperature, air velocity and sample loading density respectively)) and it took 226 minutes.

The multiple regression analysis showed that there was a significant model term in predicting the moisture content and in this case A, AC, A^2 are significant model terms where A is drying air temperature and C is sample loading density. Therefore , the moisture content of the dried injera is highly affected by the drying air temperature and sample loading density and their interaction as well.

The following is the model equation developed from the data for moisture content.

$$M.C = 5.66 + 0.67 * x_1 + 0.72 * x_1 * x_2 - 0.58 * x_1^2 \quad \mathbf{4.1.1}$$

Where x_1 and x_2 are drying air temperature and sample loading density respectively

The contour plot bellow showed that there is a considerably minimum moisture content when the drying air temperature is minimum and air velocity is increasing when the sample loading density is held at 1.5 kg/m^2 .

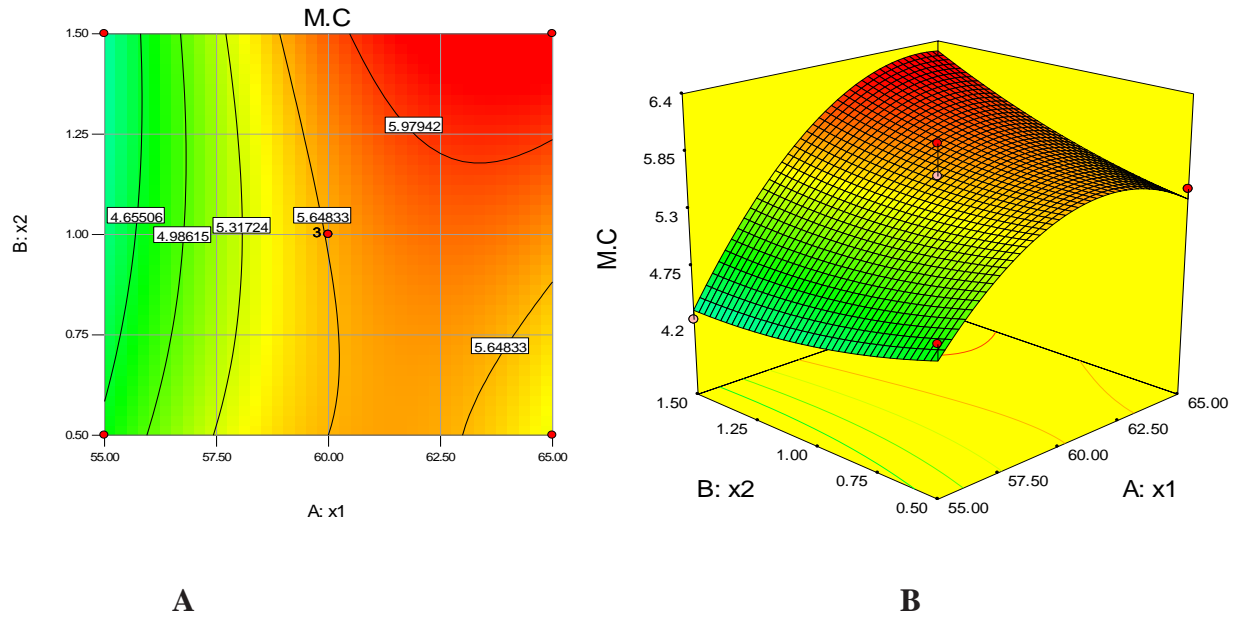


Figure 4.2:A) Contour, B) 3D surface plots for moisture content obtained using actual-drying parameters.

4.2. Water Activity of the dried/Dirkosh injera

New concepts and hypotheses are being developed and proposed in the areas of food properties. In the middle of the twentieth century, scientists began to discover the existence of a relationship between the water contained in a food and its relative tendency to spoil. They also began to realize that the active water could be much more important to the stability of a food than total amount of water present. Thus, it is possible to develop generalized rules or limits for the stability of foods using water activity. For example, no microorganisms can grow below a critical water activity. For most foods, this critical range is in the 0.6–0.7 water activity. Pathogenic bacteria cannot grow below a water activity of 0.85–0.86, whereas yeasts and molds are more tolerant of a reduced water activity of 0.80, but usually no growth occurs below a water activity of about 0.62(Mathlouthi, 2001).

Therefore, for a dehydrated food product knowing water activity is much better than microbial load of the dried sample. During the experiment, the fresh and the respective dried/Dirkosh injera has a great difference in terms of the water activity.

AquaLab (Model HB-300 made in Japan) is the fastest and most accurate instrument for measuring water activity, giving readings in five minutes. Its readings are reliable, providing $\pm 0.003aw$ accuracy. The fresh injera @6hrs was recorded water activity of 0.9964, 0.9977 and 0.9875 with temperature of 23.79, 24.47 and 24.87 °C respectively and the water activity of the dried injera were 0.2690, 0.2839 and 0.2728 at temperature of 24.92, 25 and 24.87 °C.

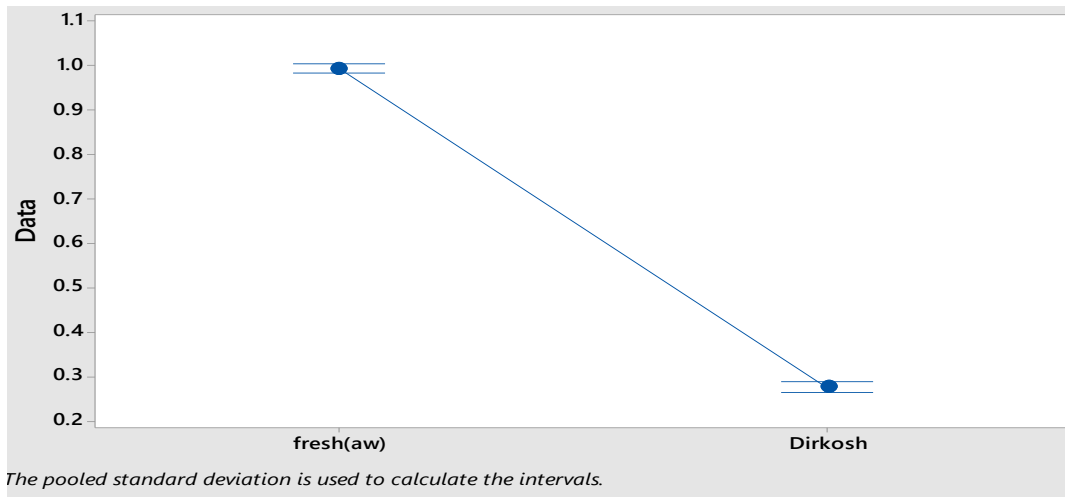


Figure 4.3: Interval Plot of fresh (aw), Dirkosh/dried injera

Table 4.1: Analysis of Variance of fresh and dried injera

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	0.774651	0.774651	17069.06	0.000
Error	4	0.000182	0.000045		
Total	5	0.774832			

From both the above graph and table, there is a great significant different in water activity. The dried injera's water activity is bellow 0.3aw perfectly showed, as there will no microbial proliferation and foods generally within this range are Whole milk powder, dried vegetables, freeze dried, corn starch, potato chips, corn chips. Moreover, after this research get published the Ethiopian Dirkosh will be grouped.

4.2.1. Drying time

Drying time was plotted for all the experimental runs of the samples. A representative plot is shown below in Fig.4.3. The drying time was not significantly different from among the drying process parameters but it was significant when drying air temperature and sample loading density were crossed and did have significant model terms, AC. From the interaction graph, the drying time is highly affected by drying air temperature and sample loading density.

Design-Expert® Software

Drying time

● Design Points

■ C- 1.000

▲ C+ 2.000

X1 = A: x1

X2 = C: x3

Actual Factor

B: x2 = 1.00

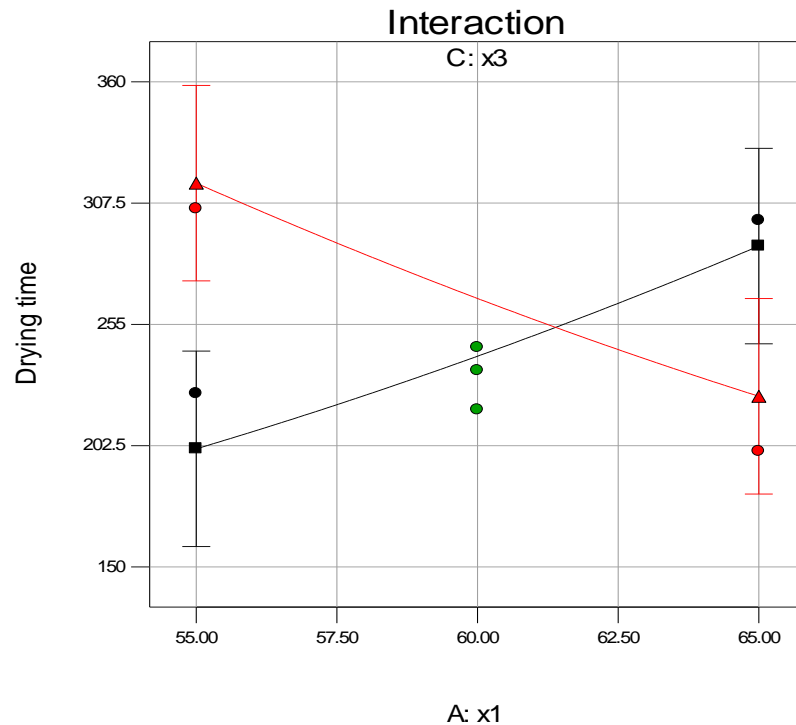
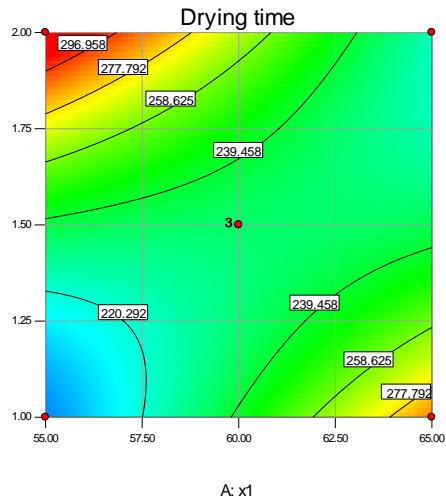
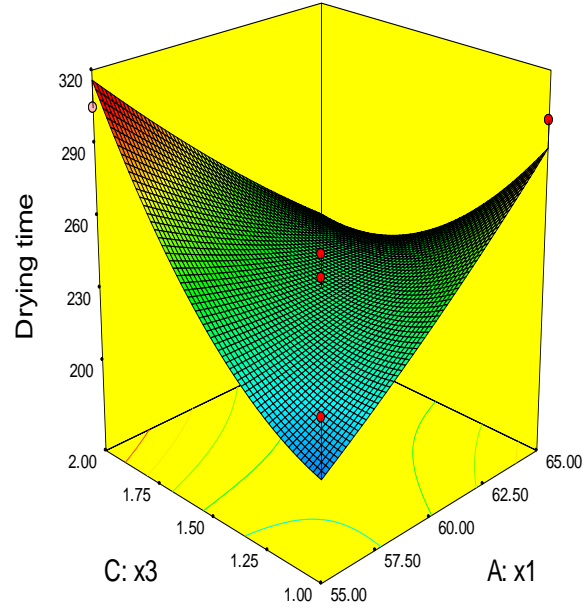


Figure 4.4: The interaction plot of drying air temperature and sample loading density

The contour plot bellow showed that there is a considerably minimum drying time for the sample when the drying air temperature is minimum(55°C) and sample loading was also minimum(1kg/m²).



A



B

Figure 4: A) Contour, B) 3D surface plots for model terms of Drying Time obtained using actual-drying parameters.

4.2.2. Drying rate

The drying rate was found maximum when the drying air temperature was around 60° C and the air velocity was maximum (1.5m/s) when the sample loading density was held at 1.5 kg/m². the minimum drying rate was also recorded when the drying air temperature and air velocity was minimum and the sample loading density was maximum.

There was no model term that showed significances it might because of the injera sample nature when drying proceeds, the drying rate might be varied thermodynamically (the heat and mass transfer properties).

4.3. The relation between Moisture Content, Drying rate and Drying Time

A representative drying time plot between drying time and moisture content is shown below in Fig.4.3. The relationship between moisture content and drying time was non-linear and moisture decreased with respect to drying time. Initially moisture content decreased rapidly at constant rate and then slowed down in falling rate period region.

The total drying time varied with different drying conditions. R11(Dirkosh made from processing parameters combination(55°C,1m/s and 2kg/m²) was the minimum moisture content with relatively long time duration(305 minutes). The maximum moisture content was obtained in R14 ((65°C, 1.5 m/s and 1.5 kg/m²) of air temperature, air velocity and sample loading density respectively)) and it took 226 minutes.

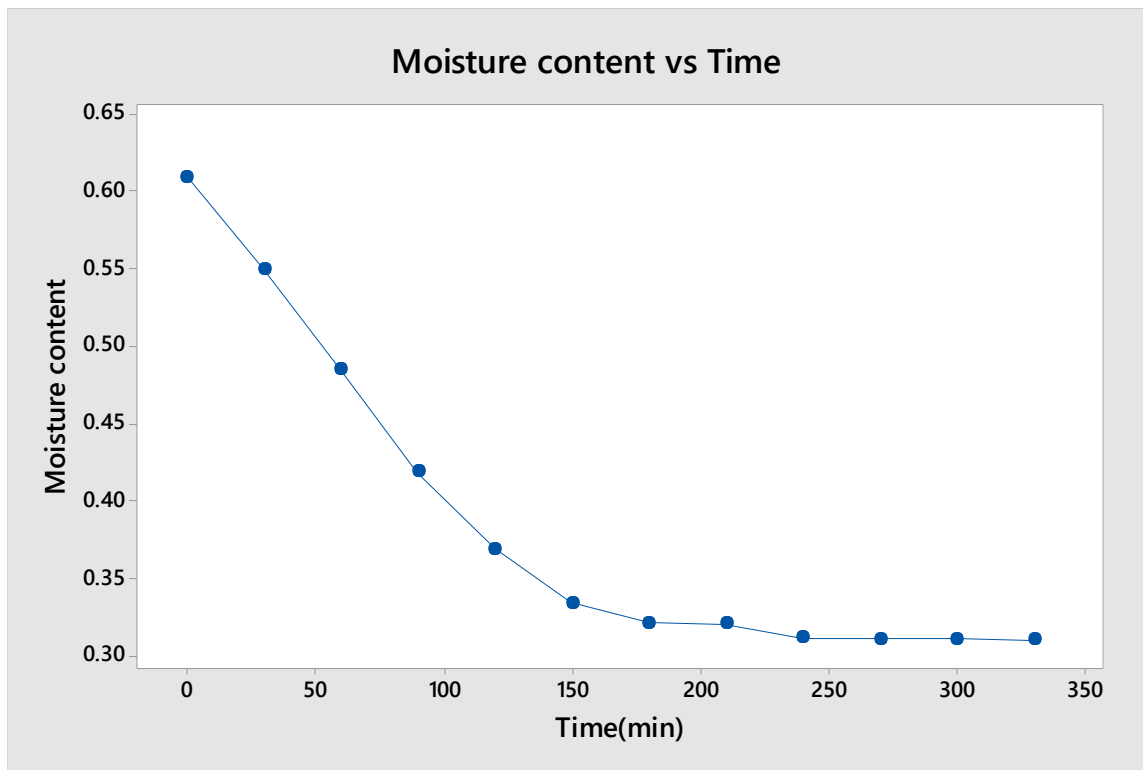


Figure 4.6: Graph of Moisture Content versus Time

Higher drying rates were observed at higher temperatures and higher air velocities. The drying rate was found maximum for 1kg/m^2 of samples dried at 65°C and 1.5m/s air velocity. In some cases, drying rate was less initially then it started to increase and later on remained constant for some time. The period for which drying rate increased initially is known as heating period. A constant rate period and a falling rate period were observed (Fig. 4.4). The extent of these constant and falling rate periods depended on Drying air temperature, air velocity and sample loading density.

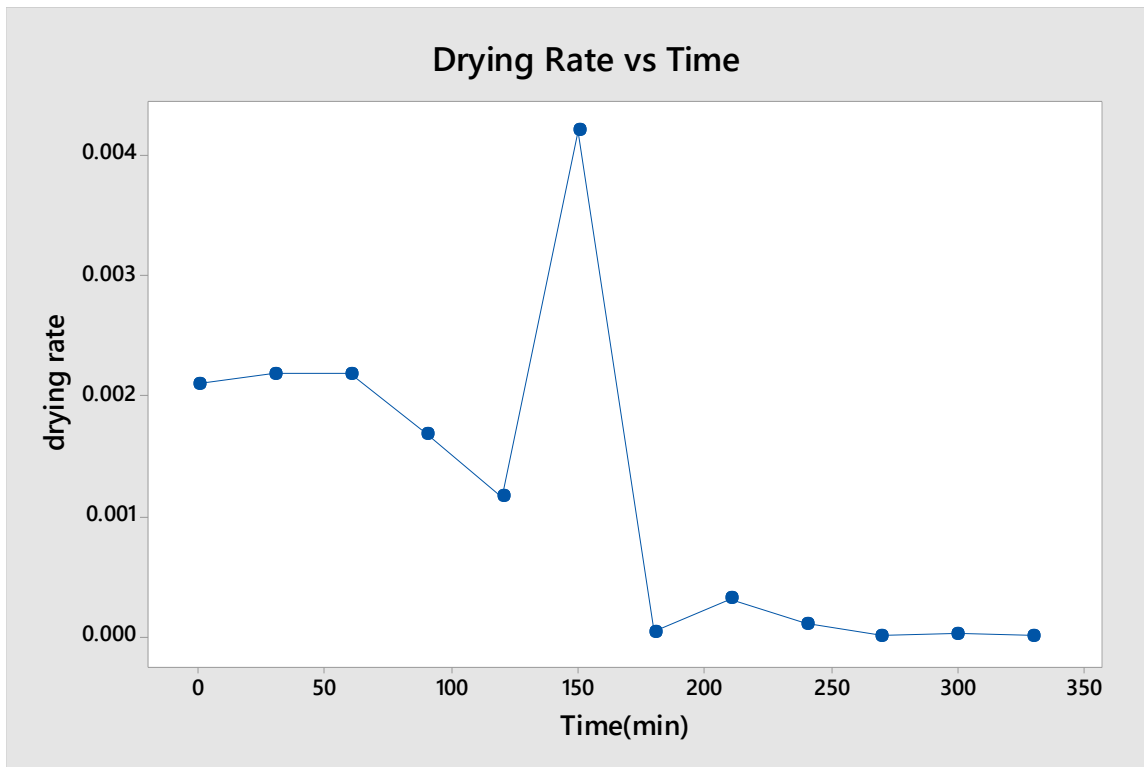


Figure 4.7: Graph of Drying Rate versus Time

The graph shows slight increase in drying rate from time 0 min to 60 min then decrease until time 125 min. From time, 125 min to 150 min the drying rate is rapidly increasing. At time 150 min to 180 min, the graph shows rapid decrease before drop rapidly at time 250 min to 300 min.

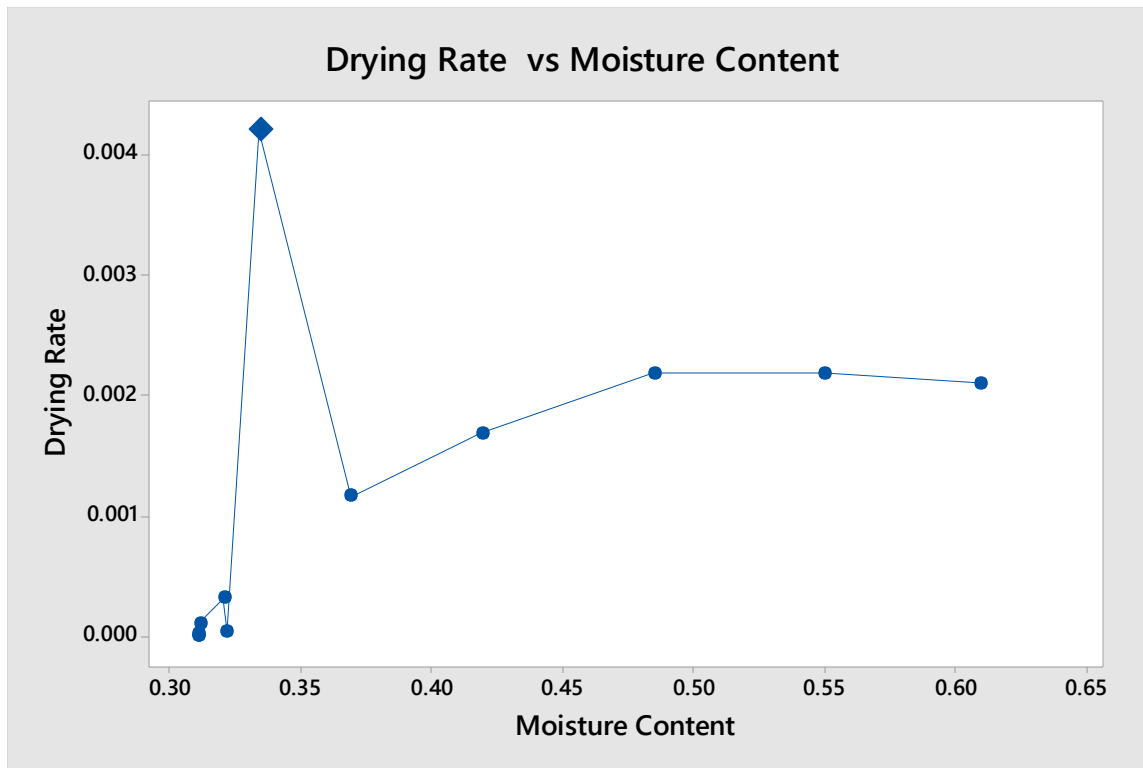


Figure 4.8: Graph of Drying Rate versus Moisture Content

The graph shows the drying rate increases first and it is going constant and finally decreases rapidly.

4.4. Sensory Acceptability of the baked injera and the Dirkosk

4.4.1. Sensory acceptability of fresh baked injera

The sensory acceptability (visual color, taste, texture, appearance (no of eyes, eye size, eye distribution and top & bottom surfaces), and overall acceptability of fresh samples of injera baked and analyzed after 6 hours were presented at table 4.5 below. From the table there is no significant difference observed by panelists because the fresh baked injera is prepared from the same Quicho teff and all the preparations were controlled and managed.

Table 4.2: The sensory acceptability test result of fresh injera after baked 6 hours using 9-point hedonic scale.

Sensory analysis	Visual color	Taste	Texture	Appearance	Overall acceptability
Score Values	7.12±0.35	6.87±0.08	6.58±1.15	6.04± 0.45	6.45± 1.04

Values followed by different letters with in a rows for a fresh injera indicate significant difference ($p < 0.05$).

Scores are based on a 9-point hedonic scale with 1=dislike extremely, 2=dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like nor dislike, 6=like slightly, 7=like moderately, 8=like very much and 9=like extremely.

4.4.2. Sensory acceptability of Dirkossh injera

The sensory acceptability (visual color, texture and overall acceptability) were only done because the dried or Dirkossh is quite different from the fresh baked injera in its physical form and its usage. The quality parameters of Dirkossh is mainly its color and crispiness/texture and overall acceptance. Therefore, the above-mentioned sensory quality of Dirkossh injera were presented and discussed independently.

4.4.2.1. Visual color of Dirkossh Injera

The visual color of the Dirkossh injera was found and ranged from 4.67 to 6.91. There is a significant difference ($p < 0.05$) in the preference of the panelists among the 15 experimental trials.

R14(the dried injera made from tray dryer process parameters (65°C, 1.5m/s and 1.5 kg/m²) of the drying air temperature, air velocity and sample loading density respectively)) was the most preferred visual color by the panelists . The minimum visual color value was obtained in R11 (55°C, 1 m/s and 2 kg/m²) of the drying air temperature, air velocity and sample loading density respectively)).

The multiple regression analysis showed that there is a significant model term in predicting the sensory score for visual color in this case A, BC, A² are significant model terms where, A=drying air temperature, B=air velocity and C=sample loading density.

The following is the model equation developed from the data for visual color.

$$\text{Visual color} = 6.42 + 0.59 * x_1 + 0.57 * x_1 * x_2 - 0.48 * x_1^2 \quad 4.3.2.1$$

Where x_1 and x_2 are drying air temperature and sample loading density respectively

The contour plot bellow showed that there is a considerably preference when the drying air temperature and air velocity was around 65°C and 1.5m/s respectively and when the sample loading density is held at 1.5kg/m².

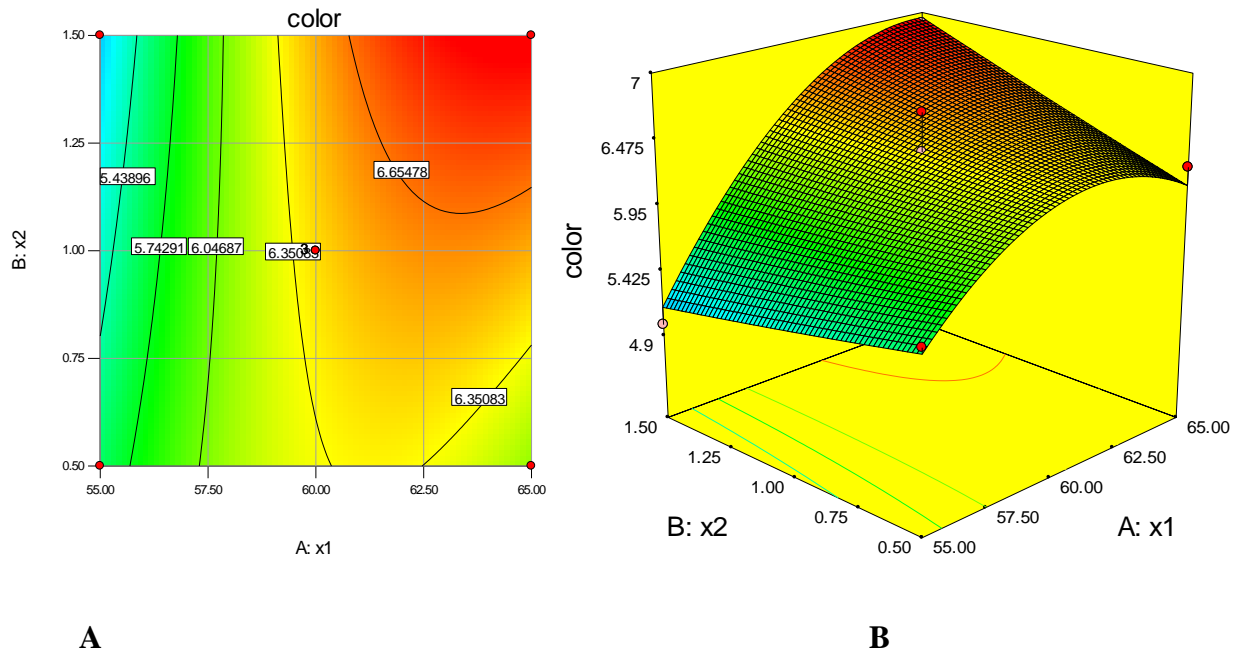


Figure 4.9: A) Contour, B) 3D surface plots for visual color obtained using actual-drying parameters.

4.4.2.2. Texture of dried /Dirkosh Injera

Textural properties are key drivers in food acceptability. Texture in food is perceived through a combination of visual, tactile, kinesthetic and auditory sensations. Crispy and crunchy properties are the main texture attributes affecting acceptability of food with regard to auditory sensations(Chauvin, Younce, Ross, & Swanson, 2008)

The sensorial texture value for the dried/Dirkosh injera scored by the panelists were found to be in the ranges 4.2 to 7.04 based up on the above mentioned dried food texture perceptions. Panelists texture response varies among the 15 experimental runs at $p < 0.05$. The maximum response and Minimum value for texture was obtained in R14 (65°C, 1.5m/s and 1.5kg/m²) and R11 (55°C, 1m/s and 2kg/m²) of the drying air temperature, air velocity and sample loading density respectively).

The RSM application on texture scores showed that the model was significant ($p < 0.022$), no lack of fit was obtained since the lack of fit is not significant ($p = 0.397$) with relative to the pure error. The multiple regression analysis showed that there is a significant model term in predicting the sensory score for texture in this case A and AC are significant model terms where, A=drying air temperature and C=sample loading density.

The model obtained for the texture of the samples was:

$$\text{Texture} = 6.28 + 0.74 * x_1 + 0.72 * x_1 * x_3 \quad 4.3.2.2$$

Where x_1 and x_3 are drying air temperature and sample loading density respectively

The contour and 3D surface plots bellow showed that there is a considerably preference when the drying air temperature and air velocity was around 65°C and above 1.25m/s respectively and when the sample loading density is held at 1.5kg/m².

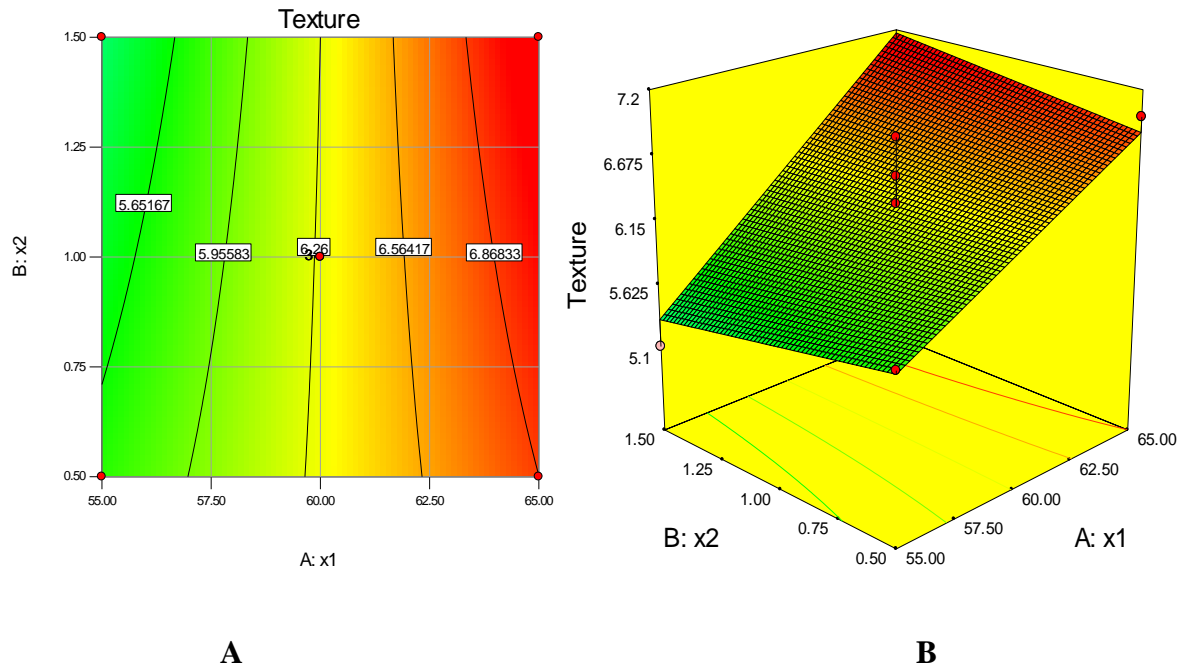


Figure 4.10: A) Contour, B) 3D surface plots for texture obtained using actual-drying parameters.

4.4.2.3. Overall acceptability of dried/Dirkosh Injera

The overall acceptability of the 15 experimental runs of the dried/Dirkosh injera were found to be in the ranges of 3.93 to 6.77. The dried injera made from process factor combinations R14 (65°C, 1.5m/s and 1.5kg/m²) was the most preferred dried injera and R11 (55°C, 1m/s and 2kg/m²) was the least preferred. The process parameters were the drying air temperature, air velocity and sample loading density respectively.

The regression model obtained for the overall acceptability of the dried injera sample was:

$$\text{Overall acceptability} = -53.1 + 2.36 * x_1 + 0.03 * x_1^2 - 0.28 * x_1 * x_3 \quad \mathbf{4.3.2.3}$$

Where x_1 and x_3 are drying air temperature and sample loading density respectively

Statistical analysis indicated that the model was significant in predicting the overall acceptability of dried injera ($p= 0.025$). The model could explain about 92.37% of the observed variations and

did not present significant lack of fit ($p=0.312$). There were significant model terms in case of A, A^2 and AC.

The contour and 3D surface plots bellow showed that there is a considerably preference when the drying air temperature and air velocity was around 65°C and above 1.25m/s respectively and when the sample loading density is held at 1.5kg/m^2 .

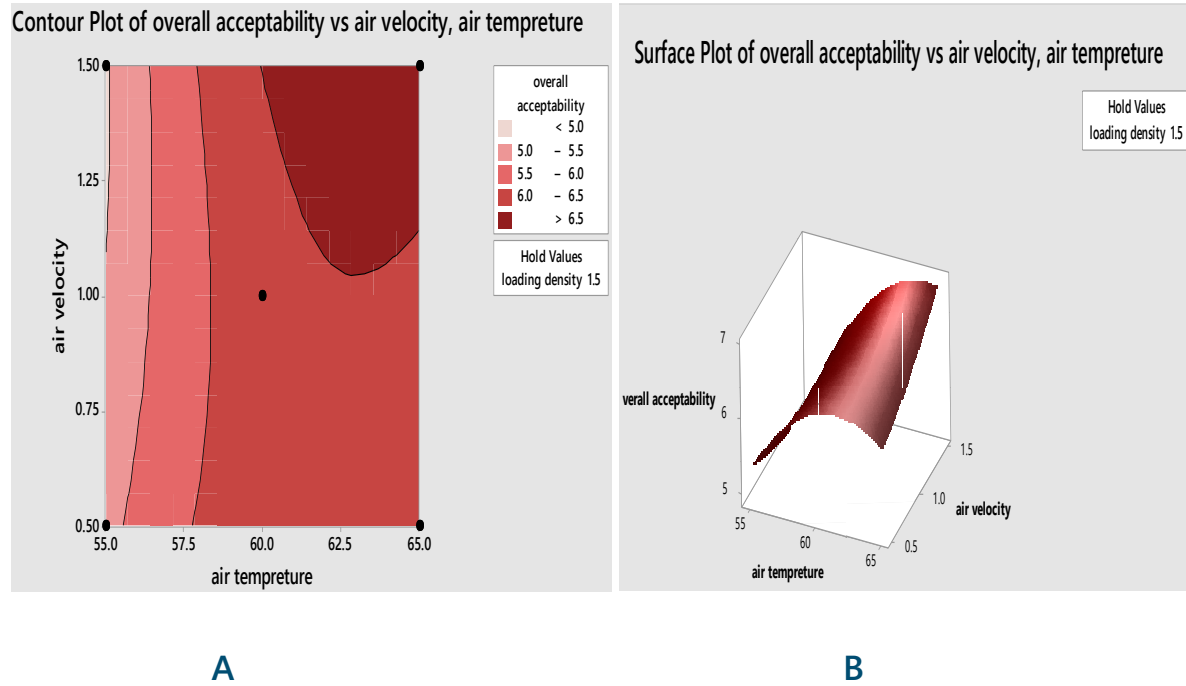


Figure 4.11: A) Contour, B) 3D surface plots for Overall acceptability obtained using actual-drying parameters.

Table 4.3: Coefficient estimates, model significance, adjusted regression coefficient (adj R²) and lack of fit values for the dried injera samples.

Dependent variables	Predictive models									Model (Prob>F)	Adj R ²	R ²	Lack of fit
	Y _i =a ₁ X ₁ +a ₂ X ₂ +a ₃ X ₃ +a ₄ X ₁ ² +a ₅ X ₂ ² +a ₆ X ₃ ² +a ₇ X ₁ X ₂ +a ₈ X ₁ X ₃ +a ₉ X ₂ X ₃												
(Y _i)	a ₁	a ₂	a ₃	a ₄	a ₅	a ₆	a ₇	a ₈	a ₉				
Color	0.59	-	-	-0.48	-	-	-	0.57	-	0.0244*	0.7874	0.9241	0.4252 (ns)
M.C	0.67	-	-	-0.58	-	-	0.32	0.72	-	0.0246*	0.7865	0.9237	0.3117 (ns)
OAA	-6.83	-	-	-0.023	-	-	0.287	-	-	0.025*	0.7865	0.9237	0.312 (ns)
Texture	0.74	-	-	-	-	-	-	0.72	-	0.0233*	0.6210	0.7834	0.2149 (ns)
DT	-	-	-	-	-	-	-	-45	-	ns	0.4588	0.8067	0.1507(ns)

Key: a_i = L-pseudo-component value, (X₁) = drying air temperature, (X₂) = air velocity, (X₃) = sample loading density, * = Significant at P < 0.05, (ns) = not Significant, DT: Drying time, M.C: moisture content, OAA: Overall acceptability.

From the above-completed information about the coefficient estimate, regression model significance, R² and lack of fit values, it is clearly showed that the drying parameters for Dirkosh by was highly affected by the drying air temperature, and sample loading density and slightly by air velocity.

4.5. Optimization of drying process parameters

The numerical optimization technique (design expert 7.0 software) was used to get the optimum values of the independent variables i.e. drying air temperature, air velocity and sample loading density of the drying of Dirkosh injera. The response variables selected for optimization were color, texture, overall acceptability, drying rate and drying time of the dried/Dirkosh injera. Multi-objective optimization was aimed at to achieve better Dirkosh injera.

Table 4.4. Response Optimization

Response	Goal
Color	Maximum
Texture	Maximum
Overall Acceptability	Maximum
Moisture Content	Minimum
Drying Time	Minimum
Drying Rate	Maximum

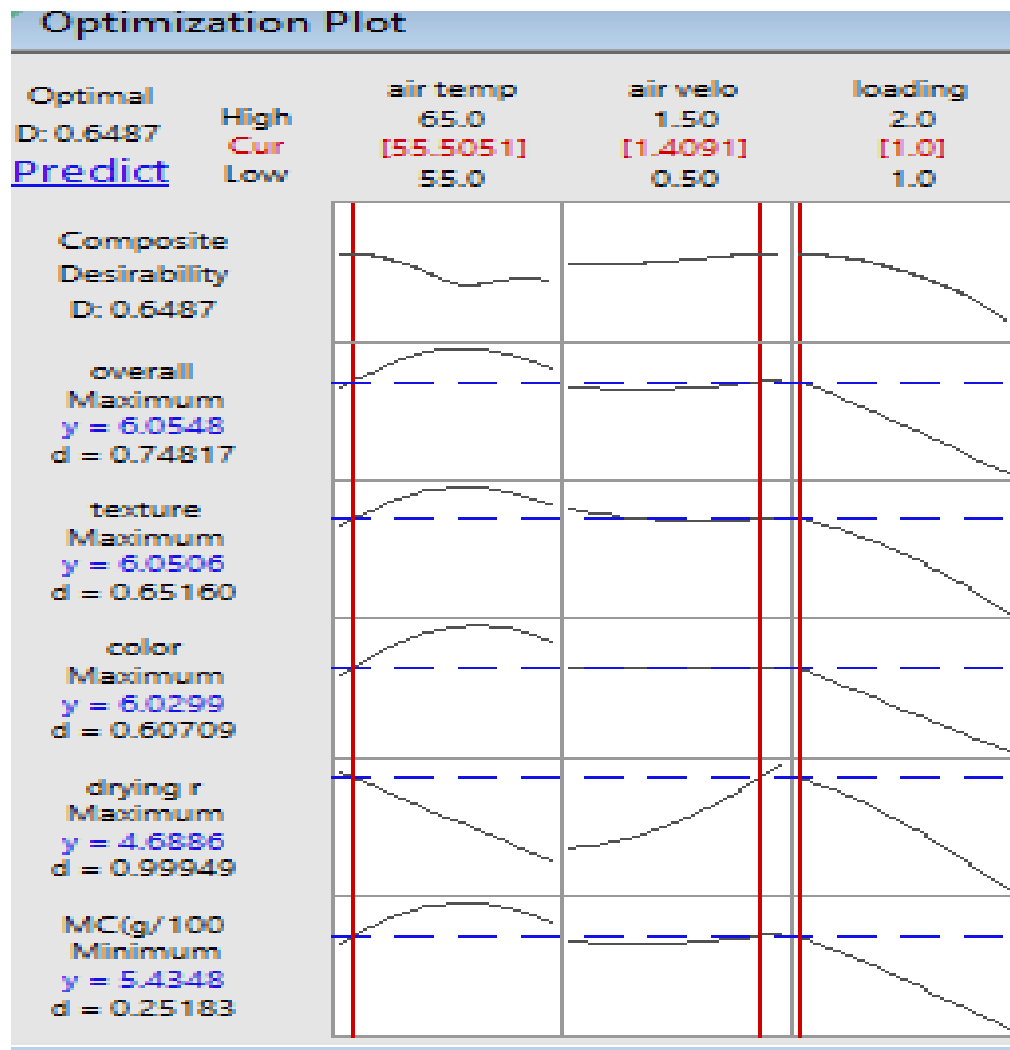


Figure 4.12: Optimization plots obtained using actual-drying parameters.

Accordingly, optimization criteria for each response were selected as given in Table 4.8 below that is the best Solution satisfying the above criteria and obtained using the ‘Design Expert’ software, which is given below and it has the overall desirability of 0.65.

Table 4.5. Optimized values of the selected drying process parameters with the response variables of Dirkosh/dried injera

DT	AV	SLD	Color	Texture	OAA	MC	DR	D
55	1.4	1	6.02	6.23	6.05	5.43	4.68	0.65

Key: DT= Drying air temperature (°C), AV= Air velocity (m/s), SLD= Sample loading density (kg/m²), OAA= Overall Acceptability, MC= Moisture Content, DR= Drying rate (min⁻¹) and D=Desirability

Moreover, the contour plot presented below in figure 4.3.4, shows the variation of desirability with change in drying air temperature, air velocity and sample loading density was kept constants at 1kg/m².

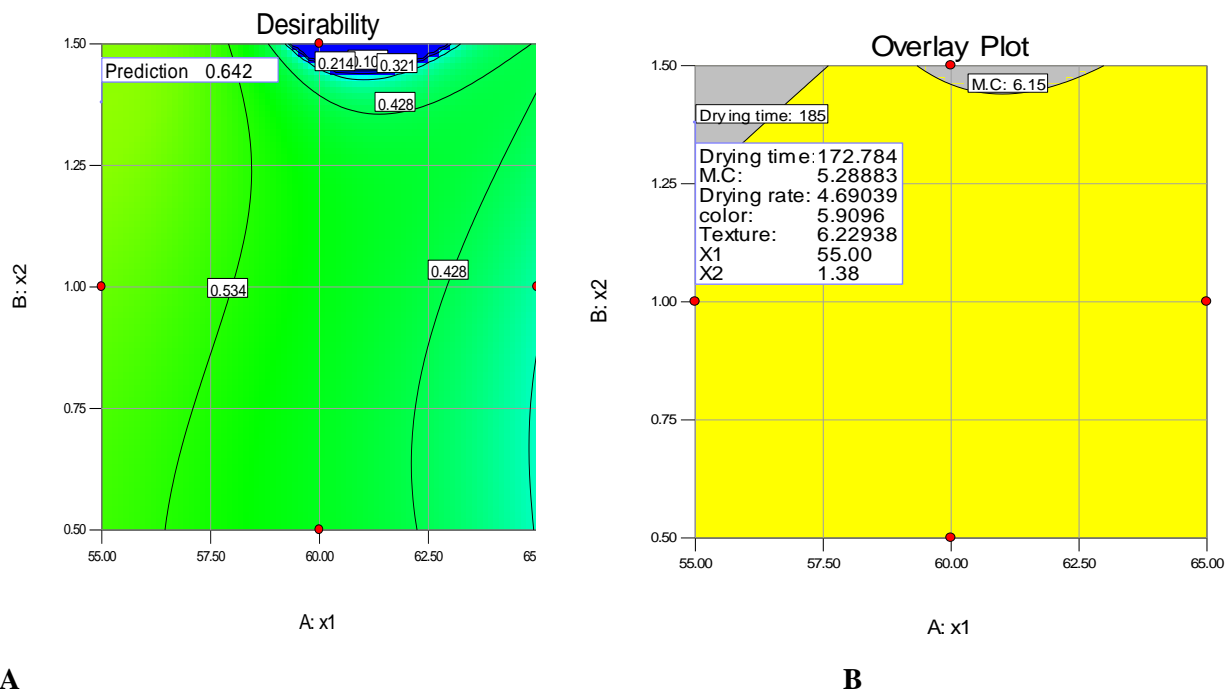


Figure 4.13: A) Contour plots for desirability and B) Overlay plots illustrating the optimum responses using graphical optimization

CHAPTER FIVE

5. Conclusion and Recommendations

5.1. Conclusion

Different drying parameters of computer controlled tray dryer were evaluated to find out the effect of the three parameters on different responses: moisture content, visual color, texture, overall acceptability, drying time, and drying rate of the dried/Dirkosh injera. The drying time were reduced with increasing drying air temperature and air velocity with reducing the sample loading density. The color, texture, overall acceptability and final moisture content of the dried injera were also significantly affected by the processing conditions of the drying. In addition to the selected responses, the drying parameters also affected the final water activity of the dried/Dirkosh produce.

Optimization process was employed to find out the best combination of process parameters. Drying air temperature 55°C, air velocity 1.4m/s and sample loading density 1kg/m² were the optimized conditions for Dirkosh drying in convective hot air and for the combination drying time, moisture content, color, texture, overall acceptability, drying rate were 172.84 min, 5.56, 5.9, 6.23, 6.05 and 4.69g/100g min respectively. The desirability factor for the combination was 6.42.

5.2. Recommendations

More researches on the application of RSM to food science and technology (food process, formulation and optimization, recipe formulation and optimization) need to be done.

Based on the findings of this research work, a special type of dryer can be designed and constructed for Dirkosh production at a larger scale.

Design of Good packaging for Dirkosh should be done.

Households, entrepreneurs, and injera making industries can prepare Dirkosh injera using this same type of dryers.

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Appendices

Appendix I: Sensory evaluation score sheet and questionnaire

Health status: ok	not ok	Age:	Sex: Male	Female
Panelist No:-	Sample Code:	Date:		

Instruction:-Please mark your degree of preference for the given sample on the scale below

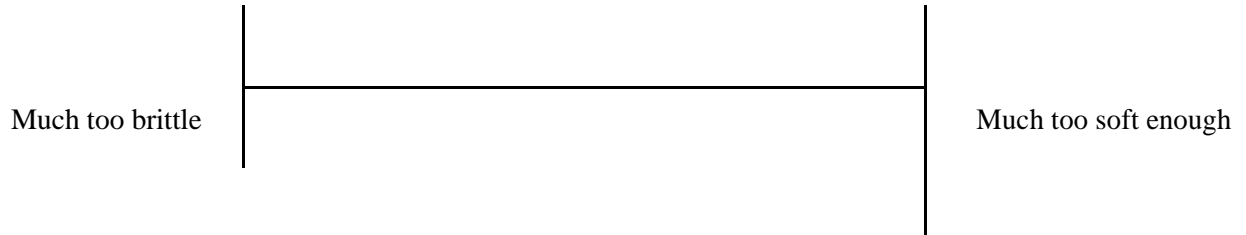
1. Color

Much too dark			Much too light

2. Taste

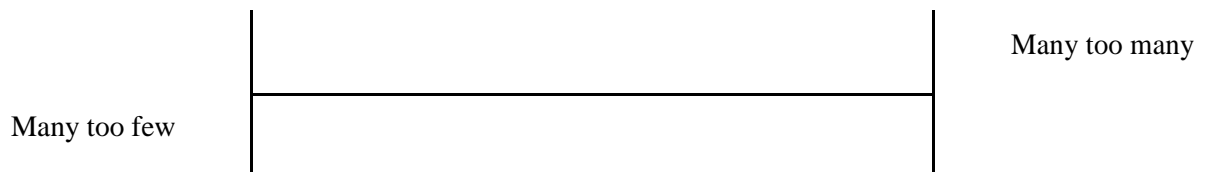
Not sour enough			Much too sour

3. Texture

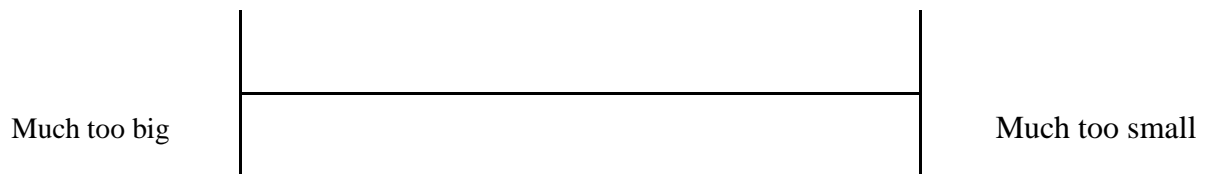


4. Appearance

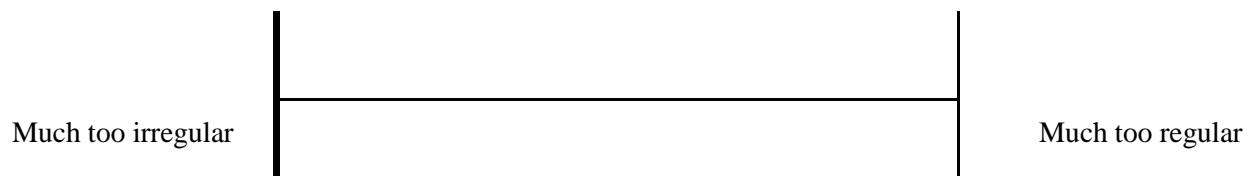
4.1. Number of eyes



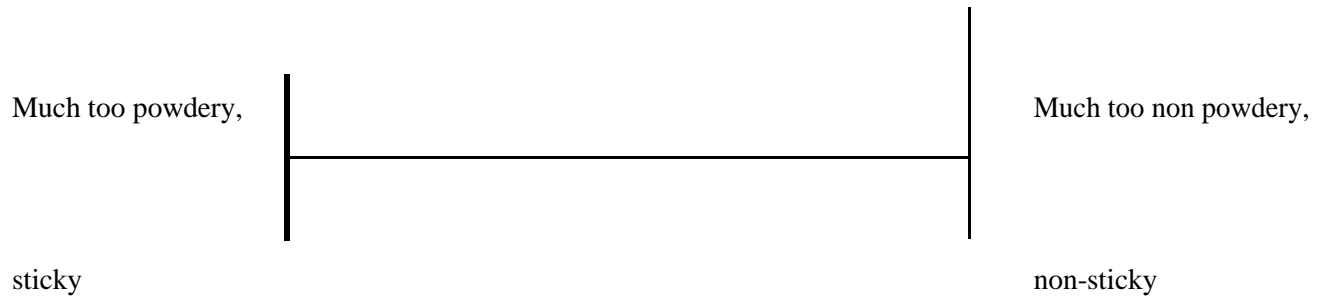
4.2. Eye size



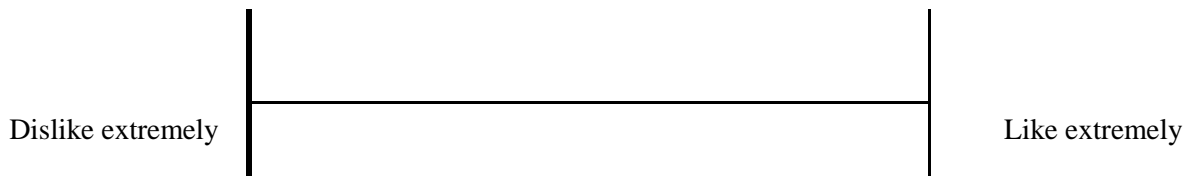
4.3. Eye distribution



4.4. Top and bottom surfaces



5. Overall acceptability



Questionnaire: Please fill the following few inquiries after you finish marking the scale, thank you in advance

1. Please specify your work place: _____, and living place: _____

2. From your perspective, how do you describe a good injera in terms of color: _____, thickness: _____ and eye size: _____

Appendix II. Psychrometric chart during drying

