Optimization of Process Parameters for Production of Honey powder from Ethiopian Honey By Spray-drying: a case study on its application in Bread

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By

Abera Berhanu

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Food Engineering Program

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By

Abera Berhanu

Approved by the Examining Board:

________________________ __________________
Chairman, Department’s Graduate Committee

________________________ __________________
Advisor:  Dr. Eng.Belay Woldeyes (PhD)

Department of Chemical and Bioengineering Institute of Technology

Addis Ababa University

Ethiopia

________________________ __________________
External Examiner

________________________ __________________
Internal Examiner
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### List of Acronyms and Abbreviations

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<th>Acronym</th>
<th>Full Form</th>
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<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>AOAC</td>
<td>Association of Official Analytical Chemists’</td>
</tr>
<tr>
<td>CSA</td>
<td>Central Statistics Authority</td>
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<tr>
<td>DOE</td>
<td>Design of Experiment</td>
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<tr>
<td>EHNRI</td>
<td>Ethiopian Health and Nutrition Research Institute</td>
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<tr>
<td>EU</td>
<td>European Union</td>
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<tr>
<td>FAO</td>
<td>Food and Agricultural Organization</td>
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<td>GI</td>
<td>Glycemic Index</td>
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<tr>
<td>HMF</td>
<td>Hydroxymethylfurfural</td>
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<tr>
<td>HPLC</td>
<td>High Pressure Liquid Chromatography</td>
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<tr>
<td>MoARD</td>
<td>Ministry of Agriculture and Rural Development</td>
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<tr>
<td>MTs</td>
<td>Metric Tons</td>
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<tr>
<td>NORAD</td>
<td>Norway’s development agency</td>
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<td>RSM</td>
<td>Response Surface Methodology</td>
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<tr>
<td>SD</td>
<td>Standard Deviation</td>
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<tr>
<td>UAE</td>
<td>United Arab Emirates</td>
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<td>UK</td>
<td>United Kingdom</td>
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<td>WHO</td>
<td>World Health Organization</td>
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<td>IHC</td>
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Abstract

The study was conducted with the objective of optimizing process parameters for production of honey powder by spray drying, characterizing the powder, and using it as a substitute for sugar in bread formulations.

Experimental design with inlet temperature (150 to 190 °C), feed flow rate (5–15ml/min), aspirator rate (80 to 100%) and gum Arabic ratio to liquid honey (20 to 60%) as independent variables was studied to investigate the effect on product responses. RSM was used to optimize process parameters. The spray dried honey powder was characterized for Moisture content, Particle size distribution, Hygroscopicity test and yield.

Four bread formulations were prepared with 100% of sugar liquid honey (LH), 50% substitution of sugar with honey powder (HP_{50%}) and 100% honey powder (HP_{100%}) and control. Breads produced from all four formulations were analyzed for loaf volume, weight loss, density, specific volume, moisture content, and texture.

The dried honey powders contained moisture content between 4.01% and 6.31%, particle size between 5.16µm and 5.76µm, hygroscopicity between 22.10 and 25.65 g /100g and powder yield between 5.12g and 9.45g.

Among the bread samples HP_{100%} showed highest loaf volume (mL) at 2055±65.14 while HP_{50%}, LH and control showed decreasing loaf volumes at 1907±189.45, 1887±96.21 and 1800, respectively. All bread samples showed an increase in firmness and HP_{100%} had a lower rate of staling than the other bread samples during storage. The study demonstrated that spray dried honey powder with retrograded starch could be used as a substitute for sucrose in baking bread.

Keywords: Honey powder; retrograded starch; optimization; response surface methodology; spray drying, Gum Arabic.
CHAPTER ONE

INTRODUCTION

1.1. Background

Owing to its varied ecological and climatic conditions, Ethiopia is the home to some of the most diverse flora and fauna in Africa. Its forests and woodlands contain diverse plant species that provide surplus nectar and pollen to foraging bees (Girma, 1998). Beekeeping is one of the oldest farming practices in the country. There is an ancient tradition for beekeeping in Ethiopia which stretches back into the millennia of the country's early history (Girma, 1998). Of all countries in the world probably no country has a longer tradition of beekeeping than Ethiopia (Hartmann, 2004). It has been practiced traditionally. Moreover, beekeeping is an appropriate and well-accepted farming technology and it is best suited to extensive range of ecosystems of tropical Africa. To date, over 10 million of bee colonies are existing, which include both feral, and hived ones (Ayalew, 2001).

Ethiopia's wide climatic and edaphic variability have endowed this country with diverse and unique flowering plants, thus making it highly suitable for sustaining a large number of bee colonies and the long established practice of beekeeping. Nevertheless, the bees and the plants they depend on, like all renewable natural resources, are constantly under threat from lack of knowledge and appreciation of these endowments (Girma, 1998).

Ethiopia is the largest honey producer in Africa and 10th largest honey producer all over the world. From 2005-2010, Ethiopian honey production increased 26% from 36,000 MTs to 45,300 MTs.

Ethiopia produces dozens of honey varieties based on pollen source, season, and agro-ecological region of production and these factors also determine production and harvest cycles. Honey consistency and color range from white varieties that are buttery-creamy or sandy-sugary, to red varieties that are tart and acidic, with aromatic amber and yellow varieties in between. The white, grainy honey from Tigray, the most northern region of Ethiopia, is made from a local blossom of the sage plant family, known as labiate, which gives it its unusual color. The smooth, amber-colored honey produced near the Wenchi crater located about 120 kilometers east of Addis
Ababa is made from tree heath, a variety of the *Erica* species flower found in the crater. (Source: Ethiopian custom Authority, HS Code 0409.00.00, January-July 2012)

### 1.1.1. Honey Production in Ethiopia

Since 1976 to 2005 honey production in Ethiopia was in the range of 25-30 thousand tons per year. However, estimates made by Ministry of Agriculture and that of the Central Statistics Authority have shown to be about 30 thousand tons per year. (Source: Ethiopian custom Authority, HS Code 0409.00.00, January-July 2012)

The CSA data shows that honey production has been growing at about 12% over the 1997-2005. This suggests that honey production grew from 13.6 thousand tons in 1997 to over 30 thousand tons in 2005. (Source: Ethiopian custom Authority, HS Code 0409.00.00, January-July 2012)

Ministry of Agriculture of Ethiopia suggested the presence of 10 million bee colonies while the recent unofficial information from the same office is indicating to be about 12 million.

Production and supply of honey by regions shows that Oromia accounts for over 55% of the bee colonies and 53% of the Honey production, followed by Amhara which accounts for about 20% of the colonies and 21% of the honey production. The Southern Nations, Nationalities Peoples Regional State, on the other hand, accounts for about 15% of the bee colonies and 17% of the honey production. Tigray and Benshangul accounts for 4.5% and 3.6% of the total bee colonies, and 5.5% and 3% of the total honey production respectively. (Source: Ethiopian custom Authority, HS Code 0409.00.00, January-July 2012)

### 1.1.2. Honey Future Market Opportunities

Ethiopia exports only small amount to the international market, with the majority of exports being shipped to neighboring Sudan (531 MTs in 2011). From 2009-2011, Norway emerged as the second largest importer, with purchases rising from 40 MTs to 121 MTs. From January to July 2012, Norway imported 200 MTs, surpassing its 2011 import total. This rise is due to assistance from a Norwegian processor and distributor of honey, as well as from Norway’s development agency (NORAD) and its Development Fund. Within the EU, from 2006-2011, the UK was the largest buyer, but imports never surpassed 45 MTs for any given year. Within the Middle East, Saudi Arabia and Yemen were the top two buyers, averaging 21 MTs and 14 MTs.
per year, respectively. Kuwait and UAE also recorded small amounts of imports from Ethiopia. From the previous trend the demand for Ethiopian honey is expected to increase in the future (Source: Ethiopian custom Authority, HS Code 0409.00.00, January-July 2012)

1.1.3. Honey Powder Value Added products

Honey powder can be used in areas where process or product constraints previously prevented the use of liquid honey. The honey powder retains all its desirable properties while eliminating the flavor and color variability, handling difficulties, and storage problems inherent with their liquid counterparts. The powder is used not only for use in general formulations where convenience is desired, but also for use in product applications where a dry ingredient is necessary.

High-quality liquid materials are dried on different kind of starch carrier and converted to free flowing powders. The use of starch makes the powders less hygroscopic and more resistant to caking in storage than materials dried with other carriers. As starch gelatinizes during baking, it also increases absorption and provides thickening in many food products.

Honey powder is applied in a variety of food industries. When used in dairy Products, cold drinks, condiments, candies and meat products, it has always presented its special and best performances while liquid honey used in the above products can not satisfy all the functions and effects as required.

Honey powder restrains unsatisfactory smells and improves product performance in an effective manner. For instance, when applied in cake products it significantly betters product taste by covering the fishy smell of eggs and greasiness. And in the crust of moon cakes it increases crust hardness after baking process and shortens the time for oil reversion so as to extend product durability and shelf life.
1.2. Statement of the Problem

Though beekeeping is the oldest farming practice in Ethiopia, the consumption of honey in the country is mostly in unprocessed state i.e., liquid, crystallized or in the comb. The country produces excess amount of honey but it consumes or exports less amount.

Thus, large amount of honey produced in the country is stored for long period of time improperly at farmers’ houses. As it is stored for a long time there is change in its color, aroma, flavor, etc and the quality of honey will be deteriorated due to physical and chemical changes in the honey. As a result, large amount of honey produced in the country do not have market and wasted.

Most farmers in the country operate at a small scale and lack modern technologies that could increase their productivity and benefits. Many farmers are also unaware of the quality of their products and market demand outside their immediate communities. As a result, most of the current product is traded informally and used to produce tej, a popular Ethiopia honey.

Honey powder is healthy and safe. Liquid honey fails to meet mass industrial continuous production as a result of problems of the invisible impurities in it, the existence of massive glucose-tolerant yeast and its potential threat to pollen allergic group.
1.3. Objectives

1.3.1. General objective

The general objective of the research was optimization of process parameters for production of honey powder from Ethiopian honey by spray drying and its utilization in bakery products.

1.3.2 Specific objectives

The specific objectives of the research were to:

- Optimize process parameters for honey powder production by spray drying and make honey powder using selected process parameters
- Characterize the honey powder
- Formulate bread using honey as an ingredient
- Characterize the bread made from honey
1.4. Significance of the study

While most of honey products can be consumed or used in the state in which they were produced by the bees, there are many additional uses where these products form only a part of all the ingredients of another product. Because of the quality and sometimes almost mystical reputation and characteristics of most primary bee products, their addition to other products usually enhances the value or quality of these secondary products.

Many of the primary beekeeping products do not have a market until they are added to more commonly used, value added products. Even the value of the primary products increase if good use is made of them in other products, thereby increasing the profitability of many beekeeping operations.

Outside the thousands of homemade recipes in each cultural tradition, honey is largely used on a small scale as well as at an industrial level in baked products, confectionary, candy, marmalades, jams, spreads, breakfast cereals, beverages, milk products and many preserved products.

In some cases the traditional and early technological uses of primary bee products have been replaced by other (often synthetic products) because of better availability, lower cost and/or easier processing. But in regard to food or health products, there are no synthetic substances which can substitute for the wide variety of characteristics of primary bee products. Only when it comes to highly specialized applications and conditions, will synthetics sometimes outperform these unique and versatile products. In that sense, all products containing one or several of the primary bee products are value added products. Furthermore, the combination of several bee products synergistically increases their beneficial significance beyond their individual biological values.

Honey powder is healthy and safe. Liquid honey fails to meet mass industrial continuous production as a result of problems of the invisible impurities in it, the existence of massive glucose-tolerant yeast and its potential threat to pollen allergic group.

Honey powder is stable in properties while liquid honey is diverse in physical attributes and varieties, including significant differences of physical and chemical indexes of routine indexes (moisture, sucrose, fructose, and glucose, etc.) together with taste and smell of different flowers. It is obvious that all the above factors will fail finished product in stability.
CHAPTER TWO
LITERATURE REVIEW

2.1. General Overview of Honey

The Codex Alimentarius Commission (1981) defines honey as the natural sweet substance produced by honey bees from nectar of blossoms or from secretions of living parts of plants or excretions of plant sucking insects on the living part of plants, which honey bees collect, transform and combine with specific substances of their own, store and leave in the honey comb to ripen and mature. Honey is the oldest and only available unique natural sweetener to mankind and is the last of natural unprocessed food to be consumed (Bogdanov and others 2008; Ouchemoukh and others 2010). The mention of honey dates back to as long as 2100-2000 B.C in a Sumerian tablet which proclaims the use of honey as a drug and ointment. The Bible also mentions King Solomon’s words “Eat honey my son, because it is good!” (Old Testament, proverb 24:13). Bee honey has significant nutritional and prophylactic-medicinal value (Juszczak and Fortuna 2006). Honey can be produced from the nectar of flowers or from honeydew and in some cases can even be a combination of both (Juszczak and Fortuna 2006). When derived from the nectar of flowers honey is known as nectar or blossom honey and can be further categorized as mono/unifloral honey and multifloral honey whereas honey produced from honeydew is known as honeydew honey (Ouchemoukh and others 2007). Nectar honeys are classified as monofloral and multifloral based on the pollen content analyzed by microscopic analysis which is known as mellisopalynological studies. Monofloral honeys are those whose pollen frequency from a single plant species is above 45% unless the pollen grains are under- or over-represented in which case around 10-46% is accepted as in Lavender, Citrus and Rosemary honeys (Felsner and others 2004). Honey produced from Eucalyptus, Castanea and Myosotis the pollen content is over-represented for a monofloral honey (Ouchemoukh and others 2007).

Honeydew honeys on the other hand are produced when bees ingest honeydew which is a sugar containing substance that is excreted by other insects which feed on plants (Ouchemoukh and others 2007).

Honey has been reported to have several important properties. Honey is a solution of high osmolarity which inhibits bacteria (Efem, 1988). The predominant acid found in honey is gluconic acid which originates largely form the activity of glucose oxidase (which the bees add
at ripening) and, to a lesser extent from the bacterial action which occurs (Ruiz-Argueso et al.,
1973). Glucose oxidase is of considerable interest since it causes the production of hydrogen
peroxide which not only stabilizes the ripening of nectar against spoilage but also has micro
bactericidal action (Malika et al., 2005). In addition to glucose oxidase, honey contains
polyphenols which are antibacterial (Bogdanov, 1983). The floral source of honey may also be
responsible for some of the antibacterial activities of honey (Molan and Russell, 1988).

Medicinally, honey is used to enhance wound- healing in humans (Adesunkanmi and Oyelami,
1994; Cooper, 2001; Aysan et al., 2002), treatment of gastric ulcer (Kandil et al., 1987) and
shortening of the duration of diarrhea (Salem, 1981; Haffejee and Moosa, 1985).

The intrinsic properties of honey have been reported to affect the growth and survival of
microorganisms by bacteriostatic or bactericidal actions (Iurlina and Fritz, 2005).

The low pH and high sugar content of undiluted honeys prevent the growth of many species of
microorganisms.

2.1.1. Honey Composition and Characteristics

Honey is an extremely complex mixture of carbohydrates that is found naturally (Swallow and
Low 1990) with almost 70-80% sugars, 10-20% water and other minor constituents such as
organic acids, mineral salts, vitamins, proteins, phenolic compounds, lipids and free amino acids
(Gomes and others 2010; Ouchemoukh and others 2007). Honey maturity, the manner of
production, processing and storage climatic conditions of the region of production and the nectar
source have a substantial influence on the quality, composition and biochemical properties of
honey (Guler and others 2007; Anupama and others 2003). The composition of honey in turn
influences its physicochemical properties such as viscosity, hygroscopicity and granulation
(Lazaridou and others 2004).

Honey can therefore be expected to contain a small number and a limited variety of
microorganisms. The microorganisms of interest in honey are those that withstand the
concentrated sugar, acidity and antimicrobial character of honey. These microorganisms include
certain yeasts and spore - forming bacteria; coliforms or yeasts indicative of sanitary or
commercial quality (Snowdon and Cliver, 1996). The presence of _Bacillus cereus_ has been
reported to reflect a generally higher tolerance of the organism among other endospore-forming rods to antimicrobials that are present in honey (Roth et al., 1986).

There are enormous reports on the physico-chemical, antimicrobial, microbiological and medicinal properties of honey from other countries (Singh and Kuar Bath, 1997; Molan and Russell, 1988; Anupama et al., 2003; Iurlina and Fritz, 2005; Iurlina et al., 2006). There is paucity of information on Ethiopian honey.

Honey is the most important primary product of beekeeping both from a quantitative and an economic point of view. It was also the first bee product used by humankind in ancient times. The history of the use of honey is parallel to the history of man and in virtually every culture evidence can be found of its use as a food source and as a symbol employed in religious, magic and therapeutic ceremonies (Cartland, 1970; Crane, 1980; Zwaeneprel, 1984) an appreciation and reverence it owes among other reasons to its unique position until very recently, as the only concentrated form of sugar available to man in most parts of the world. The same cultural richness has produced an equally colorful variety of uses of honey in other products.

Honey is a supersaturated solution of sugar, which together with other constituents in minor amounts, is made by bees from the nectar of flowers. Because of multiple importance of honey from food to medicine, it is of great interest to carry out complete analysis of honey and to formulate values and ranges of various honey constituents and characteristics.

Honey is generally evaluated by a physico-chemical analysis of its constituents. Several of these constituents are of great importance to the honey industry as they influence the storage quality, granulation, texture, flavour and the nutritional and medicinal quality of the honey. The International Honey Commission (IHC) has therefore proposed certain constituents as quality criteria for honey. These include: moisture content, electrical conductivity, reducing sugars, amount of fructose and glucose, sucrose content, individual sugars, minerals, free acidity, diastase, HMF, invertase and praline. (Bogdanov, S. et al, 1999)

From physical viewpoint, honey can be visualized as an aqueous dispersion of varying sized particles. Though sugars are the major constituents of honey, yet various physical characteristics of honey, such as, refractive index, viscosity, density, and conductivity differ somewhat from an
invert sugar solution of same moisture content because of presence of other minor constituents in honey as well as different ratios of different sugars in various samples.

Sugars predominate the composition of honey and among them glucose and fructose are the prominent monosaccharides (60-85% of honey solids) which account for 85-95% of the honey carbohydrates (Swallow and Low 1990; Lazaridou and others 2004). Generally fructose is present in higher concentrations than glucose with the exception of honeys produced from plants like rape (Brassica napus), dandelion (Taraxacum officinale) and blue curls (Trichostema lanceolatum) (White 1976). The ratio of fructose to glucose on an average is 1.2:1 (Rodriguez and others 2004). Granulation of honey occurs due to spontaneous crystallization of the predominant sugars with glucose crystallizing first due to its lower solubility in water thus producing nucleation seeds in the form of glucose monohydrate (Venir and others 2009; Lazaridou and others 2004). Crystallization leads to an increase in the water content of the honey which causes an increase in the water activity, sometime over 0.60 which is the critical threshold for microbial stability (Venir and others 2009). This change in water activity allows the osmophylic yeasts present in honey to multiply thereby causing fermentation of honey and a decrease in its shelf life (Cui and others 2008). Crystallization affects the quality and textural properties of honey making it undesirable and in some cases could also cause corrosion of metal containers in which honey is stored (Lazaridou and others 2004; Cui and others 2008).

The important disaccharides present are maltose and sucrose (7-10%) (Cui and others 2008). An increase in sucrose content in the honey can occur when bees are over fed with sucrose by bee keepers (Anklam 1998). Azeredo and others (2003) reported that sucrose content also increased when the honey is harvested very early in fall thereby not giving the enzyme invertase enough time to convert sucrose to fructose and glucose. Honey also contains other low molecular weight oligosaccharides like melezitose, trehalose panose and turanose (Cui and others 2008; Bogdanov 2008).

Proteins account for 0.5-1% of the honey composition with proline constituting 50-80% of the total amino acids (Ouchemoukh and others 2007). Proline is produced during the conversion of nectar to honey by the honeybee and serves as an indicator of honey ripeness, and saccharose and glucose oxidase activities (Hermosin and others 2003). There are 26 other amino acids present in honey whose concentrations depend on the floral source in case of nectar honey and
also if the honey is of honeydew origin (Hermosin and others 2003). The important enzymes present in honey are diastase (amylase), invertase (α-glucosidase) and glucose oxidase while catalase and acid phosphatase are present in lower amounts (National Honey Board 2005). Estevinho and others (2008) reported that the phenolic compounds present in honey are flavonoids and phenolic acids which can also serve as markers for determining the botanical origin of honey. They also reported that the phenolic acids were divided into two subclasses: substituted benzoic acids and cinnamic acids while the flavonoids were divided into three classes with structural similarity namely flavonols, flavones and flavanones. The phenolic compounds contribute to the beneficial properties of honey due to their anti-oxidant nature (Estevinho and others 2008).

By international legislation the moisture content of honey should be less than 20-21% (Silva and others 2009; Mendes and others 1998) and generally average moisture content of honeys from different parts of the world ranges between 16-19% (Yanniotis and others 2006; Al-Khalifa and Al-Arify 1999; Juszczak and Fortuna 2006). The low moisture of honey causes a decrease in its water activity as water activity shows a linear dependency on water content (Abramovic and others 2008). Generally water activity of honey is within the range of 0.5-0.65 which is very low for most micro-organisms to grow since molds need around 0.70, yeast around 0.80 and bacteria 0.90 to grow (Gleiter and others 2006). Natural micro-flora of honey includes osmophillic yeasts of which the *Saccharomyces ssp.* are dominant, and have the ability to grow at low water activities of around 0.61-0.62 (Zamora and others 2005). When the water content of honey increases during storage due to granulation, the yeasts start fermenting the honey by acting on the glucose and fructose to produce ethanol and carbon dioxide (Zamora and others 2005; Gleiter and others 2006). The pH of acids is also a limiting factor to the growth of micro-organisms since generally honeys are of acidic pH in the range of 3.6-5 (Al-Khalifa and Al-Arify 1999; Ahmed and others 2007; Gomes and others 2010). The acidity of honey is contributed to the presence of organic acids, mostly gluconic acid and inorganic acids ions such as phosphate and chloride (Ouchemoukh and others 2007). However honey does have several sources of microbial contamination, primarily pollen, the digestive tract of honey bees, dust, air, and secondary sources maybe during handling and processing of honey (Snowdon and Cliver 1996). These micro-organisms include fungi such as *Penicillium* and *Mucor*, yeasts such as *Saccahromyces*, *Schizosaccharomyces* and *Torula*, molds and spores of *Bacillus ssp.* and *Clostridium ssp.*
(Migdal and others 2000). Not many studies are devoted to the microbial contamination of honeys and most of them concentrate on Clostridium botulinum (Gomes and others 2010) since the presence of Clostridium spores pose a risk of contracting botulism in infants who consume the honey (Finola and others 2007).

Viscosity of honeys is an important property that has been studied by various researchers (Sopade and others 2002; Junzheng and Changying 1998; Yoo 2004; Yanniotis and others 2006; Bhandari and others 1999; Lazaridou and others 2004). Viscosity has an influence on the physico-chemical and sensory properties of honey (Juszczak and Fortuna 2006) and knowledge about the rheological properties of honey is useful in its processing, handling and storage (Ahmed and others 2007). Viscosity of honey depends on factors such as temperature, water content, chemical constitution, amount and size of crystals, and types of colloids present in it (Juszczak and Fortuna 2006; Yoo 2004). Effect of temperature on viscosity is generally documented since a variety of temperature ranges are encountered during the processing, storage and handling of honey (Yoo 2004). Generally honey is considered to exhibit Newtonian behavior (Al-Malah and others 2001; Sopade and others 2002; Bhandari and others 1999; Zaitoun and others 2001) but there are a few reports about non-Newtonian behavior of honey (Ahmed and others 2007; Juszczak and Fortuna 2006).

### 2.1.2 Honey Beneficial Properties

The benefits of honey are many and it has been long used both as a source of nutrients and also as a medicine (Bogdanov and others 2008). A branch of medicine known as apitherapy has developed in recent years which utilize honey and its product in stimulation of wounds and burn healing and also in gastric and ulcers treatment (Bogdanov and others 2008; Ouchemoukh and others 2007). Anti-oxidant properties of honey are due to the presence of compounds such as pinocembrin, pinobanksin, chrysin and galagin (Cui and others 2008). Anti-oxidants are believed to protect against oxidation which is important for the prevention of chronic diseases (Ames and others 1993). Studies conducted by Schramm and others (2003) and Al-Waili (2003) showed that consumption of honey increased antioxidant levels and decreased serum levels and they also increased Vitamin C concentration by 47%, β-carotene by 3%, uric acid by 12% and glutathione reductase by 7%. However even the antioxidant activity of honeys is heavily influenced by the botanical origin of honey (Al-Mamary and others 2002).
Glycemic index (GI) is an important indicator of the carbohydrate level in a food which bears a relation with the blood glucose level (Bogdanov and others 2008). A lower value of glycemic index is indicative of the ability to induce only a small increase in blood glucose level and vice versa. Another quality of honey is that, when it is compared with the same amount of sugar, it gives 40% less calories to the body. Although it gives great energy to the body, it does not add weight. Rapidly diffuses through the blood: When accompanied by mild water, honey diffuses into the bloodstream in 7 minutes. Its free sugar molecules make the brain function better since the brain is the largest consumer of sugar, thus, reduces fatigue (Arcot and Brand Miller 2005).

The only available data on honey GI is that of Australian honeys which was determined to be an average of 58 (Brand-Miller 1995). However this was of blended honeys (nectar and honeydew honey) rather than individual honeys from floral sources. Arcot and Brand Miller (2005) carried out studies to determine the GI of nectar honeys and reported that most nectar honeys were within the low GI range (55 or less) or intermediate GI range (56-69). However some blend honeys were in the high GI range (70 and above). The study also reported that the GI value of a honey was negatively correlated to its fructose content and hence honeys with higher fructose showed lower GI values. Fructose is absorbed more slowly than glucose from the gastrointestinal tract which causes only a minimal rise in the blood sugar levels (Jeffrey and Echazarreta 1996). Also the glycemic index of fructose is 19 which is very low when compared to that of sucrose which is 68 (Bogdanov 2010). Studies conducted by various researchers have shown that honey could be tolerated by patients afflicted with either types of diabetes i.e. type I and type II (Katsilambros and others 1988; Samanta and others 1985).

Honey also exhibits antimicrobial, antiviral, antiparasitic, antimitagenic and anti-inflammatory properties (Bogdanov 2008). Honey was seen to affect the levels of antibodies produced against thymus dependent antigens in mice and sheep (Al-Waili and Haq 2004). Al-Waili 2003 reported that consumption of honey by humans on a 1.2g/kg body weight daily showed an increase of the following in their blood serum: monocytes (50%), iron (20%), copper(33%), and a slight increase in lymphocytes, eosinophils, zinc, magnesium, and hemoglobin. The study also reported a reduction in ferritin (11%), immunoglobulin E (34%), aspartate transaminase (22%), alanine transaminase (18%), lactic acid dehydrogenase (41%), creatine kinase (33%) and fasting sugar (5%).
Application of honey in food products is attributed to its properties such as antimicrobial and antioxidant nature. They prevent the spoilage of meat due to microbial growth or lipid oxidation as in the case of meats (Antony and others 2000; Nagai and others 2006). Honey also has the ability to prevent enzymatic browning of sliced fruits such as apple (Oszmianski and Lee 1990), in raisins (Mclellan and others 1995) and in vegetables (Chen and others 2000) too. They are used for clearing fruit juices and fruit drinks (Lee and others 1990; Oszmianski and Lee 1990). Shin and Ustunol (2005) reported that the presence of honey in yogurt not only enhanced the growth of indigenous bifidobacteria in the GI tract but also inhibited the growth of _C.perfringens_ and _E. aerofaciens_. Honey has a diverse application in the bakery, cereal and confectionary industry (Bogdanov 2010). It is assumed that the advantages of adding honey to a product include moisture retention, good texture, improved baking, flavor and sensory properties (Bogdanov 2010).
2.2. Honey Powder Processing

Honey powder processing involves the removal of wax and any other foreign materials from liquid honey and transforming it into free flowing powder using spray drying method.

![Honey Powder Processing Steps Diagram](image_url)

*Figure 2.1: Honey Powder Processing Steps*
2.2.1. Some Important Honey Purifying Techniques

The following are some of the important techniques of purifying liquid honey before spray drying.

a) Honey extractors

- These can be either electrically or manually driven machines which operate on the principle of centrifugal force.

- Extractors vary in size ranging from small two-frame units to big ones holding up to 85 frames.

- Manual extractors are equipped with either a hand crank or a bicycle chain while the electrical ones are motor driven.

Figure 2.2: Hand crank manual extractor
b) Simple Straining Method:

- This method is suitable for freshly harvested honey.
- Uncap (remove the thin wax layer that seals the honey cells) the honey and allow it to pass through a straining cloth or net into a clean and dry suitable container.
- Folded the straining net (nylon mostly) once, to form two layers and tie over the mouth of the container.
- Use a wide mouth container to collect the strained honey
- Allow the liquid honey to settle overnight.
- Remove the scum (cream) from the surface of the honey using a spoon before the honey is packed.

![Diagram of simple straining method](image)

**Figure 2.3**: Simple straining method

c) Water Bath Method:

- This is also referred to as batch processing. This method is suitable for semi-processed honey which has been stored for some time and possibly crystallized.
- Honey is first heated in a water-bath (indirect heating), up to about 45°C - 50°C.
- Honey is heated to facilitate both straining and fast handling, secondly, to destroy yeast that may be present and may cause fermentation particularly if the moisture content is above 17%.

- The indirect heating method involves the use of two ‘sufurias’; the smaller one containing honey is placed inside a bigger one containing some water and a piece of wood placed at the bottom so that the smaller one does not touch the bottom of the bigger sufuria.

- The honey that is being warmed must be stirred to distribute the heat evenly.

- A straining cloth is then folded twice (forms four layers) and firmly tied onto a clean, dry suitable container as in the case of simple straining method above.

- Once all the warm honey has passed through the cloth, cover the bucket with a lid, and allow it to settle for a minimum of 3 days to allow the scum to collect at the top of the strained honey.

**Figure 2.4:** Water Bath Method
Figure 2.5: Honey straining through a cloth

d) Bulk Processing:

- It is used for large quantities of honey.

- In this method, honey is made to flow through a series of sieves of various sizes.

- The sieves are arranged in a concentric form, the finest mesh being on the outside and coarser on the inside.

- The semi-refined honey is heated to 45-50°C in a sump tank and then flows by gravity through the sieves usually referred to as strainers; into a settling tank and is left there for at least 3 days.

- The scum collects on top of the strained honey, it is then removed and the honey packed.

e) Pressing Method:

- Honey is forced out of the comb by pressing it out using a honey press.

- This should be done as soon as possible after harvesting.

- After pressing out the honey, it is then warmed using a water-bath and strained.
f) Honey extraction using the centrifuge

- This method is used to extract honey from combs without destroying the comb.
- It is used especially where honey has been produced using the langstroth hives.
- Some extractors can be used with combs from the KTBH and even from the log hives.

2.3. Spray Drying

Spray drying is a method for convective drying of liquids (Strumillo and Kudra 1986) which has been in operation for over a century but is still an active field of interest for continuous innovation given the demand for better quality product (Vehring and others 2007). Spray drying was first recorded in a patent by Samuel Perry in 1872 (Bhandari and others 2008). The process involves the transformation of feed slurry into a dried particulate form by spraying in a hot drying medium which is generally air (Goula and Adamopoulos 2005). This technology has application in varied fields including food and dairy industries, pharmaceutical, agrochemical, light and heavy chemicals, detergent, pigment, biotechnology and ceramics (Vehring and others 2007). Masters 1996 reported that there were more than 15000 industrial size spray dryers in the world and almost double of that number in pilot plants and laboratories. According to Bhandari and others (2008) some of the key advantages of spray drying are

i. Particles of predetermined characteristics (moisture, size, density etc) and type (particles, granules and agglomerates) can be produced.

ii. Heat spoilage is relatively small in the product due to the extremely short exposure time, the cooling effects in a critical drying period and also due to evaporation of solvent phase at a temperature lower than its normal boiling point. Thus heat sensitive and heat resistive products can be spray dried using the machine.

iii. The process is versatile with the ability to use the same equipment for a variety of different products.

iv. Spray drying is a continuous process with high production rates which makes it economical and also the product is produced in the desired powdered form thereby requiring no additional grinding.
2.3.1 Drying Techniques

There are several drying techniques for production of food powders. They are: hot air, vacuum, freeze and spray drying. Among them spray drying is the simplest and commercially used method for transforming a wide variety of liquid food products into powder form.

The selection of a particular dryer/ drying method depends on the following factors:

• form of raw material and its properties

• desired physical form and characteristics of dried product

• necessary operating conditions;

• operating costs.

![Spray drying Process](image)

**Figure 2.6:** Spray drying Process

Spray dryer uses hot air and can use fairly high air temperatures because the drying temperature drops drastically as water evaporates from the product being dried. The drying process can be completed within a short period of time, thus enabling to prepare dried honey powder without heat degradation even at comparatively high air temperatures.

The development of spray drying equipment and techniques evolved over a period of several decades from the 1870s through the early 1900s. Spray drying comes of age during World War II, with the sudden need to reduce the transport weight of foods and other materials.
This technique enables the transformation of feed from a fluid state into dried particulate form by spraying the feed into a hot drying medium. It is a continuous particle processing drying operation. The feed can be a solution, suspension, dispersion or emulsion. The dried product can be in the form of powders, granules or agglomerates depending upon the physical and chemical properties of the feed, the dryer design and final powder properties desired (Michael, 1993).

Spray drying process mainly involves five steps:

(i) **Concentration**: feedstock is normally concentrated prior to introduction into the spray dryer.

(ii) **Atomization**: the atomization stage creates the optimum condition for evaporation to a dried product having the desired characteristics.

(iii) **Droplet-air contact**: in the chamber, atomized liquid is brought into contact with hot gas, resulting in the evaporation of 95%+ of the water contained in the droplets in a matter of a few seconds.

(iv) **Droplet drying**: moisture evaporation takes place in two stages- 1) during the first stage, there is sufficient moisture in the drop to replace the liquid evaporated at the surface and evaporation takes place at a relatively constant rate (Keey & Pham, 1976), and 2) the second stage begins when there is no longer enough moisture to maintain saturated conditions at the droplet surface, causing a dried shell to form at the surface. Evaporation then depends on the diffusion of moisture through the shell, which is increasing in thickness.

(v) **Separation**: cyclones, bag filters, and electrostatic precipitators may be used for the final separation stage. Wet Scrubbers are often used to purify and cool the air so that it can be released to atmosphere.
Spray drying process have advantages that can be designed to virtually any capacity required. Feed rates range from a few pounds per hour to over 100 tons per hour. Operation is continuous and adaptable to full automatic control (Gharsallaoui et al., 2007). It can be used with both heat-resistant and heat sensitive products.

Nearly spherical particles can be produced. There are some limitation that includes limited versatility in producing particles or structures with the complex morphologies, and rapid drug release rates often exhibiting a burst effect (Katta & Gauvin, 1976).

2.3.2. Design and critical elements of spray drying

2.3.2.1. Atomizers

The "heart" of any spray dryer is the atomizer, small in size, big in importance, installing the right atomizer is essential to spray drying success.
The atomizer must fulfill several important functions which are summarized below:

i. It must disperse the feed material into small droplets, which should be well distributed within the dryer and mixed thoroughly with the hot gas.

ii. The droplets produced must not be so large that they are incompletely dried, nor so small that product recovery is difficult. Small particles may also overheat and become scorched.

iii. The atomizer must also act as a metering device, controlling the rate at which the material is fed into the dryer: a) Air atomization or two fluid nozzles, b) Airless atomization nozzles, c) Pressure nozzles, d) Rotary or disk nozzles and, d) Ultrasonic nozzles.

2.3.2.2. Air flow

Spray dryers can be designed in different flow patterns of the spray and hot air entering the drier. These are Co-current flow, Counter-current flow and mixed flow.

a) **Co-current flow**: in a co-current dryer, the spray is directed into the hot air entering the dryer and both pass through the chamber in the same direction.

b) **Counter-current flow**: in this dryer design, the spray and the air are introduced at opposite ends of the dryer, with the atomizer positioned at the top and the air entering at the bottom.

c) **Mixed flow**: dryers of this type combine both concurrent and counter current flow. In a mixed flow dryer, the air enters at the top and the atomizer is located at the bottom.

2.3.2.3. Spray drying chamber

Air within the chamber maintains a flow pattern, preventing deposition of partially dried product on the wall or atomizer (Ronald, 1997). Air movement and temperature of inlet air influence the type of final product.
2.3.3. Types of spray drier

Based on the nature of the product to be dried and the quality of the powder to be obtained, the following are some common types of spray driers. These are:

**A. Single Stage Drier:** In single stage spray dryer the product is dried in to final moisture content in spray drying chamber.

![Diagram of Single Stage Drier](image)

*Figure 2.8:* Single stage dryer (1-Feedstock; 2-drying chamber; 3-dried product; 4-cyclone; 5-wet scrubber; 6-bag filter; 7-heater; 8-atomizer)

**B. Two Stage Dryer**

Two stage dryers allow the use of lower temperatures in the dryer, making the design a good choice for products that are particularly heat sensitive (Katta & Gauvin, 1976)
Figure 2.9: Two stage dryer: 1-air; 2-feedstock; 3-dried product; 4- drying chamber; 5-cyclone; 6-stationary fluid bed; 7-fluid bed cyclone; 8-heater; 9-atomizer.

C. Horizontal spray dryer

Figure 2.10: Horizontal dryer

The components are: 1-drying air; 2-feedstock; 3-pneumatic conveyor; 4-drying chamber; 5-powder conveyor; 6-filter bags; 7- cyclone; 8-dust return; 9-exhaust to atmosphere; 10-dried powder.
D. Vertical dryer

It is suited for both non-fat and fat-containing products, producing non-agglomerated and agglomerated free-flowing powders.

E. Fluidized Spray Dryer

The Fluidized Spray Dryer combines spray drying and fluid bed drying technologies and offer excellent product flexibility and excellent thermal efficiency. Sticky products can be dried successfully, and the concept is ideal for drying heat sensitive products, and improved aroma retention is accomplished (Sommerfeld & Blei, 1992).

![Fluidized spray drier diagram](image)

**Figure 2.11**: Fluidized spray drier

F. Multi stage drier

The process produces non-dusty, free flowing agglomerated powders with high flavor retention. It operates with low outlet-temperatures, achieving high thermal efficiency. This design concept is successful for drying high fats, hygroscopic, and sticky products that are difficult to handle in more conventional designs.

G. Compact Spray Dryer

In compact spray dryer, atomization is created by either a rotary atomizer or spray nozzle atomizer. The location of the fluid bed within the drying chamber achieves drying at lower
temperature levels. It results in higher thermal efficiencies and cooler conditions for powder handling.

H. Integrated filter drier

An integrated filter drier combines an integrated fluid bed and filter arrangement. It is an adaptable and flexible spray dryer for the food ingredients, food, dairy, chemical, and pharmaceutical industries.

The Integrated Filter Dryer (IFD™): features and benefits include: improves powder quality, no handling of product outside drying chamber, reduced noise level and lower energy consumption.

I. Filtermat Dryer

The Filtermat Spray Dryer is frequently used in food and dairy applications. It operates at a low outlet temperature, achieving high thermal efficiency. It is the recommended system for drying high fat, sugar-based, hydrolyzed, and fermented products.

2.3.4. Critical parameters of spray drying

The precise control of critical parameters of spray drying is very important to ensure the quality of the powder is within the expected level. The following are the key parameters of spray drying.

a) Inlet temperature of air: higher the temperature of inlet air, faster is the moisture evaporation but the powder is subjected to higher temperature, which may distort the chemical/physical properties of heat sensitive product (Michael, 1993).

b) Outlet temperature of air: it govern the sizing of powder recovery equipments, higher is the outlet air temperature larger will be the size of powder recovery equipment and conveying ducts and plenums (Maury et al., 2005). Outlet air temperatures control final moisture content of powder.

c) Viscosity: high viscosity hinders correct drop formation.

As the viscosity is lowered, less energy or pressure is required to form a particular spray pattern.

d) Solid content: care must be taken with high solid loadings (above 30%) to maintain proper atomization to ensure correct droplet formation.
e) **Surface tension**: addition of a small amount of surfactant can significantly lower the surface tension.

This can result in a wider spray pattern, smaller droplet size, and higher drop velocity.

f) **Feed temperature**: as the temperature of a solution to be sprayed is increased, the solution may easily dry as it brings more energy to the system.

g) **Volatility of solvent**: a high volatility is desirable in any drying process.

Unfortunately, choices are limited today. In many cases, these restrict the solvent choice to water.

h) **Nozzle material**: most pharmaceutical applications use stainless steel inserts. However, tungsten carbide nozzles are often available and have excellent resistance to abrasion and good corrosion resistance for most feedstock.

### 2.3.5. Innovations in spray drying

Though spray drying has been in operation for over a century it is still an active field of interest for continuous innovation given the demand for better quality product (Vehring and others 2007). The following two are recent innovations in spray drying.

a) **Sterile spray drying for stable injectable liquid formulation**

Soluble glass microspheres forming a mono disperse suspension in anhydrous fluorocarbon liquid because the microspheres are solid, their density can be precisely controlled to match that of the surrounding liquid (Bucktonnet al., 2002; Roser, 2005). Such suspensions are physically stable and the particles neither settle nor float in the liquid phase.

b) **Foam spray drying**

In this method liquid food is foamed, such as milk or coffee, before spraying it into the drier. The result is faster drying rate from the expanded foamed droplet surface area, and lighter density dried product. This is known as foam-spray drying (Hanrahan & Webb, 1961).

Spray drying is known to produce predominately amorphous material due to the almost instantaneous transition between liquid and solid phases. However, spray drying can also be used
to obtain crystalline products (Shoyele & Cawthorne, 2006). To achieve such a goal, the product is fed in a crystalline suspension, instead of a solution, to the drying chamber. Feeding the crystals in the right form allows spray drying to fine tune crystal size distribution and final content of residual solvents (Jorge & Felipe, 2004).

2.3.6. Stickiness and Glass Transition Temperature in Spray Drying

The processing of liquid honey into honey powder is difficult as the high sugar content contributed to the stickiness of the dried honey (Canovas et al., 2005).

Roos and karel (1991a,b) stated that the sticky point temperature of sugar rich products decreases with increasing water content concurrently with glass transition temperature of the product (Tg) and the critical viscosity of about 107 Pa.s.

Roos and Karel (1991c) and Slade and Levine (1994) pointed out that sticky point of food powders decreases with decreasing molecular weight and products with low Tg have also sticky point at low temperatures. Foods that contain high amount of monosaccharides *viz.*, glucose, fructose, fruit juices have low Tg values and sticky points. Stickiness of such sugar rich products can be reduced and stability increased by adding compounds with higher Tg values.

Basin et al. (1996) studied the role of Tg on the stickiness behavior of the maltodextrin - sugar mixtures (fructose, glucose and sucrose) during spray drying.

Roos and Karel (1991b) and Bhandari et al. (1997a) correlated the glass transition temperature with critical viscosity and found that the critical viscosity is reached at temperature 10-20°C above Tg. Based on these studies, it can be assumed that the temperature of the surface of the product during spray drying should not reach 10-20°C above Tg.

The honey powder is usually produced by adding ingredients such honey, emulsifier, anti caking agent and filler materials of high molecular weight to increase glass transition temperature of a mixture and to minimize the problem during drying (sticky and difficult to dry) (Bhandari and Howes, 1999).

The filler materials used are carbohydrate group such as starch, carboxy methyl cellulose, Arabic gum, maltodextrin and protein group such as gelatin (Canovas et al., 2005).
The stickiness problem of honey during drying can be addressed by applying the concept of glass transition temperature (Tg) through two approaches; low drying temperature (if possible lower than honey’s Tg) and addition of high molecular weight filler material (Bhandari and Howes, 1999), as the addition of filler to honey could increase its Tg and also encapsulate the honey itself.

Spray drying is a dehydration technique applied to many types of food products. These products can be generally categorized into sticky and non-sticky products. For non-sticky products such as skim milk, gums, and proteins, a simple dryer design can be used and the resulting powder is non-hygroscopic and free flowing. On the other hand, sticky products are difficult to spray dry because these materials stick to the walls of the drying chamber and may remain in a syrup form after the drying process. These material properties lead to operational issues, low yields, and caking during storage (Bhandari et al., 1997).

The main food constituents which cause stickiness issues are sugars, organic acids, and fats as seen in products such as fruit juice, vegetables, honey, and amorphous lactose. High hygroscopicity, high solubility, low glass transition temperatures, and low melting point contribute to stickiness (Bhandari et al., 2001).

2.3.7. Glass Formation in Spray Drying

During the spray drying process, dehydration of the atomized liquid particles proceeds from the particle surface to the inner core. A layer of concentrated solutes is formed on the particles surface and there is a decrease in the particle temperature due to evaporative cooling. The extremely rapid removal of water increases the viscosity of the remaining solution. The particle surface may approach the glassy state before colliding with other particles or drier walls. Downton et al. (1982) found that a critical surface viscosity resulting in stickiness and caking is > 107 Pa.s. The general accepted value for the viscosity of glassy materials is > 1012 Pa.s (Sperling, 2006, Roos, 2002, Allen, 1993) which is an ideal viscosity for non-sticky powders. The verifications of the particles surface in spray drying is essential in allowing the free flow of the particles through the drying chamber and avoiding caking of particles with each other and on the drier surfaces.
At the end of the drying process, the particle temperature and water content should support the solid, glassy state (Roos, 2002).

### 2.3.8. Additives in spray drying

Other than the operational techniques, such as cooling the drier wall and blowing with cold air, an additive or drying aid can be used to reduce stickiness during spray drying (Kudra, 2002; Gupta, 1978). A drying aid is added for many purposes such as improving the drying rate, stickiness prevention, reducing hygroscopicity, maintaining flowability of the dry powder and maintaining quality of the powder in storage (Langrish et al., 2007).

Maltodextrins at different dextrose equivalence values (DE) are the most common carriers in spray drying of honey (Gupta, 1978; Masters, 1985; Roos 1995; Bhandari et al., 1997; Rodriguez-Hernandez et al., 2005; Langrish et al., 2007).

### 2.3.9. Techniques for Minimizing Stickiness

Various methods have been used to overcome the sticky problem in spray drying operations; some common ones are given below.

- **Introduction of cold air**: Cold air is introduced at the bottom of a drying chamber (Lazar et al., 1956). A limited amount of air can only be introduced because the cooling process increases the relative humidity of the air, which is capable of reviving the sticky problem again (Bhandari et al., 1997a).

- **Control of wall temperature**: Application of this technique to orange juices, black currants, and raspberries (Bhandari, et al., 1993) are reported to minimize the wall deposition. High wall temperature (> sticky point) not only causes stickiness and wall deposition of thermoplastic powders but also discoloration, self-heating and burning of deposited powder. However, low wall temperature (< sticky point) leads to heat loss and under dried products.

- **Scraped surface drying chamber**: It has been used by Karatas and Esin (1990) for tomato paste to continuously remove the wall depositions that improved the yield and quality.
• **Low temperature drying (Birs dryer):** Air of 30°C and 3% relative humidity is used in association with a very large spray-drying tower. This is a humidity-driven rather than temperature-driven process. Today this dryer is no longer in use (Hayashi, 1989).

• **Drying aids:** Addition of high molecular weight additives, in the feed, before drying has long been practiced. The additives raise the glass transition temperature of the drying particle and also reduce hygroscopicity and thermoplasticity of the resultant mixture. Maltodextrins has been used widely for many juices such as orange (Gupta, 1978), black currants, and raspberry (Bhandari et al., 1993), honey, and pineapple (Bhandari et al., 1997b). The use of additives is the most common way of spray-drying sugar-rich foods.

• **Control of Drying Parameters:** Based on the knowledge of glass transition temperature and drying kinetics (drying rate, particle temperature, and skin formation etc.), it is possible to define a safe drying regime at which a successful drying operation can be accomplished. Fundamental studies to optimize the drying operation as a function of glass transition temperature and drying parameters are still awaited (Truong et al., 1999).

### 2.3.10. Advantages of Spray Dried Powders:

Spray drying does have many advantages, particularly with regard to the final product form. This is especially so where pressing grade materials are required, i.e., in the production of ceramics and dust-free products such as dyestuffs. With the introduction of new geometries and techniques, there has been further development into areas such as foods, and in the production of powders which may be easily reconstituted:

• Can be designed to virtually any capacity required. Feed rates range from a few pounds per hour to over 100 tons per hour.

• Powder quality remains constant during the entire run of the dryer.

• Operation is continuous and adaptable to full automatic control.

• A great variety of spray dryer designs are available to meet various product specifications.

• Can be used with both heat-resistant and heat sensitive products.

• Feedstock can be in solution, slurry, paste, gel, suspension or melt form.
• Nearly spherical particles can be produced.

• These spray dryers usually incorporate one or two fluid beds – static and vibrating – for the final drying and cooling of the agglomerated powder.

• Dry flavors are easier to handle in dry application than liquid flavors. Some applications of dry flavors are cake mixes, pudding powder, instant foods, beverage powders, high temperature products, etc.

2.3.11. Disadvantages of spray drying

• The equipment is very bulky and with the ancillary equipment is expensive.

• The overall thermal efficiency is low, as the large volumes of heated air pass through the chamber without contacting a particle, thus not contributing directly to the drying.

2.4. Bread Baking

Baking is a complex physicochemical process that involves a set of processes which must be carried out in a specific period of time and in a specific sequence (Fu 2006). It begins with the mixing and kneading of the dough, followed by fermentation of the dough which allows biochemical and chemical modifications to occur to the polymers in dough. During fermentation the CO₂ produced causes leavening (Scanlon and Zghal 2001). This is then followed by the moulding and proofing step where the dough is allowed to rise and expand in volume (Kent and Evers 1994). This is followed by baking where a lot of reactions and changes occur simultaneously. The proteins present in the flour and any other ingredient aggregate causing them to harden (Scanlon and Zghal 2001) while simultaneously gelatinization of the starch molecules occurs due to moisture absorption (Vaclavik and Christian 2003). Evaporation of water occurs while creating an outer crust which turns brown due to the Maillard browning reaction (Vaclavik and Christian 2003).

2.4.1. Bread Baking Principles

Bread is made by mixing wheat flour, water, salt and yeast. Optional additives such as fat or oil, improvers, ascorbic acid, and sugar are added as necessary. Bread dough can be regarded as a
solid foam (bubbles of carbon dioxide trapped in a solid). Brownsell et al. (1989) reported that the overall reactions taking place during fermentation of dough can be summarized as:

![Figure 2.12: Overall Reactions taking place during fermentation of Dough](image-url)

Wheat flour is a key ingredient in most bread production. Flour quality is particularly important in bread making as the quality of the flour will have a significant impact on the finished product.

When flour is moistened and stirred, beaten or kneaded, gluten develops to give dough stretch. The elastic framework of gluten holds the gas produced by the fermentation action of the yeast (Federation of Bakers, 2002).

Mondal and Datta (2008) reported in their review 3 methods by which baked products including bread is produced:

**Straight dough method:** also known as bulk fermentation process is a relatively slow process where all ingredients (flour, yeast, salt and other ingredients) are mixed in one mixing stage. The dough is left to ferment for about 3 hours (Federation of Bakers, 2002). It is then knocked back and passes through the divider to get dough balls. The dough balls are rounded to obtain a smooth surface and develop air cells. The rounded dough balls are allowed to stay at the intermediate proofer for about 16 minutes. The dough balls are molded and cut in to the desired shape before the final proofing. The dough pieces allowed fermenting in the proofer for 50-60 minutes at a temperature of 35 °C and 80 % relative humidity. Baking takes place afterwards in an oven set at a temperature of 250 °C on average for a period of 22-40 minutes (Brownsell et al., 1989).

**Sponge and dough method:** in this process part of the ingredients usually 50% of them are first mixed in stiff dough and let to ferment for about 3 hours (Lapades, 1977). The fermented dough is then mixed with the remaining ingredients and kneaded in a bread dough mixer. Thus, this
process takes place in two stages of mixing. The dough is then divided into dough balls and rounded in a rounding machine. The purpose of rounding is to make the dough smooth and help the gluten stretch. Air cells are also created due to rounding. The rest of the process is similar to that of the straight dough method. The main advantage of this process is it yields good aroma, well-leavened and textured bread.

**Chorleywood bread baking process:** the process employs high speed mechanical mixing of the dough in addition to the normal ingredients. The dough is mixed intensely for about three minutes in a high speed mixer. The temperature of the dough has to be carefully controlled at 28°C so that the yeast can grow and the dough becomes elastic (The federation of baking.2002). When mixing is completed, the large mass of dough is tipped into a divider. It is then divided into individual pieces and shaped into a ball. The dough pieces are allowed to `recover` for about eight minutes in a conveyor proofer. This is the first or intermediate proving stage. Each piece of dough is then shaped and molded and placed in a tin, to make a loaf of bread. The texture and size of the dough piece is automatically controlled. The dough then travels through the final proofer which allows the dough to rise gently for about one hour in strictly controlled temperature and humidity conditions. It is then ready for baking.

The bread is baked for about 20 minutes at 200°C. The loaves then go into a cooler. Cooling is usually done under carefully controlled conditions to ensure correct temperature, humidity and time. This is very important for quality. The bread is then wrapped and ready for dispatch.

The process of making dough and baking bread have received attention since it is believed that modifications in these processes may affect the keeping quality of bread and delay its staling while simultaneously exploring the relationships between bread quality and temperature and holding time (Giannou and others 2003).
CHAPTER THREE
MATERIALS AND METHODS

3.1. Description of the Study Area

The honey samples used in this study were obtained from 5 selected Woredas of Amhara, Oromiya and Tigray regions. The selected areas were Wonchi woreda (Oromia, South west Shoa zone), Ada Woreda (Oromiya, East Shoa Zone), Wolmera woreda (West shoa zone), Adigrat honey (Tigray), and Bure Woreda (Amhara).

These liquid honeys were mixed in the same proportion and transported to AAIT food engineering lab for spray drying and then the powder made were transported to defense engineering college and EHNRI to characterize the spray dried honey for its moisture content, particle size, and hygrosкопity.

The powder was also applied in bread as a substitute for sugar and Sensory Evaluation, Yield Characteristics of the Bread (Loaf volume, Specific Volume and Density), Ageing Tests, and Proximate composition of Bread were done.
Figure 3.1: Study areas
Equipments

✓ Stopwatch  graduated cylinder
✓ Oven  Spray dryer
✓ Texture analyzer  Desiccators
✓ Magnetic stirrer  Laser diffraction particle size analyzer
✓ Weighing boat  Spatula
✓ Measuring cylinder  colorimeter

Chemicals

✓ Molybdovanate  Salt, Margarine
✓ Flour  yeast
✓ Sucrose (sugar)  Gum Arabic
✓ liquid honey  distilled water
✓ Conc.NaCl solution
3.2. Optimization Design of process parameters and Statistical analysis:

A four variable (three levels of each variable) Box-Behnken experimental design was employed (Montgomery, 2001). The parameters and their levels were chosen based on related literature available on spray drying of high sugary sticky substances.

Table 3.1: The process parameters and responses to be achieved from RSM

<table>
<thead>
<tr>
<th>Process parameters</th>
<th>Goal</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet drying temperature (°C)</td>
<td>In Range</td>
<td>150</td>
<td>190</td>
</tr>
<tr>
<td>Feed flow rate (ml/min)</td>
<td>In Range</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Aspirator rate</td>
<td>In Range</td>
<td>80</td>
<td>100</td>
</tr>
<tr>
<td>Gum Arabic proportion (%)</td>
<td>In Range</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>Moisture content</td>
<td>minimum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particle size</td>
<td>minimum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Powder yield</td>
<td>maximum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hygroscopicity</td>
<td>Minimum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As shown above (Table 3.1), the objective of the optimization was to obtain the combinations of the four process parameters, which would produce the desired powder quality. Based on preliminary studies the inlet drying temperature was taken in range of 150°C to 190°C, feed flow rate in the range of 5 to 15 mL/min, aspirator speed in the range of 80% to 100% and gum Arabic proportion in range of 20% to 60% of liquid honey.
As indicated above (Table 3.2), optimization of the four main process variables was performed using the Response Surface Methodology (RSM) of Design Expert Software 6.0. The Box Behnken experimental design for the three variables with three levels was employed for optimization. Thus a total of 29 runs were performed.
Figure 3.2: The Spray dryer set up

As can be seen above(Figure 3.2) a laboratory scale Buchi mini spray dryer (model BÜCHI Mini Spray Dryer B-290) with a 0.6 m diameter x 1.1 m high chamber, 0.7 mm nozzle tip diameter pneumatic (or two-fluid) were used in the experiment. Compressed air supply was provided at a pressure of 5-8 bars.

A solution comprising 80% to 40% honey, 20% to 60% Gum Arabic (retrograded starch) and about 3x water (of honey and gum Arabic) by weight was prepared at room temperature. The proportions were determined based on preliminary studies. The solution was prepared by mixing continuously using a magnetic stirrer until the honey dissolved completely in the solution (20 mins).

The honey solution was then pumped at a flow rate of 5, 10 and 15 mL/min and spray dried at 150, 170 and 190°C. The spray dried honey powder was stored at 4°C until analyzed.
3.3. Characterization of Spray-dried Honey Powder

The spray dried honey powder was characterized for its moisture content, particle size distribution, hygroscopicity and yield as follows.

3.3.1. Moisture content of spray dried honey powder (AOAC 2000, 925.05)

A Dish was dried at 130°C for one hour and was placed in a desiccator for about 15-20 minutes. The mass of the dish was measured (Wa). About 2-3g of the sample was weighed into the moisture dish (Wi). The sample was dried at 105°C for 12h overnight. After drying is completed, it was measured as Wf.

\[
MC_{wb} = \frac{(Wi - Wf)}{(Wi - Wa)} \times 100
\]

Where:

- \(MC_{wb}\) is the moisture content in wet basis (%)
- \(Wi\) is the initial weight of samples before drying plus aluminum dish and lid (g)
- \(Wf\) is the final weight of dried samples plus aluminum dish and lid (g)
- \(Wa\) is the weight of aluminum dish and lid (g)

3.3.2. Particle size distribution

The particles size distribution was analyzed using the laser diffraction particle size analyzer.

The particle size distribution of the powder sample was analyzed by using LS230 laser diffraction particle size analyzer (Beckman Coulter, Miami, FL). The analyzer was in the polarization intensity differential scattering optical mode, which enhances the detection resolution of particles 0.8 μm.

3.3.3. Hygroscopicity test

Powder hygroscopicity was tested using the method proposed by Tonon et al. One gram of the powders of each powder was placed into the weighing boat and weighed. The samples in the weighing boat was then placed in a closed container at 25 °C with saturated salt solution of NaCl which can provide relative humidity of 75.3%. After one week, samples were weighed again, and the hygroscopicity was expressed as g of adsorbed moisture per 100 g of dry solids (g/100g).
3.3.4. Powder yield

The weight of the dry material in the powder produced and the honey consumed was used to determine the spray-drying yield. This factor was calculated from following equation:

\[
Yield = \frac{PXSp}{LXSf} \times 100
\]

where \( P \) is the rate of powder production (g/min), \( Sp \) is the percent of total solids of the powder, \( L \) is the feed flow rate (g/min), and \( Sf \) is the percent of total solids of the feed (Chegini and Ghobadian 2007).

3.4. Bread Formulation

The bread was prepared using the Straight dough method for white pan bread followed by American Institute of Baking (AIB). A bread formulation prepared with only sugar (S) was used as a control. The wheat type used was T.aestivum L which is cultivated in Ethiopia and used for making bread in the country.

The procedure began with mixing and kneading of the dough, followed by fermentation of the dough which allowed biochemical and chemical modifications to occur to the polymers in dough. During fermentation the CO\(_2\) produced causes leavening (Scanlon and Zghal 2001). This was then followed by the moulding and proofing step where the dough was allowed to rise and expand in volume (Kent and Evers 1994). This was followed by baking where a lot of reactions and changes occur simultaneously. The proteins present in the flour and any other ingredient aggregate causing them to harden (Scanlon and Zghal 2001) while simultaneously gelatinization of the starch molecules occurs due to moisture absorption (Vaclavik and Christian 2003). Evaporation of water occured while creating an outer crust which turns brown due to the Maillard browning reaction (Vaclavik and Christian 2003).
3.4.1. Bread Formulation Method

Three bread formulations were prepared with 100% liquid honey, 50% substitution of sugar with honey powder and 100% honey powder.

**Table 3.3: Formulation of Bread**

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Control(with sucrose)/g</th>
<th>Substitution with liquid honey(LH)/g</th>
<th>Substitution with 50% honey powder (HP50%)/g</th>
<th>Substitution with 100% honey powder (HP100%)/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Yeast</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Sucrose</td>
<td>14</td>
<td>-</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Liquid Honey</td>
<td>-</td>
<td>21</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Honey powder</td>
<td>-</td>
<td>-</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td>Salt</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Margarine</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Water</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>

3.5. Characterization of the Formulated Bread Sample

3.5.1. Yield Characteristics of the Bread (Loaf volume, Specific Volume and Density)

3.5.1.1. **Loaf volume:** of bread was determined an hour after baking on day 0 by the bean displacement method (Greene and Bovell-Benjamin 2004; Wang and others 2002). A bean was poured so as to cover the bottom of a container of known volume. The bread loaf was then placed and the remainders of the bean seeds were poured into the container. The bean was leveled on the surface of the container using a spatula. The beans that were not required to fill the container was measured in a graduated cylinder and represented the volume of the loaf. The results were expressed as means of triplicate values along with standard deviation.

3.5.1.2. **Specific volume:** was calculated as the ratio of the loaf volume to the loaf mass determined an hour after baking according to the method of Penfield and Campbell (1990).

\[
\text{Specific volume (cm}^3/\text{g)} = \frac{\text{Loaf volume of bread}}{\text{mass of bread}} \quad \text{................................. (3.1)}
\]
Bread density was calculated as the ratio of the loaf mass to the loaf volume (Shogren and others 2003). 

\[ \text{Density (g/cm}^3\text{)} = \frac{\text{Mass of bread}}{\text{Loaf volume of bread}} \]  

\[ \text{(3.2)} \]

3.5.1.3. Weight Loss of Bread

Weight of the dough and the bread baked was measured and the \% weight loss was calculated as follows:

\[ \% \text{Weight loss} = \frac{\text{weight of dough} - \text{weight of baked bread} \times 100}{\text{Weight of Dough}} \]  

\[ \text{................. (3.3)} \]

3.5.2. Crumb and crust color of bread during storage

Bread samples were stored for 12 days at 20\(^\circ\)C in a temperature controlled incubator. Analysis was conducted on day 0, 1, 3, 6, 9 and 12. Color values for crust and crumb were measured in triplicate at 3 different locations on the same loaf using the HunterLab Labscan XE colorimeter. The results were reported as \(L^*\) (lightness), \(a^*(\text{redness or greenness})\), and \(b^*\) (yellowness or blueness). The measurements were made in triplicate and the means and standard deviations were reported.

3.5.3. Moisture content of bread during storage

Moisture for the crust and crumb was determined by AOAC 969.38b method, using a forced air convection oven. Three grams of crust and crumb each from 3 different locations on the bread were placed in an oven at 105\(^\circ\)C for 24hrs. Triplicate measurements were done and values were reported as means along with standard deviations.

3.5.4. Texture profile analysis of bread

Texture was analyzed using a texture analyzer (TA-XT plus) with a 51 mm diameter cylindrical probe at test speed of 10 mm/s and a 5 kg load. Bread slices used for testing were cut from the center of the loaf and were 25 mm thick. Firmness, cohesiveness, springiness values were determined. Chewiness was calculated as follows:

\[ \text{Chewiness} = \text{Firmness} \times \text{Cohesiveness} \times \text{Springiness} \]  

\[ \text{......................... (3.4)} \]

Triplicate measurements were done and results were expressed as means along with standard deviation.
3.5.5. Sensory Evaluation

Sensory characteristics such as color, taste, aroma, texture, and overall acceptability were done by panelists using sensory score numbers. The panelists were semi trained. The score numbers range from values 1 (represent dislike extremely) to 9 (represent like extremely). Water was provided to rinse their mouth after tasting each sample. The test was conducted over a 2-day testing period in 10 panel sessions. Just before each test session, panelists were given a 20 min orientation about the procedure of sensory evaluation.
CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1: Experimental Result of 29 Runs of experimental Design

The experimental result of moisture content, particle size distribution, powder yield, hygroscopicity and Gum Arabic proportion of the powders are shown in Table 4.1.

**Table 4.1:** The moisture content, particle size distribution, powder yield and hygroscopicity for the 29 runs of the experimental design

<table>
<thead>
<tr>
<th>Inlet temperature (°C)</th>
<th>Feed flow rate (ml/min)</th>
<th>Aspirator rate (%)</th>
<th>Gum Arabic Proportion (%)</th>
<th>Moisture content (%)</th>
<th>Particle size(µm)</th>
<th>Powder yield (g)</th>
<th>Hygroscopicity (g/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>190</td>
<td>10</td>
<td>100</td>
<td>40</td>
<td>4.60</td>
<td>5.35</td>
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<td>2</td>
<td>190</td>
<td>10</td>
<td>90</td>
<td>60</td>
<td>4.51</td>
<td>5.45</td>
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<tr>
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<td>100</td>
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<td>40</td>
<td>5.21</td>
<td>5.51</td>
<td>14.35</td>
</tr>
</tbody>
</table>
A statistical analysis was done on the experimental results to obtain the regression models. To evaluate the significance of each variable on the resulted model, ANOVA was used.

The statistical analysis of the data and three dimensional plotting were performed using Design Expert six software (Stat-Ease, 2000).

From ANOVA, linear model for moisture content and hygroscopicity responses was significant. For powder yield and particle size distribution, quadratic model was significant.

### 4.1.1. Final Model Equations for Optimization of process parameters for Production of Honey Powder by Spray drying

**A. Moisture content:** The model equation for moisture content of the powder as obtained from RSM is given as:

\[
\text{Moisture content} = 5.19 - 0.38 \times A + 0.32 \times B - 0.051 \times C - 0.32 \times D \ldots (4.1)
\]

**B. Particle size:** Final Equation in Terms of Coded Factors for Particle Size is given as:

\[
\text{Particle size} = 5.32 + 0.055 \times A - 0.024 \times B - 0.022 \times C + 0.016 \times D + 0.021 \times A^2 + 9.25 \times B^2 \\
+ 0.015 \times C^2 + 0.017 \times D^2 - 0.040 \times A \times B - 0.030 \times A \times C + 0.015 \times A \times D + 0.032 \times B \times C - 0.015 \times B \times D - 0.015 \times B \times D - 0.037 \times C \times D \ldots (4.2)
\]

**C. For Powder Yield:** Final Equation in Terms of Coded Factors for powder yield is given as:

\[
\text{Powder Yield} = 13.95 + 1.90 \times A - 1.07 \times B + 0.98 \times C + 1.14 \times D - 0.088 \times A^2 - 0.27 \times B^2 + 0.20 \times C^2 - 0.24 \times D^2 + 0.37 \times A \times B - 0.095 \times A \times C + 0.36 \times B \times C - 0.33 \times B \times D - 0.27 \times C \times D \ldots (4.3)
\]

**D. For Hygroscopicity:** Final Equation in Terms of Coded Factors for hygroscopicity is given as:

\[
\text{Hygroscopicity} = 23.42 + 1.37 \times A - 0.80 \times B + 0.48 \times C - 1.05 \times D \ldots (4.4)
\]

Where;

- **A** = Inlet temperature
- **B** = Feed flow rate
- **C** = Aspirator rate
- **D** = Gum Arabic Proportion for all equations 4.1-4.4
4.1.2. Response surface Plots for the Process parameters

4.1.2.1. Moisture Content

From Figure 4.1 below, it shows that the moisture content decreases with increasing inlet drying temperature. This is due to the fact that at higher inlet drying temperature, there is a larger temperature gradient between the fine droplets feed and the hot drying air, ensuring in greater rate of heat transfer to particle and provide better driving force for moisture evaporation. Hence, powders with lower moisture content were formed. Ersus and Yurdagel [8] who were working on microencapsulation of anthocyanin pigments of black carrot (*Daucus carota L.*) by spray dryer also observed the same finding that an increase in spray drying temperature resulted in reduced moisture content of powder. The moisture content of the powder decreased linearly as the aspirator rate increased. Papadakis et al. [4] who were working on spray drying of raisin concentrate also reported that increased in airflow rate led to an increase in powder moisture content. This could be explained by the fact that the energy available for evaporation was according to the amount of drying air AM Goula [4]. A lower aspirator rate caused an increased in product sojourn time in the drying chamber [19] which led to lower moisture content. Increased residence times led to a greater degree of moisture removal [9]. Hence, as the aspirator rate increased, the residence time of the product in the drying chamber decreased, resulting higher moisture content powder. As the feed rate increased, the moisture content of the powder increased. Chegini & Ghobadian [7] observed that increasing the feed flow rate at constant atomizer speed resulted in more liquid to be atomized in the drying chamber. Hence, the drying time was reduced because of shorter contact time between the fine droplets feed and the drying air. Heat transfer between the feed droplets and the drying air became less efficient causing lower water evaporation, thus producing higher moisture content in the powder. Increasing gum arabic concentration decreased the powder moisture content. This result in agreement with result by Goula and Adamopoulos (2008) which reported that moisture content of powder had decreased with the increase of maltodextrin concentration.
Moisture content

A. Inlet temperature

B. Feed flow rate

C. Aspirator rate
4.1.2.2. Particle size distribution

As presented in Figure 4.2, the particle size increases with the increase of inlet drying temperature. Research work by Chegini and Ghobadian [12] also stated that particle size increased with increasing inlet drying temperature. This phenomenon was explained by Goula et al. [18] that in the early stages of drying, the droplets have a free liquid surface and evaporation from this surface was rapid. The evaporation of liquid will cause the solute to be more concentrated at the surface and this depended on the rate of evaporation and the rate which the liquid can be replenished form the core of the droplet. Thus, higher inlet drying temperature caused higher initial drying rates which will produce larger particles with thin shells. While the low initial drying rate produced smaller particles with thick shells. The particle size decreases with increasing aspirator rate. This phenomenon was explained by Stahl et al., [23] that an increased of atomization nozzle flow which is equivalent to the increase in inlet air flow rate which reduced the particle size. This is because the higher the atomization flow or air flow rate,
the more energy is supplied for breaking up the liquids into droplets during the atomization step, resulting in smaller droplets formed. The particle size decreased by the increase of feed rate. As the concentration of gum Arabic increased the particle size also increased. The higher gum arabic proportion was also led to produce the larger particles, which may be related to the feed viscosity, which exponentially increased with gum Arabic concentration. According to Masters (1979), the mean liquid droplet size varies directly with the liquid viscosity at constant atomizer speed. The higher the liquid viscosity, the larger the droplets formed during atomization and thus, the larger particles obtained by spray drying. This is in an agreement with the results published by Jinapong et al. (2008), on instant soymilk powders produced by ultrafiltration and spray-dried in a rotary atomizer. Keogh et al. (2003) observed a linear increase of the particles size with feed viscosity on spray drying of ultra-filtered whole milk concentrated, in a two-fluided nozzle atomizer. In both works, the authors attributed the increase in particle size to the increase on feed viscosity.
4.1.2.3. Powder yield

The influence of the inlet air temperature, aspirator rate, inlet feed flow rate, and gum Arabic proportion on the process yield is shown on Figure 4.3. This response was significantly influenced by all the process parameters. The process yield increased with an increase in the inlet air temperature. This is because at higher inlet temperature, there is greater efficiency of heat and mass transfer process and leads to higher process yield. This is in agreement with the result reported by Tonon et al. [25]; who were working on the spray drying of Amaranthus betacyanin and acai respectively. The process yield decreased with increasing feed flow rate. This is due to slow heat and mass transfer with higher feed flow rate. Moreover, when higher feed flow rates were used, part of the feed passed straight to the chamber without atomization resulting in a
higher of process waste and a lower process yield. Toneli et al. [109] who were working with spray drying of inulin also observed an increase in the mass production with decreasing pump speeds, which is lower feed flow rate.

As the aspirator rate increased, the powder yield also increased. As the proportion of gum Arabic increased the yield increased. This is in agreement with result reported by Quek et al. (2007) which explained that low concentration of carrier agent may obtain the stickiness powder. Quek et al. (2007) investigated the effect of maltodextrin concentrations (0, 3 and 5%) on the properties of the watermelon juice powder. The result showed that there were hardly any powders accumulated in the collector if maltodextrin was not added to the feed. The particles produced were very sticky and mainly deposited onto the wall of drying chamber and cyclone and could not be recovered. The addition of 5% maltodextrin to the feed appeared to give better results than addition of 3% maltodextrin. These results showed that the maltodextrin was a useful drying aid in the spray drying process of watermelon juice and as results it was improved the yield of product.
(b) 

C: Aspirator rate

A: Inlet temperature

D: Gum Arabic proportion

C: inlet temperature
**Figure 4.3:** Response surface for powder yield for (a) Aspirator rate 90%, gum Arabic proportion of 40% (b) feed flow rate of 10ml/min, gum Arabic proportion 40% (c) feed flow rate of 10ml/min, aspirator rate of 90% (d) inlet temperature 170°C, Gum Arabic proportion 40% and (e) aspirator rate of 90%, inlet temperature 170°C and feed flow rate of 10ml/min.

### 4.1.2.4. Hygroscopicity

From Figure 4.4, the lowest powder hygroscopicity values were observed with decreasing inlet temperature, increasing feed flow rate and decreasing aspirator rate. All these variables were also the variables that affected the powder moisture content in an opposite way except gum Arabic proportion. This indicates that the powder was more hygroscopic when it had lower moisture content. This is because the powder with lower moisture content had greater capacity to absorb ambient moisture. The lower the powder moisture content, there is a greater water concentration gradient between the powder and the surrounding water and aids in the powder hygroscopicity. Tonon et al. [25] who carried out spray drying on acacia also observed the same trend. Research work done by Goula et al. [12] also reported that the powder hygroscopicity increased inversely with powder moisture content. High concentration of Gum Arabic reduces the hygroscopicity of powder. This was in agreement with Tonon *et al.* (2008). The lowest hygroscopicity values
were obtained when the highest maltodextrin concentrations were used. This was due to the fact that maltodextrin having low hygroscopicity and confirmed its efficiency as a carrier agent. This was in an agreement with Cai and Corke (2000) and Rodriguez-Hernandez et al. (2005).

Hygroscopicity decreased with increasing gum Arabic concentration. This was in an agreement with Tonon et al. (2008). The lowest hygroscopicity values were obtained when the highest maltodextrin concentrations were used. This was due to the fact that maltodextrin having low hygroscopicity and confirmed its efficiency as a carrier agent. This was in an agreement with Cai and Corke (2000) and Rodriguez-Hernandez et al. (2005).
Figure 4.4: Response surface for powder hygroscopicity for (a) aspirator rate of 90%, Gum Arabic proportion 40% (b) feed flow rate of 10ml/min, Gum Arabic proportion 40% and (c) feed flow rate of 10ml/min, aspirator rate of 90%.
Table 4.2: Optimization solution for production of honey powder by spray drying

As calculated from RSM the following result was obtained. It was selected because the desirability was higher than other solutions displayed from RSM design expert six.

<table>
<thead>
<tr>
<th>No.</th>
<th>In Temp (°C)</th>
<th>FFR (ml/min)</th>
<th>AR (%)</th>
<th>GAP (%)</th>
<th>MC (%)</th>
<th>PS(µ)</th>
<th>PY(g)</th>
<th>Hyg (g/100)</th>
<th>Desirability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>188</td>
<td>9.64</td>
<td>99.6</td>
<td>46.5%</td>
<td>4.73</td>
<td>5.29</td>
<td>15.62</td>
<td>22.84</td>
<td>0.788 Selected</td>
</tr>
</tbody>
</table>

Where: In Temp. = inlet temperature  
FFR= feed flow rate  
AR= aspirator rate  
GAP= Gum Arabic proportion  
MC= Moisture content  
PS= particle size  
PY= powder yield  
Hyg= Hygroscopicity

To check the above selected solution was desirable, the experiment was run using the parameters obtained above and the following result were obtained. And the two results were comparable showing the solution obtained from RSM were desirable.

<table>
<thead>
<tr>
<th>In Temp (°C)</th>
<th>FFR (ml/min)</th>
<th>AR (%)</th>
<th>GAP (%)</th>
<th>MC (%)</th>
<th>PS(µ)</th>
<th>PY(g)</th>
<th>Hyg (g/100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>188</td>
<td>9.64</td>
<td>99.6</td>
<td>46.5%</td>
<td>4.71</td>
<td>5.11</td>
<td>15.05</td>
<td>22.93</td>
</tr>
</tbody>
</table>

4.3. Characterization of Bread formulated using Honey as one Ingredient

4.3.1. Sensory Evaluation of Bread Samples

The sensorial evaluation results of color, aroma, taste, texture and over all acceptability of bread samples each formulation were determined and presented in table 4.3.

Table 4.3: Sensorial evaluation Result of Bread samples from Different Formulations

<table>
<thead>
<tr>
<th>Sample</th>
<th>Color</th>
<th>Aroma</th>
<th>Taste</th>
<th>Texture</th>
<th>Overall acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>8.50±0.52</td>
<td>7.67±0.49</td>
<td>6.42±0.66</td>
<td>7.33±0.88</td>
<td>7.42±0.67</td>
</tr>
<tr>
<td>LH</td>
<td>7.42±0.51</td>
<td>6.58±0.51</td>
<td>6.67±0.65</td>
<td>6.83±0.72</td>
<td>7.08±0.51</td>
</tr>
<tr>
<td>HP50%</td>
<td>7.75±0.45</td>
<td>6.00±0.60</td>
<td>7.58±0.66</td>
<td>7.50±0.90</td>
<td>7.66±0.49</td>
</tr>
<tr>
<td>HP100%</td>
<td>6.67±0.49</td>
<td>7.83±0.72</td>
<td>8.50±0.52</td>
<td>8.50±0.52</td>
<td>8.5±0.52</td>
</tr>
</tbody>
</table>

Hedonic parameters with scales: 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, 9 = like extremely . A-D Means with the same superscript letters within the same column are not significantly different at P < 0.05.

The sensory score for color, aroma, taste, texture and overall acceptability indicated that all products have a mean value greater than 6, indicating that the products are well liked by panelists. Scores of color, aroma, taste, texture and overall acceptability revealed that significant
(p<0.05) differences exist between the products. The mean value of color for HP100% is less than LH, HP50% and control. This may be due to the fact that HP100% had a much darker crust as compared to the other samples which could be attributed to the presence of more types of sugars in the honey powder that contributed to more Maillard browning. But in terms of aroma, taste, texture and overall acceptability it is higher than control, LH, and HP50%.

4.3.2. Loaf volume, Density, Specific density and %Weight loss of bread samples (Day 0)

The loaf volume, Density, Specific density and %Weight loss of bread samples at day 0 is given in Table 4.4. below.

**Table 4.4:** Loaf volume, Density, Specific density and %Weight loss of bread samples (Day 0)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Loaf volume(mL)</th>
<th>Density(g/cm³)</th>
<th>Specific volume(cm³/g)</th>
<th>% weight loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1800±75.85[^B]</td>
<td>0.45±0.04[^A]</td>
<td>2.23±0.30[^A]</td>
<td>10.12±1.25[^A]</td>
</tr>
<tr>
<td>LH</td>
<td>1887±96.21[^B]</td>
<td>0.43±0.06[^A]</td>
<td>2.32±0.38[^A]</td>
<td>11.30±1.99[^A]</td>
</tr>
<tr>
<td>HP50%</td>
<td>1907±189.45[^AB]</td>
<td>0.40±0.08[^A]</td>
<td>2.51±0.65[^A]</td>
<td>12.25±2.26[^A]</td>
</tr>
<tr>
<td>HP100%</td>
<td>2055±65.14[^A]</td>
<td>0.36±0.02[^A]</td>
<td>2.78±0.19[^A]</td>
<td>12.36±2.35[^A]</td>
</tr>
</tbody>
</table>

Loaf volume (Table 4.4) was the highest for HP100% and was significantly higher than the control bread and LH while HP50% was an intermediate to both. However no significant differences in density, specific density or weight loss were observed. Hathorn [13] reported that when bread dough was supplemented with sweet potato flour as well as dough enhancers it caused an increase in loaf volume while increasing concentrations of sweet potato flour alone caused a decrease in loaf volume. This was attributed to the presence of the protein instead of gluten since it is the latter that is required for forming the structural framework in bread. However the retrograded starch does not contain any protein to contribute to gluten formation and hence higher loaf volume could be due to the presence of a variety of sugars for the yeast to work on. The bread samples had loaf volumes that ranged from 1800 ±75.85 mL to 2055±65.14 mL which is within range of that reported for supplemented breads especially those with replaced flour [6].

Specific volume (Table 4.4) is an important parameter as it is associated with dough inflating ability and oven spring and extremes in its values affect crumb structure.
Smaller values of specific density are associated with compact, dense and closed grain structure while larger values indicate open grain airy structures.

Density gives an indication of the size and ratio of air cells to solid product while the % weight loss is associated with the loss of moisture and entrapped CO₂ from the dough matrix. Shogren reported density values of 0.29-0.73 g/cm³ for whole wheat bread supplemented with varying concentrations of soy flour which is comparable to the bread samples in this study.

4.3.3. Crumb and crust color and moisture content of bread during storage

The Crumb and crust color and moisture content of bread during 12 days storage is given below (Table 4.5, Table 4.6, Table 4.7 and Table 4.8).

Table 4.5: Moisture content (%) values of bread crumb

<table>
<thead>
<tr>
<th>Sample</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 6</th>
<th>Day 9</th>
<th>Day 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>42.11±0.65</td>
<td>41.55±0.89</td>
<td>39.78±0.88</td>
<td>38.61±0.06</td>
<td>38.62±0.76</td>
<td>38.64±0.84</td>
</tr>
<tr>
<td>LH</td>
<td>43.25±2.51</td>
<td>42.32±1.65</td>
<td>38.83±1.61</td>
<td>37.32±1.62</td>
<td>39.65±1.53</td>
<td>38.71±0.14</td>
</tr>
<tr>
<td>HP₅₀%</td>
<td>40.36±3.21</td>
<td>39.21±1.02</td>
<td>36.83±1.15</td>
<td>34.08±1.11</td>
<td>36.23±1.15</td>
<td>33.11±0.94</td>
</tr>
<tr>
<td>HP₁₀₀%</td>
<td>51.22±4.12</td>
<td>38.24±1.56</td>
<td>34.12±0.69</td>
<td>33.95±1.36</td>
<td>31.86±1.70</td>
<td>30.12±1.56</td>
</tr>
</tbody>
</table>

Values are means ± SD of 3 determinations. A-B Means with different letters in each row are significantly different. a-c Means with different letters in each column are significantly different (P>0.05)

Moisture content of food is an indicator of the quality of the product and has a potential impact on the sensory, physical and microbial properties of bread in particular [21]. In terms of crumb moisture it was seen that HP₁₀₀% was the highest on day 0 from the other three samples which were comparable to each other (Table 4.5). Higher moisture content as long as it is in the acceptable range has shown to positively increase the loaf volumes of bread [23]. All of the breads showed an expected trend of decrease in crumb moisture over the 12 day storage period.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 6</th>
<th>Day 9</th>
<th>Day 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>25.12±</td>
<td>27.98±</td>
<td>29.88±</td>
<td>29.74±</td>
<td>31.16±</td>
<td>31.21±</td>
</tr>
<tr>
<td></td>
<td>1.32B,ab</td>
<td>1.56AB,ab</td>
<td>0.65A,a</td>
<td>0.64A,ab</td>
<td>1.95A,a</td>
<td>1.91A,a</td>
</tr>
<tr>
<td>LH</td>
<td>28.25±</td>
<td>29.14±</td>
<td>30.86±</td>
<td>32.82±</td>
<td>30.45±</td>
<td>31.65±</td>
</tr>
<tr>
<td></td>
<td>2.12A,a</td>
<td>2.25A,a</td>
<td>1.32A,a</td>
<td>1.82A,a</td>
<td>1.68A,a</td>
<td>2.25A,a</td>
</tr>
<tr>
<td>HP&lt;sub&gt;50%&lt;/sub&gt;</td>
<td>22.14±</td>
<td>24.41±</td>
<td>28.54±</td>
<td>29.51±</td>
<td>29.76±</td>
<td>30.82±</td>
</tr>
<tr>
<td></td>
<td>1.23C,b</td>
<td>1.32AB,a</td>
<td>1.42AB,ab</td>
<td>1.55AB,ab</td>
<td>0.58A,a</td>
<td>2.52A,a</td>
</tr>
<tr>
<td>HP&lt;sub&gt;100%&lt;/sub&gt;</td>
<td>20.85±</td>
<td>22.85±</td>
<td>24.64±</td>
<td>25.39±</td>
<td>26.11±</td>
<td>28.98±</td>
</tr>
<tr>
<td></td>
<td>1.52C,b</td>
<td>0.02BC,b</td>
<td>1.74BC,b</td>
<td>1.84AB,b</td>
<td>0.51AB,b</td>
<td>0.52A,a</td>
</tr>
</tbody>
</table>

Values are means ± SD of 3 determinations. A-C Means with different letters in each row are significantly different. a-b Means with different letters in each column are significantly different (P>0.05).

The decrease in crumb moisture corresponded to an increase in the crust moisture (Table 4.6) over the 12 days. Altamirano and Rossel [3] reported the same and also contributed any increase in moisture during storage to absorption of water from the atmosphere due to the moisture gradient between crumb and crust. This moisture gradient varied with each bread sample even though storage conditions remained the same.
Table 4.7: Crumb Color L*, A* and B* Values of Bread during Storage

<table>
<thead>
<tr>
<th></th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 6</th>
<th>Day 9</th>
<th>Day 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>L*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60.64±0.02</td>
<td>55.57±0.17</td>
<td>60.91±0.05</td>
<td>61.63±0.08</td>
<td>69.15±0.05</td>
<td>73.32±0.52</td>
</tr>
<tr>
<td>LH</td>
<td>66.53±0.01</td>
<td>63.98±0.06</td>
<td>66.16±0.01</td>
<td>58.79±0.10</td>
<td>68.55±0.03</td>
<td>69.35±0.02</td>
</tr>
<tr>
<td>HP50%</td>
<td>57.74±0.01</td>
<td>55.13±0.02</td>
<td>61.28±0.01</td>
<td>59.13±0.21</td>
<td>66.82±0.01</td>
<td>71.94±0.06</td>
</tr>
<tr>
<td>HP100%</td>
<td>64.98±0.04</td>
<td>44.30±0.02</td>
<td>50.69±0.21</td>
<td>63.36±0.01</td>
<td>66.64±0.02</td>
<td>72.78±0.03</td>
</tr>
<tr>
<td>Control</td>
<td>a*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.64±0.01</td>
<td>1.17±0.01</td>
<td>0.77±0.02</td>
<td>0.74±0.02</td>
<td>0.44±0.01</td>
<td>0.40±0.02</td>
</tr>
<tr>
<td>LH</td>
<td>1.34±0.01</td>
<td>1.14±0.01</td>
<td>0.99±0.01</td>
<td>0.83±0.01</td>
<td>0.66±0.01</td>
<td>0.58±0.01</td>
</tr>
<tr>
<td>HP50%</td>
<td>1.54±0.01</td>
<td>1.46±0.01</td>
<td>1.44±0.01</td>
<td>0.99±0.01</td>
<td>0.83±0.01</td>
<td>0.79±0.01</td>
</tr>
<tr>
<td>HP100%</td>
<td>1.84±0.01</td>
<td>1.77±0.01</td>
<td>1.53±0.01</td>
<td>1.08±0.01</td>
<td>0.96±0.01</td>
<td>0.91±0.01</td>
</tr>
<tr>
<td>Control</td>
<td>b*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23.58±0.01</td>
<td>25.96±0.04</td>
<td>21.42±0.03</td>
<td>20.64±0.04</td>
<td>21.88±0.02</td>
<td>22.67±0.01</td>
</tr>
<tr>
<td>LH</td>
<td>23.14±0.05</td>
<td>25.18±0.01</td>
<td>31.99±0.01</td>
<td>29.12±0.01</td>
<td>22.67±0.01</td>
<td>22.89±0.01</td>
</tr>
<tr>
<td>HP50%</td>
<td>23.67±0.02</td>
<td>25.38±0.02</td>
<td>23.50±0.01</td>
<td>22.18±0.01</td>
<td>22.54±0.01</td>
<td>24.03±0.01</td>
</tr>
<tr>
<td>HP100%</td>
<td>24.10±0.02</td>
<td>25.51±0.03</td>
<td>24.05±0.02</td>
<td>23.88±0.01</td>
<td>24.37±0.02</td>
<td>25.04±0.01</td>
</tr>
</tbody>
</table>

*Values are means ± SD of 3 determinations. A-F means with different letters in each row are significantly different. a-d means with different letters in each column are significantly different (P>0.05).
**Table 4.8: Crust Color L*, A* and B* Values of Bread during Storage**

Values are means ± SD of 3 determinations. A-F means with different letters in each row are significantly different. a-d means with different letters in each column are significantly different (P>0.05).

<table>
<thead>
<tr>
<th></th>
<th>Day 0</th>
<th>Day 1</th>
<th>Day 3</th>
<th>Day 6</th>
<th>Day 9</th>
<th>Day 12</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L*</td>
<td>73.34±0.01</td>
<td>56.5±0.02</td>
<td>55.94±0.01</td>
<td>43.89±0.03</td>
<td>50.58±0.04</td>
<td>61.91±0.03</td>
</tr>
<tr>
<td><strong>LH</strong></td>
<td>60.69±0.05</td>
<td>53.60±0.09</td>
<td>42.03±0.01</td>
<td>50.76±0.02</td>
<td>65.21±0.01</td>
<td>55.73±0.03</td>
</tr>
<tr>
<td><strong>HP50%</strong></td>
<td>48.80±0.04</td>
<td>49.34±0.01</td>
<td>48.59±0.02</td>
<td>54.43±0.15</td>
<td>61.82±0.01</td>
<td>48.86±0.03</td>
</tr>
<tr>
<td><strong>HP100%</strong></td>
<td>44.30±0.02</td>
<td>49.54±0.02</td>
<td>39.96±0.02</td>
<td>43.43±0.15</td>
<td>45.91±0.01</td>
<td>38.54±0.01</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>11.58±0.01</td>
<td>13.72±0.02</td>
<td>14.08±0.01</td>
<td>11.86±0.02</td>
<td>10.69±0.01</td>
<td>13.76±0.01</td>
</tr>
<tr>
<td><strong>LH</strong></td>
<td>15.13±0.01</td>
<td>12.33±0.01</td>
<td>13.52±0.01</td>
<td>8.63±0.06</td>
<td>7.66±0.01</td>
<td>7.58±0.01</td>
</tr>
<tr>
<td><strong>HP50%</strong></td>
<td>13.54±0.03</td>
<td>14.46±0.01</td>
<td>16.44±0.01</td>
<td>10.99±0.01</td>
<td>0.83±0.01</td>
<td>14.79±0.01</td>
</tr>
<tr>
<td><strong>HP100%</strong></td>
<td>14.84±0.02</td>
<td>15.77±0.24</td>
<td>17.53±0.01</td>
<td>16.08±0.03</td>
<td>14.96±0.01</td>
<td>15.59±0.01</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b*</td>
<td>29.58±0.01</td>
<td>25.96±0.01</td>
<td>21.42±0.03</td>
<td>22.64±0.03</td>
<td>29.88±0.02</td>
<td>25.67±0.01</td>
</tr>
<tr>
<td><strong>LH</strong></td>
<td>29.14±0.04</td>
<td>24.18±0.01</td>
<td>25.99±0.01</td>
<td>24.12±0.10</td>
<td>27.67±0.01</td>
<td>26.89±0.03</td>
</tr>
<tr>
<td><strong>HP50%</strong></td>
<td>29.67±0.03</td>
<td>28.38±0.01</td>
<td>23.50±0.02</td>
<td>29.18±0.14</td>
<td>34.54±0.01</td>
<td>28.03±0.04</td>
</tr>
<tr>
<td><strong>HP100%</strong></td>
<td>29.10±0.01</td>
<td>30.51±0.01</td>
<td>28.05±0.03</td>
<td>31.88±0.04</td>
<td>30.37±0.03</td>
<td>29.04±0.04</td>
</tr>
</tbody>
</table>

Values are means ± SD of 3 determinations. A-F means with different letters in each row are significantly different. a-d means with different letters in each column are significantly different (P>0.05).
The color of bread crust is mostly attributed to Maillard browning and also caramelization due to the presence of sucrose. Though a clear pattern could not be discerned in terms of lightness of crumb it was seen that in all cases the lightness was higher at the end of 12 days as compared to day 0 (Table 4.7). Redness indicated by a* values decreased over time indicating a lightening of the crumb. HP100% showed lowest L* values for the crust which was followed by HP50%, LH and control in ascending order (Table 4.8). This indicates that HP100% had a much darker crust as compared to the other samples which could be attributed to the presence of more types of sugars in the honey powder that contributed to more Maillard browning. Mohamed[17] reported similar findings for bread made with banana flour which was high in sugar content. The crust of bread supplemented with 30% banana flour was much darker as compared to the breads containing 10% banana flour and no banana flour. Irregularity in patterns over storage may be due to differences in sampling region and lack of uniformity in browning of the crust.

4.3.4. Texture profile analysis Result of bread

Texture which was analyzed using a texture analyzer in terms of Firmness, cohesiveness, springiness values was determined. The following results were obtained and graphically depicted below.

![Firmness Changes during 12 day storage of control, LH, HP50% and HP100% breads](image)

Figure 4.5: Firmness Changes during 12 day storage of control, LH, HP50% and HP100% breads
The four bread samples showed increased firmness (Figure 4.5) with an increase in days of storage and there was a significant change in the firmness values over the 12 days which is attributed to staling, mainly the phenomenon of amylopectin retrogradation. On day 1 Control, LH and HP50% showed no significant difference in their firmness values and were significantly higher only in comparison to HP100%. However day 2 saw a marked increase in HP100% bread which was comparable to HP50% but significantly higher than control. On days 3, 6 and 9 however, HP100% and control did not show any significant difference in values in comparison to each other though they were significantly lower than the LH and HP50%. On day 12 all of the four samples did not show any significant difference in firmness values. The decrease in crumb moisture values correspond to the increase in firmness though the differences in firmness were much more significant that the corresponding moisture content. This is due to the fact that amylose leaches out during baking thus causing retrogradation to occur quickly during cooling leading to crumb firming while the longer storage period is characterized by amylopectin retrogradation as the main ageing factor. Presence of increased sugar levels is attributed to increasing bread firmness as it affected water distribution as well as trapped moisture within the bread structure [17]. However the presence of fibers helps decrease the firmness Mohamed [17] thus explaining why HP100% showed the least firmness among all four samples.

Figure 4.6: Cohesiveness change during 12 day storage of control, LH, HP50% and HP100% breads
Cohesiveness (Figure 4.6) for the control bread decreased overall during the storage period though there was no clear trend. However, LH showed no significant change in cohesiveness during storage while HP50% and HP100% showed an increase in cohesiveness values. On all days HP100% showed lower values of cohesiveness than the control while LH and HP50% were for most part comparable to the control values.

![Graph of cohesiveness changes during 12 day storage of control, LH, HP50% and HP100%](image)

**Figure 4.7:** Springiness changes during 12 day storage of control, LH, HP50% and HP100%

Springiness values (Figure 4.7) for all samples were highest on day 0 and decreased from day 1 onwards. However, on each day the springiness of HP100% and control did not significantly differ from each other and they were lower than those of LH and HP50% which were again not significantly different from each other. Firmness, springiness and cohesiveness are the indicators of bread freshness. Charoenthaik reported a similar trend of increasing firmness with a decrease in both cohesiveness and springiness values over storage time in wheat flour bread substituted with germinated rice flour. Thus a decreasing cohesiveness value and springiness value adds to the firming of bread. From the above it can be concluded that overall the degree and extent of firmness of control bread and HP100% was almost the same.
Chewiness is given as the energy required for masticating a solid food (Stable Micro Systems, Texture Exponent Analysis). The four bread samples showed increase in chewiness values (Figure 4.8) over the 12 days with a significant difference between day 0 and day 12 in all samples. Day 1, 3, 6 and 9 did not show very significant changes in chewiness generally though they were significantly different from the values obtained on day 0 and 12.

**Figure 4.8:** Chewiness changes during 12 day storage of control, LH, HP50% and HP100%
CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

In the first part of the thesis, optimization of process parameters for the production of honey powder by spray drying was done using RSM. Response surface methodology (RSM) was effective in optimizing process parameters for the production of honey powder by spray drying since it is an indispensable tool for process optimization. The main advantage of RSM is the reduced number of experimental runs needed to provide sufficient information for statistically acceptable results (Montgomery, 2001).

The effects of four process parameters; inlet drying temperature, feed flow rate, aspirator rate and Gum Arabic proportion on the powder quality of the spray dried honey powder had been successfully investigated by factorial experimental design. The powder quality was studied in terms of the moisture content, hygroscopity, yield and particle size distribution.

In the second part of the thesis, the effect of adding honey powder in bread was examined by formulating bread using honey powder as one ingredient.

It was observed that:

✓ The moisture content of the powder decreased with an increase in the inlet drying air temperature, aspirator rate and gum Arabic proportion but with a decrease in the feed flow rate.

✓ The powder particle size decreased with a decrease in the inlet drying air temperature and gum Arabic proportion. However, particle size decreased slightly with an increase of feed flow rate and an aspirator rate.

✓ The powder hygroscopicity decreased with a decrease in the inlet drying air temperature and aspirator rate. However, it decreased with an increase in gum arabic proportion and aspirator rate.
The process yield increased with an increase in the inlet drying air temperature, aspirator rate and a decrease in the feed flow rate.

Honey powder can be as an important sugar substitute in making bread. Because it improved the quality and shelf life of the bread.

From RSM, it revealed that the optimum operating conditions for the lowest moisture content; the smallest particle size; highest powder yield and lowest hygroscopicity were obtained at inlet drying temperature of 188 °C; feed flow rate of 9.64ml/min and aspirator rate of 99.61 % and gum Arabic proportion of 46.5%.

The optimal properties of spray-dried powder obtained from this study were 5.29 μm in particle size; 4.73% in moisture content; 15.62 g of powder yield and 22.84% of hygroscopicity.

5.2. Recommendations

- More researches should be done on ways to develop more value added honey products.
- Further studies should be done on solving stickiness problems during spray drying of honey.
- High attention should be given to ways to utilize excess honey produced and wasted in different parts of the country in various food industries.
- Further studies should be done to design spray dryer that suit for drying high-sugar sticky products.
6. References


2. Adesunkanmi and Oyelami, 1994; Cooper, 2001; Aysan et al., 2002)


23. Stahl; M Claesson; P Lilliehorn; P Linden; K Backstrom.International the physicochemical properties of acai (*Euterpe oleracea* Mart.) powder .


### Annex 1: Score Sheet for Sensory evaluation of bread

**Instructions**

You are provided with four bread samples coded Control, LH, HP50% and HP100%. You can taste, feel, shake and rub between the fingers and indicate your perception for each parameter by using the values 1 (represent dislike extremely) to 9 (represent like extremely) as shown below:

Water is provided to rinse your mouth after tasting each sample.

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

Product code: ................................................. Date: .........................

<table>
<thead>
<tr>
<th>Sensory attributes</th>
<th>Hedonic scales</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Color</td>
<td></td>
</tr>
<tr>
<td>Aroma</td>
<td></td>
</tr>
<tr>
<td>Taste</td>
<td></td>
</tr>
<tr>
<td>Texture</td>
<td></td>
</tr>
<tr>
<td>Overall acceptability</td>
<td></td>
</tr>
</tbody>
</table>

**Comments** ........................................................................................................

...........................................................................................................

Signature........................................
Annex 2: honey production in Ethiopia from 1997 to 2005

<table>
<thead>
<tr>
<th>Region/Year</th>
<th>Tigray</th>
<th>Amhara</th>
<th>Oromiya</th>
<th>Benishangul</th>
<th>SNNPR</th>
<th>Gambella</th>
<th>Others</th>
<th>Total</th>
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<tr>
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<td>4309</td>
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<td>709</td>
<td>46</td>
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<td>1998</td>
<td>802</td>
<td>2875</td>
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<td>729</td>
<td>3733</td>
<td>401</td>
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<td>4797</td>
<td>5892</td>
<td>921</td>
<td>3908</td>
<td>1008</td>
<td>83</td>
<td>18075</td>
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<tr>
<td>2004</td>
<td>1376</td>
<td>5831</td>
<td>11704</td>
<td>713</td>
<td>4608</td>
<td>925</td>
<td>28</td>
<td>25186</td>
</tr>
<tr>
<td>2005</td>
<td>1659</td>
<td>6342</td>
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<td>896</td>
<td>5200</td>
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<tr>
<td>Av. growth</td>
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<td>6.9</td>
<td>22.2</td>
<td>23.6</td>
<td>8</td>
<td>15.5</td>
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<tr>
<td>Share</td>
<td>5.5</td>
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<td>53</td>
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<td>17</td>
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</tbody>
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Annex 3. Major Honey Producing Countries for 2001

<table>
<thead>
<tr>
<th>Countries</th>
<th>Output (‘000 tons)</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>256</td>
<td>20.3</td>
</tr>
<tr>
<td>Russia</td>
<td>125</td>
<td>9.9</td>
</tr>
<tr>
<td>USA</td>
<td>100</td>
<td>7.9</td>
</tr>
<tr>
<td>EU</td>
<td>111</td>
<td>8.8</td>
</tr>
<tr>
<td>Argentina</td>
<td>90</td>
<td>7.1</td>
</tr>
<tr>
<td>Turkey</td>
<td>71</td>
<td>5.6</td>
</tr>
<tr>
<td>Ukraine</td>
<td>52</td>
<td>4.1</td>
</tr>
<tr>
<td>Mexico</td>
<td>56</td>
<td>4.4</td>
</tr>
<tr>
<td>India</td>
<td>52</td>
<td>4.1</td>
</tr>
<tr>
<td>Canada</td>
<td>32</td>
<td>2.5</td>
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<td>Ethiopia</td>
<td>31</td>
<td>2.45</td>
</tr>
<tr>
<td>World</td>
<td>1,263</td>
<td>75</td>
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</tbody>
</table>

*Source: MOARD 2007*
Annex 4

**Response: Moisture content**

ANOVA for Response Surface Linear Model

Analysis of variance table [Partial sum of squares]

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>4.17</td>
<td>4</td>
<td>1.04</td>
<td>20.13</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>A</td>
<td>1.70</td>
<td>1</td>
<td>1.70</td>
<td>32.72</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>B</td>
<td>1.23</td>
<td>1</td>
<td>1.23</td>
<td>23.72</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>C</td>
<td>0.031</td>
<td>1</td>
<td>0.031</td>
<td>0.60</td>
<td>0.4467</td>
</tr>
<tr>
<td>D</td>
<td>1.22</td>
<td>1</td>
<td>1.22</td>
<td>23.48</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Residual</td>
<td>1.24</td>
<td>24</td>
<td>0.052</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>1.24</td>
<td>20</td>
<td>0.062</td>
<td>2.47</td>
<td>0.0002 not significant</td>
</tr>
<tr>
<td>Pure Error</td>
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<td>4</td>
<td>6.300E-004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cor Total</td>
<td>5.41</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Model F-value of 20.13 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant.

In this case A, B, D are significant model terms.

Values greater than 0.1000 indicate the model terms are not significant.

The "Lack of Fit F-value" of 2.47 implies the Lack of Fit is not significant. There is only a 0.02% chance that a "Lack of Fit F-value" this large could occur due to noise.

<table>
<thead>
<tr>
<th></th>
<th>Std. Dev. 0.23</th>
<th>R-Squared 0.7704</th>
<th>Mean 5.19</th>
<th>Adj R-Squared 0.7321</th>
<th>C.V. 4.38</th>
<th>Pred R-Squared 0.6732</th>
<th>PRESS 1.77</th>
<th>Adeq Precision 14.726</th>
</tr>
</thead>
</table>

The "Pred R-Squared" of 0.6732 is in reasonable agreement with the "Adj R-Squared" of 0.7321.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 14.726 indicates an adequate signal. This model can be used to navigate the design space.
Annex 5

Response: **Particle size**

ANOVA for Response Surface Quadratic Model

### Analysis of variance table [Partial sum of squares]

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Prob &gt; F</th>
</tr>
</thead>
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<td>14</td>
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<td>2.66</td>
<td>0.0390</td>
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<tr>
<td>A</td>
<td>0.036</td>
<td>1</td>
<td>0.036</td>
<td>17.29</td>
<td>0.0010</td>
</tr>
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<td>B</td>
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<td>3.34</td>
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<td>0.1237</td>
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<tr>
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<td>3.008E-003</td>
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<td>0.2512</td>
</tr>
<tr>
<td>A²</td>
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<td>1</td>
<td>2.726E-003</td>
<td>1.30</td>
<td>0.2736</td>
</tr>
<tr>
<td>B²</td>
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<td>0.1779</td>
</tr>
<tr>
<td>BD</td>
<td>9.000E-004</td>
<td>1</td>
<td>9.000E-004</td>
<td>0.43</td>
<td>0.5233</td>
</tr>
<tr>
<td>CD</td>
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<td>5.625E-003</td>
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<td>0.1240</td>
</tr>
<tr>
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<td>14</td>
<td>2.100E-003</td>
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<td></td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>0.027</td>
<td>10</td>
<td>2.708E-003</td>
<td>4.67</td>
<td>0.0354</td>
</tr>
<tr>
<td>Pure Error</td>
<td>2.320E-003</td>
<td>4</td>
<td>5.800E-004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cor Total</td>
<td>0.11</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Model F-value of 2.66 implies the model is significant. There is only a 3.90% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A are significant model terms.

Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The "Lack of Fit F-value" of 4.67 implies there is a 7.54% chance that a "Lack of Fit F-value" this large could occur due to noise. Lack of fit is bad -- we want the model to fit.

### Summary Statistics

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Std. Dev.</td>
<td>0.046</td>
</tr>
<tr>
<td>Mean</td>
<td>5.35</td>
</tr>
<tr>
<td>C.V.</td>
<td>0.86</td>
</tr>
<tr>
<td>PRESS</td>
<td>0.16</td>
</tr>
</tbody>
</table>

A negative "Pred R-Squared" implies that the overall mean is a better predictor of your response than the current model.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 5.765 indicates an adequate signal. This model can be used to navigate the design space.
Annex 6

Response: **Powder yield**

ANOVA for Response Surface Quadratic Model

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>87.33</td>
<td>14</td>
<td>6.24</td>
<td>14.45</td>
<td>&lt; 0.0001 significant</td>
</tr>
<tr>
<td>A</td>
<td>43.51</td>
<td>1</td>
<td>43.51</td>
<td>100.78</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>B</td>
<td>13.61</td>
<td>1</td>
<td>13.61</td>
<td>31.53</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>C</td>
<td>11.43</td>
<td>1</td>
<td>11.43</td>
<td>26.47</td>
<td>0.0001</td>
</tr>
<tr>
<td>D</td>
<td>15.69</td>
<td>1</td>
<td>15.69</td>
<td>36.33</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>A²</td>
<td>0.051</td>
<td>1</td>
<td>0.051</td>
<td>0.12</td>
<td>0.7369</td>
</tr>
<tr>
<td>B²</td>
<td>0.48</td>
<td>1</td>
<td>0.48</td>
<td>1.11</td>
<td>0.3093</td>
</tr>
<tr>
<td>C²</td>
<td>0.26</td>
<td>1</td>
<td>0.26</td>
<td>0.60</td>
<td>0.4531</td>
</tr>
<tr>
<td>D²</td>
<td>0.38</td>
<td>1</td>
<td>0.38</td>
<td>0.88</td>
<td>0.3638</td>
</tr>
<tr>
<td>AB</td>
<td>0.54</td>
<td>1</td>
<td>0.54</td>
<td>1.25</td>
<td>0.2821</td>
</tr>
<tr>
<td>AC</td>
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<td>0.084</td>
<td>0.7767</td>
</tr>
<tr>
<td>AD</td>
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<td>1</td>
<td>0.000</td>
<td>0.000</td>
<td>1.0000</td>
</tr>
<tr>
<td>BC</td>
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<td>0.51</td>
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<tr>
<td>BD</td>
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<td>0.3322</td>
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<td>CD</td>
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<td>0.29</td>
<td>0.68</td>
<td>0.4249</td>
</tr>
<tr>
<td>Residual</td>
<td>6.04</td>
<td>14</td>
<td>0.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>5.03</td>
<td>10</td>
<td>0.50</td>
<td>1.99</td>
<td>0.2646   not significant</td>
</tr>
<tr>
<td>Pure Error</td>
<td>1.01</td>
<td>4</td>
<td>0.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Model F-value of 14.45 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant.
Values greater than 0.1000 indicate the model terms are not significant.
If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The "Lack of Fit F-value" of 1.99 implies the Lack of Fit is not significant relative to the pure error. There is a 26.46% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

| Std. Dev. | 0.66 | R-Squared | 0.9353 |
| Mean      | 13.78| Adj R-Squared | 0.8705 |
| C.V.      | 4.77 | Pred R-Squared | 0.6726 |
| PRESS     | 30.57| Adeq Precision | 13.952 |

The "Pred R-Squared" of 0.6726 is in reasonable agreement with the "Adj R-Squared" of 0.8705.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 13.952 indicates an adequate signal. This model can be used to navigate the design space.
Annex 7

Response: **Hygroscopicit**

**ANOVA for Response Surface Linear Model**

Analysis of variance table [Partial sum of squares]

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>46.41</td>
<td>4</td>
<td>11.60</td>
<td>3.54</td>
<td>0.0208</td>
</tr>
<tr>
<td>A</td>
<td>22.69</td>
<td>1</td>
<td>22.69</td>
<td>6.93</td>
<td>0.0146</td>
</tr>
<tr>
<td>B</td>
<td>7.74</td>
<td>1</td>
<td>7.74</td>
<td>2.36</td>
<td>0.1372</td>
</tr>
<tr>
<td>C</td>
<td>2.81</td>
<td>1</td>
<td>2.81</td>
<td>0.86</td>
<td>0.3633</td>
</tr>
<tr>
<td>D</td>
<td>13.17</td>
<td>1</td>
<td>13.17</td>
<td>4.02</td>
<td>0.0564</td>
</tr>
<tr>
<td>Residual</td>
<td>78.62</td>
<td>24</td>
<td>3.28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>69.06</td>
<td>20</td>
<td>3.45</td>
<td>1.45</td>
<td>0.3939</td>
</tr>
<tr>
<td>Pure Error</td>
<td>9.56</td>
<td>4</td>
<td>2.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cor Total</td>
<td>125.03</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Model F-value of 3.54 implies the model is significant. There is only a 2.08% chance that a "Model F-Value" this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant.
In this case A are significant model terms.
Values greater than 0.1000 indicate the model terms are not significant.
If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

The "Lack of Fit F-value" of 1.45 implies the Lack of Fit is not significant relative to the pure error. There is a 39.39% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

| Std. Dev. | R-Squared | 0.3712 |
| Mean      | Adj R-Squared | 0.2664 |
| C.V.      | Pred R-Squared | 0.0934 |
| PRESS     | Adeq Precision | 6.447  |

The "Pred R-Squared" of 0.0934 is in reasonable agreement with the "Adj R-Squared" of 0.2664.

"Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 6.447 indicates an adequate signal. This model can be used to navigate the design space.