NONI JUICE EXTRACTION: PROCESS EVALUATION AND DESIGN FOR EFFICIENCY

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DECLARATION

I declare that this work was conducted by me under supervision in the Department of Food Process Engineering, University of Ghana.

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ABSTRACT

A study examined factors affecting the time of drip extraction of noni (*Morinda citrifolia*) juice. The factors studied were the presence of noni fruit peels, temperature of extraction, extraction time, water addition during extraction and the quantity of fruits used for extraction. *Morinda citrifolia* juice was dripped extracted from the noni fruit to determine the influence of temperature, time and mass of fruit on the drip extraction process separately before combining these factors to design a CCRD experiment. The effect of each factor was assessed with a factorial experiment followed with analysis of variance.

Temperature and mass of fruit extracted were found to affect the time of drip extraction and the quality of juice produced in terms of yield and physio-chemical characteristics of the juice of which pH and total soluble solids were considered. Using the CCRD, different combinations of fruit mass (0.5, 0.8, 1.25, 1.7 and 2 kg), temperature of extraction (30, 36.08, 45, 53.92 and 60^{o}C) and extraction time (3, 6.65, 12, 17.35 and 21days) were used to drip juice from the noni fruit. Total soluble solids content, pH and juice recovered in terms of yield were measured after each extraction.

CCRD results showed that the responses of pH, total soluble solids and yield were in good agreement with the theoretically predicted values of the model. Total soluble solids content and pH were significantly affected by temperature of extraction and the extraction duration (time) whiles noni juice yield was significantly affected by the mass of fruit drip extracted.

DEDICATION

This research work is dedicated to the Almighty God for his grace and sufficiency.

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CHAPTER ONE

1.0 INTRODUCTION

Noni juice is obtained from the fruit of the noni plant. *Morinda citrifolia* is believed to have originated from Polynesia but has gained worldwide recognition since it was introduced in Hawai, Tahiti, Asia, Australia, Northern America and some parts of Africa such as Ghana. The noni plant is classified under Order Rubiales and Family *Rubiaceae*. Every part of the noni plant has been used in folk medicine and is believed to be potent in fighting several diseases. Despite the potency of the whole plant in fighting diseases, the most consumed or utilized part of the plant is the fruit which is the raw material for producing noni juice. In recent times the popularity of noni juice has increased due to the health and nutraceutical benefits derived from its consumption (Singh, 2012), (Palu *et al.*, 2012).

The colour of unpasteurized noni juice ranges between golden amber to very dark brown (Nelson and Elevitch, 2006) and is indicative of the method used in extracting the juice (Nelson, 2003). There are two major processes by which the juice is extracted from the noni fruit. The first is the drip method, where the fruit is left in a container for months to allow its water content to drip out due to disintegration of the fruit. The second method is achieved by pressing the mature fruit (Nelson 2013, Macpherson *et al.*, 2007). Even though the consumption and the popularity of *M. citrifolia* as a dietary supplement, a food functional ingredient, or as a natural health enhancer is increasing throughout the world (Assi *et al.*,2015), little information is available on the production of noni juice.

According to Singh (2012), noni has been reported for its antibacterial, antiviral, antifungal, antitumor, antihelminthic, analgesic, hypotensive, anti-inflammatory and immune enhancing effects. This has made products from noni fruits very popular especially the juice. The popularity has led to the incorporation of noni extracts in functional foods (Dixon *et al.*, 1999). Noni juice contains xeronine, a compound identified to have the potential to relief people of drug addiction, menstrual cramps, atherosclerosis, high blood pressure and mental depression (Heinicke, 2005). In view of these benefits, the consumption of noni products is continuously increasing, it was accepted in the European Union as a novel food in 2002 (Chan-Blanco *et al.*, 2006). There is an emerging noni industry that produces noni based products such as the juice, noni tea, and noni powder among others. In 2007 the noni industry in USA was making 1.3 billion in annual sales (Potterat and Hamburger, 2007).

Different pre-treatments may be given to the fruit prior to the extraction. In some processes the fruit is frozen upon harvest to damage the cell structure of the fruit. This is then thawed before pressing or allowing the juice to drip out. According to Thirukkmur *et al.* (2017), the fruit can be blanched at 100^{o}C for 2 to 10 minutes after which it is cooled to room temperature prior to pressing. These pre-treatments improve the extraction process by 6% v/m for press extraction and 18% v/m for leach or drip extraction (Sakulas *et al.*, 2010). Another method employed in the extraction of noni juice is the enzyme extraction method. This method requires the use of enzymes such as cellulase, hemicellulase and pectolytic enzymes to breakdown the cellular barriers of the fruit to release the juice (Nivas and Gaikwad, 2016). The pre-treatment and the method of juice extraction impacts the quality of juice produced. The traditional method of juice extraction does not require pre-treatment, but the fruit is allowed to soften after harvest before the fruit is placed in containers for its juice to exude. Fruit press is used in some processes after the fruit softens, this is the basic pressing method. Dripping and pressing noni fruits upon softening are the most applied methods of extracting noni juice, even though drip extraction takes a long time. Pre-treatments are employed to improve the extraction efficiency, but these pre-treatments also affect the quality of the juice obtained.

1.1 Noni Juice

There are several reports on the composition of the noni juice as well as the health benefits derived from the consumption of the juice. Example of such report is the antitumor activity of fermented noni exudates and its fractions reported by Li *et al*. (2012). They reported that noni juice activated the immune system in mice to resist tumour cells. Others have reported on the potency of noni juice in fighting various diseases due to the presence of some compounds including octanoic acid which has antifungal properties, hexanoic acid and vitamin C which are antioxidants, asperulosidic acid which is an antibacterial and damnacanthal which is anti- cancer among others (Assi *et al.*, 2015).

The presence of these compounds has resulting in the derivation of several health benefits from the consumption of noni juice. Some of these benefits include

1. Prevents cancer (Wang *et al.*, 2001)
2. Relieves symptoms of gout (Palu *et al.*, 2009)
3. Reduces Muscle spasms (Gilani *et al.*, 2010)
4. Protects heart health (Wang *et al.*, 2012)
5. Relieves fatigue (Ma *et al.*, 2007)
6. Protects liver (Wang *et al.*, 2008)
7. Anti-psychotic qualities (Vijayapandi *et al.*, 2012)
8. Relieves arthritis pain (Basar *et al.*, 2010)
9. Helps improve memory function (Pachauri *et al.*, 2012)
10. Controls diabetes (Owen *et al.*, 2008)

11. Skin care (Kim *et al.*, 2005)

12. Treats Gastric problems (Pu *et al.*, 2004)

13. Speeds up healing (Nayak *et al.*, 2007)

Despite the numerous health benefits derived from the consumption of noni juice, little work has been done in the area of juice production in Ghana.

In Ghana noni juice has been accepted as a health enhancer even though some do not know anything about the noni fruit. Noni juice is produced primarily by dripping or pressing, the production is done mostly by individuals at home and by small scale industrial setups. The extraction carried out in the home uses the drip extraction method whereby the fruits are kept in a container to allow fruit fluids to exude over time. In instances where the juice is needed urgently, the soft fruits are blended and sieved to obtain the juice. Drip extracted noni juice produced in homes are normally not pasteurised before drinking, this is partly because the juice is consumed whiles dripping. This can be attributed to the slow exudation of the juice forcing the producer to consume some of the exudate when needed, whiles the extraction is still on going. The blended and sieved noni juice is not pasteurised either in the home, exposing the consumer to potential health risks. After extraction the juice is kept in the fridge for future consumption.

In Ghana, the industrial production of noni juice and noni extracts are carried out on a small scale. The juice is produced by both drip method and press method, but the drip method is the dominant method employed. The juice produced whether pressed or dripped are pasteurised by most producers before or after bottling. The material of the bottle plays a role in determining the method of pasteurising the juice. The main noni juice and noni extracts producing brands on the Ghanaian market are Nature's own noni and Royal noni. Noni extracts are also transformed into products such as noni tea bags and noni extract powder for the Ghanaian and international market. The noni extract industry in Ghana is artisanal despite the growing demand for noni products in the country. The industry uses little technology and methods to improve quality, safety and efficiency are needed.

1.2 Objectives

The traditional drip extraction of noni juice is characterised with several challenges such as safety of the juice produced, and time taken to complete one extraction. As now it stands the drip extraction process is not controlled, exposing the resulting juice to possible contamination. The extraction process takes two months and is expensive to operate partly due to uncontrolled temperatures during the extraction process. There is the need for a drip extraction system which will improve yield, safety and juice quality. Introducing control in the main factors that affect the drip extraction of noni juice such as extraction temperature will improve juice safety, quality, extraction efficiency and extraction time.

The main objective of this study was to investigate noni juice extraction, the critical parameters which define extraction efficiency and to design a bioreactor to improve juice yield and quality.

1.3 Specific Objectives

The specific objectives were:

1. Investigate the softening profile of noni fruit after harvesting
2. Monitor temperature for drip extraction indoor and outdoor
3. Design, build and validate a bioreactor with temperature control capabilities
4. Investigate the effect of temperature and time on drip extraction
5. Investigate the effect of the presence of peels on drip extraction

6. Investigate effect of water addition during drip extraction on pH, yield and total soluble solids.
7. Use Central Composite Rotatable Design (CCRD) for $k = 3$ to optimize mass, temperature and time for drip extraction
8. Develop extraction method to improve yield, pH and total soluble solids as well as shorten extraction time

CHAPTER TWO

2.0 Literature review

2.1 Noni fruit

The noni plant grows in open coastal regions at sea level and in forest areas up to about 1300 feet above sea level, it reaches maturity after about eighteen (18) months of propagation. Noni is propagated either from the seed or the stem (Nelson, 2003). The noni fruit has an elliptical shape with the seeds distributed in a fibrous, clinging flesh. The clingy flesh is removed from the seed prior to propagation with seeds, the seeds are reddish-brown, oblong-triangular with conspicuous air chamber. The air chamber makes the seed buoyant and hydrophobic; the seed is durable and water repellent due to the presence of a relatively thick and tough seed coat (Nelson, 2003)

Noni fruits can be picked at any stage of development depending on the intended use. Noni fruit takes about two to three weeks to mature and the mature fruit can grow to about 20cm in length (Chunheing *et al.*, 2005). The mature fruit then transits through four stages before the onset of senescence, the stages are the dark green stage, green-yellow stage, pale-yellow stage and the translucent-grayish stage respectively as shown below.

Illustration 1: Noni fruit ripening stages

In each of these stages the firmness of the fruit varies, in the dark green stage and green- yellow stage the fruit is very hard and becomes fairly hard in the pale-yellow stage and subsequently becomes soft in the translucent-grayish stage (Lujan *et al.*, 2014). The fruit is required to be in the translucent-grayish stage prior to processing. Using fruit at any other maturity stage negatively impacts the quality of the resultant juice. Pressing or dripping juice from noni fruit in the dark green stage and the yellow green stage results in darken juice. The availability of water in the fruit in dependent on the maturity of the fruit, the juice extraction efficiency reduces when fruits used are not in the translucent grayish stage.

2.2 **Noni juice processing**

Noni juice is extracted by two main methods, drip extraction also known as leach extraction or fermentation and press extraction. In recent times more sophisticated extraction methods have been used, such methods include pulping and enzyme application (Brat *et al.*, 2010) and beating and filtration (Guangxuan *et al.*, 2014). Beating and filtration is a quiet simple method of noni juice extraction which is done in homes to extract noni juice on a small scale.

Some modification has been made to the traditional drip and press extraction methods in attempt to improve extraction efficiency and the quality and stability of the resulting juice. One of this modification is pre-treating the noni fruit prior to noni juice extraction whether the fruit will be drip extracted on pressed to expel the juice, this improves the final product derived from the fruit (Deng *et al.*, 2019). Another modification is the combination of press extraction and drip extraction. The modification involves pressing to extract the juice after which a microorganism is inoculated to ferment the juice (Thirukkumar *et al.*, 2017).

2.2.1 Pre-treatment

There are basically two types of pre-treatment, blanching and freezing. The blanching pre-treatment of the noni fruit involves addition of heat to the fruit whilst the freezing pre-treatment involves the removal of heat from the fruit. According to Thirukkumar *et al.* (2017), pre-treating the fruit by blanching at 100^{o}C for 2 to 10 minutes improves the juice yield and significantly affects the pH, acidity, and total soluble solids. Blanching damages the cell wall and cell membrane thereby increasing the permeability of the noni fruits cell wall and cell membrane which in turn facilitates movement of molecules out of the fruit.

Freezing the fruit for some time and thawing prior to juice extraction improve the juice yield and significantly affects the pH and total soluble solids. Freezing the fruits result in the formation of ice crystals in the fruit which damages the cell wall and the cell membrane, which in turn improves the permeability of the cell wall and cell membrane. When fruits are frozen, their texture and consistency are mainly softened but their nutrient content, antioxidants, and phytochemicals remain unaltered. Prolong freezing and freshness of fruit chosen to be frozen could affect colour, nutritive value and flavor (Silva *et al.*, 2008). In some food freezing applications, the fruits are kept in a syrup and frozen in the syrup. The application of syrup in fruit freezing reduces the degree of texture and consistency deviation. The juice of the pre-treated fruit may be pressed or dripped out, other methods such us pulping and enzyme addition may also be employed.

2.2.2 Press extraction

Noni juice is extracted by pressing the mature ripe fruit whether pre-treated or not, the pressing method takes less time than the drip extraction. Pressing the juice directly from ripe fruits yields a lighter colored juice that is higher in sugars and lower in acidity as compared with drip-extracted juice (Nelson and Elevitch, 2006). Pressed juice does not undergo natural aging or fermentation, but the juice can be aged after pressing or even fermented with the introduction of *Saccharomyces cerevisiae* (Hafiza *et al.*, 2013).

The noni fruit are harvested upon maturity and allowed to soften after which they are pressed to extract the juice. The juice obtained by pressing has a much brighter color. The juice recovery for pressing is higher than 50% of the fruit weight. It is costly to run the press for production of noni juice commercially and the juice produced after pressing has pronounced fruity flavor. For simple fruit presses, the quantity of fruit fed into the press affects the efficiency of the press.

The juice recovered from pressing is affected by the efficiency of the press and the softness of the fruit which depends on maturity of the fruit and aging of the fruit. When aged fruit is pressed, the juice recovery is more than the juice recovered from fresh fruit (Newton, 2003). The fruit juice may be treated to arrest fermentation immediately after pressing by pasteurization. When aging pressed juice, the colour and pH of the resulting juice depends on the quantity of solid particles in the juice (total solid present). The total solid content in the juice can be increased by using a press with a bigger sieve opening, this will permit more solids to be extracted with the juice.

Total solids in the juice obtained by pressing is mostly particles from the fruit pulp. These pulp particles decompose into the juice during the aging period of the juice thereby impacting on the colour and pH of the juice. The degree of decomposition of the pulp particles is dependent on the duration of the ageing, this makes it possible to obtain noni juice from pressing that is comparable to that obtained from drip extraction. The flowchart for press extraction of noni juice is shown below.

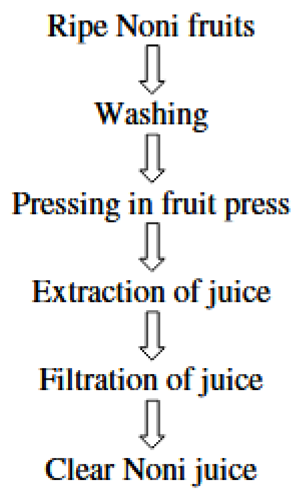

Illustration 2: Press extraction flowchart

2.2.3 Pulping and enzyme addition

Noni juice can be extracted from noni fruit by pulping the noni fruit. The seeds and pulp are separated during pulping and enzymes are added to the pulp to breakdown the juice sacs to release the juice, the juice enzyme mixture is then filtered to obtain the juice. Enzyme application improves the juice extraction as compared to juice extraction from the untreated fresh fruit due to the sliminess of the noni fruit pulp (Nivas and Gaikwad, 2016). There are various types of enzymes used for the pulp extraction, some of these enzymes are pectinase, cellulase and diastase. Enzymes are also employed to clarify the noni juice; therefore, a composite of different enzymes are used to treat the noni pulp extract to achieve the required noni juice with appropriate physicochemical properties. According to Nivas and Gaikwad (2016), enzymatic treatments of pectinase and diastase shows significant effect on juice parameters such as pH, total acidity and soluble solids. Enzymatic clarification of noni juice reduces total phenols and flavonoid content in the juice which reduces the astringency of the resulting juice.

2.2.4 Beating and filtration

This method of juice extraction is commonly employed in small scale noni juice extraction and it is normally carried out in the home with aid of a blender and a sieve. It requires the fruits to be beaten with a blade after which the juice is filtered out (Brat *et al.*, 2010). The beating of the fruits or blending of the fruit breaks down the wall of the fruit to produce a mixture of fruit juice, fiber and seeds. The resulting mash from the blend or the beating process is filtered through a sieve thereby separating the juice from the fruit fiber and seeds. This method of juice extraction is like that of pressing the fruits in the sense that both methods produces instant noni juice from the mature noni fruit. It is important to note that the quantity and quality of juice obtained from this process depends on the maturity (ripeness) of the noni fruit. The juice recovery for beating and juice method of extraction is relative lower than the juice recovery for the press extraction method, this is because the fiber retains more of the juice when a sieve is used and no force is applied to squeeze out the juice, secondly a filter cloth may be used to press out the juice from the mash but this also result in lower yield as the fiber sticks to the filter cloth and resists the permeation of juice through the filter cloth.

2.2.5 Drip extraction

The drip extraction process produces juice that is very dark in colour and has pH between 3.1 and 3.5, making the juice sour to taste. This method of extraction requires the fruits to sit in an aseptic container for 8 weeks, during this time the fruit ferments and releases the juice. The juice recovery by this method is between 40% to 50% of the fruit weight (Nelson and Elevitch, 2006) even though the fruit contains 90% water (Lujan *et al.*, 2014). The juice obtained from this process is dark and sour but lacks the fruity flavor (Nelson, 2003). During the drip extraction process the juice is susceptible to contamination from the surrounding air as well as unhygienic conditions. The juice after the 8 weeks taste slightly bitter and sour due to the fermentation and subsequent depletion of sugar in the fruit. The dark colour of the juice obtained coupled with the low pH of the juice makes it difficult to detect spoilage (cloudiness). Contamination causes the juice to develop foul odor and a relatively high pH in addition to the cloudiness. The foul odour that characterizes spoilage in drip extracted noni juice is difficult to detect due to characteristic pungent smell of the noni fruit.

In some cases, the drip method and the press method are applied together (Newton, 2003), in such cases the juice is first extracted by drip method followed by pressing. This method yields a higher juice recovery but is expensive to carry out.

It has been stated by Newton (2003) that the juice recovery is much higher in pulp pressing than in whole fruits pressing, furthermore juice recovery also increases with increase in ageing or fermentation duration. This implies that the most efficient juice extraction method is the method that presses pulp that has adequately been aged. The ageing process affects the colour of the resultant juice extracted, in the first seven days the juice colour is reddish golden amber and it darkens as the number of days aged advances (Newton, 2003).

The quality of juice produced from these methods vary depending on the processor, some processors pour water on the fruit before starting the drip extraction method. In effect the method of extraction does not yield a standardized juice thereby making room for adulterations (Ram, 2002).

Drip extraction flowchart

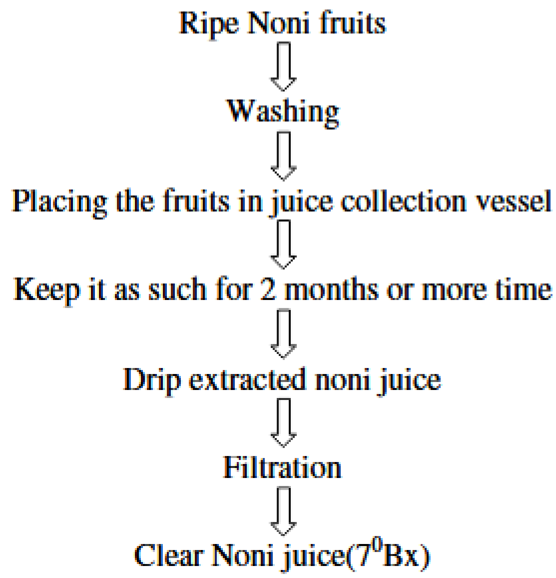

Illustration 3: Flowchart for drip extraction

2.2.6 Drip extraction kinetics

The drip extraction or leach extraction method is the most popular and most practiced method of juicing. The leach or drip extraction process allows the juice to drain out of the fruit as the fruit moves from its matured stage to senescence. The drip process is affected by a number of factors, some of these factors include the maturity of the fruit, temperature, quality of fruit (based on whether fruit is bruised, cut or not) (Wayne, 1989) and the surface area of the fruit. According to Saltvett (1998), ethylene is a naturally occurring plant growth substance that has numerous effects on the growth, development and storage life of many fruits, vegetables, and ornamental crops. Ethylene facilitates or speeds up the senescence stage of fruits, its concentration in a fruit's atmosphere depends on the maturity of the fruit and the quality of the fruit. Cut or bruised fruits produce more ethylene and hence they deteriorate faster. Ripe fruits also produce more ethylene than unripe fruits (Wayne, 1989) thus ethylene is a by-product of ripening fruits and senescing fruits. Presence of ethylene in a fruits atmosphere increases the fruits ripening rate and senescing rate by increasing respiration rate thereby providing respiration heat. Using matured fruits which are ripe in drip extraction will shorten the extraction duration compared to using unripe mature fruits.

The noni fruit is highly perishable, as a result there is onset of fermentation when the fruit softens on maturity. The fermentation temperature is not controlled during the extraction and this is a possible contributing factor for the long duration of drip extraction. Other parameters that affect the duration of extraction are sunlight, humidity in the extraction atmosphere, water vapour pressure deficit, respiration rate which depends on the gases available in the extraction atmosphere and the transpiration rate which depends on the surface area of the fruit and the nature of the fruit outer membrane (Caleb *et al.*, 2013). According to Newton (2003) the juice recovery when the fruit pulp is used in a drip extraction, yields are higher than the juice recovered when the whole fruit is used. Using the fruit pulp increases the cost of juice extraction due to the cost involved in mashing the fruit.

Some work has been done to produced fermented noni juice by alternative methods rather than the traditional drip extraction. The method employs microorganisms to ferment pressed or squeezed noni juice, some of the microorganism used are yeast and lactic acid bacteria. There are some benefits which one derive from the consumption of fermented noni juice which cannot be derived from unfermented noni juice, according to Li *et al.* (2012), fermented noni juice is reported to have anti-tumor characteristics. Fermented noni juice is more popular than the unfermented juice due to the benefits derived from fermentation coupled with nutraceutical and health benefits derived from the noni juice.

Fermented foods in general provide some benefits to its consumers which cannot be derived from unfermented foods, such benefits are backed by the growth of beneficial microorganisms and the synthesizes of vitamins and minerals, production of biologically active peptides with enzymes such as proteinase and peptidase as well as the removal of some non-nutrients (Sanlier *et al.*, 2017). Some of the health benefits derived from fermented foods include the following:

1. Improvement immunity (King *et al.*, 2014, de verse *et al.*, 2006 and Wintergerst *et al.*, 2007)
2. Improvement gastrointestinal health (Ritchie and Romanuk, 2012 and Dimidi *et al.*, 2014)
3. Improvement heart health (Khalesi *et al.*, 2014)
4. Improvement mental health (wang *et al.*, 2016 and Messaoudi *et al.*, 2011)
5. Weight management (Kadooka *et al.*, 2013 and Sanchez *et al.*, 2014)

Fermentation improves digestion of food and the subsequent nutrient absorption into the blood. fermented foods provide many health benefits such as antioxidant, anti-microbial, anti-fungal, anti-inflammatory, anti-diabetic and anti-atherosclerotic activity due to the presence of biologically active peptides, which are produced by the bacteria responsible for fermentation (Sanlier *et al.*, 2017).

Fermented noni juice presents the body with the benefits derived from fermentation as well as the benefits from the noni. This makes fermented noni juice very beneficial to consume over the consumption of unfermented noni juice. Even though unfermented noni juice possesses the potent health benefits and the nutraceutical benefits of attributed to noni juice.

Production of fermented noni juice via the drip method takes months (two months) as compared to the press extraction, pulping and enzyme application and beating and filtering which are almost instant. The long duration of the noni juice fermentation has incited the intervention of methods to shorten the extraction period whiles producing juice of comparable quality to the traditional drip extraction.

Pressing and fermenting the juice with *Saccharomyces cerevisiae* has been reported by Hafiza *et al*. (2013). The fermentation of noni juice is made possible due to the available glucose, fructose and sucrose in the noni extract which the yeast organism feeds on. This method produces noni juice that is comparable to the traditional drip extracted noni juice in terms of physio-chemical properties such as pH, total soluble solids and titratable acidity. This method produces fermented noni juice within a matter of hours unlike the traditional fermentation method which lasts for a about two months. Other researchers have also pressed and fermented noni juice with different culture strains such as lactic acid bacterial as reported by Ying *et al.* (2007).

The traditional drip extraction of noni juice is carried out under uncontrolled temperature, thereby subjecting the extraction to the influence of atmospheric temperature. The fermentation or senescence process depends on temperature therefore keeping control of temperature will significantly improve the extraction time.

1.3 Bioreactor

Bioreactors are devices that supports a biologically active environment by providing an aseptic controlled environment to ensure the quality and purity of product. The bioreactor can be considered as a device that supports a biological system to obtain desirable results, the biological system comprises of microorganisms, enzymes, plant cells, animal cells and biocatalyst. The drip extraction of noni juice is a biological process that involves the senesces of the noni fruit coupled with the action of microorganism to break down the noni fruit. The senesces process is characterised by enzymes such amylase, pectinase, cellulase, lipase, protease and nucleases. The activities of this enzymes can be supported with a bioreactor. The microorganisms that act on the fruit to break it down can also be supported with a bioreactor. The bioreactor supports biological systems by controlling physiological conditions such as temperature, pH, nutrient and oxygen levels in the biological system (Kluge *et al.*, 2008) to give right environment for optimal growth and metabolic activity of the organism or optimum action of biological substances.

Bioreactors are classified as batch, fed batch or continuous depending on feed into the bioreactor (Mcneil and Harvey, 2008). Batch stirred tank reactors and continuously stirred tank reactors are very known and widely used due to their simplicity (Mcneil and Harvey, 2008). There are other types of bioreactors based on their design and operation for specific processes, these bioreactors are membrane bioreactor, photo-bioreactor, fluidized bed bioreactor, bubble column bioreactor and air lift bioreactors. Bioreactors are used mainly in the food and pharmaceutical industry. In the food industry bioreactors are employed in the production of food such as yoghurt, beer and wine among others. The successful operation of a bioreactor depends on appropriate heat transfer and mass transfer.

2.3.1 Types of Bioreactors

There are basically 6 (six) types of bioreactors based on design and principle of operation, these bioreactors are stirred tank bioreactors, membrane bioreactor, packed bed bioreactor, fluidized bed bioreactor, bubble column bioreactor and air lift bioreactors.

Stirred tank bioreactors are mostly used compared to other types of bioreactors due to their simplicity and flexibility (Christi *et al.*, 2010). This type of bioreactor has a fitted impeller which is connected to a motor that drives the shaft, the impeller may be powered from bottom or top based on the location of the motor. The stirred tank bioreactors can achieve uniform mixing due to the presences of the impeller (Martin *et al.*, 2008), the impeller design is dependent on the intended use.

Membrane bioreactors are employed in the immobilization of enzymes and microorganisms, they consist of a hollow fibre system which are prepared from either polysulfone fibres or cellulase acetate or acrylic copolymer which has it walls irregularly configurated (Raj and Karanth, 2006). Airlift bioreactors has air supply at the bottom receptacle which arises through a column to the medium and mixes the medium to make up for the absence of an agitator. Oxygen circulation is improved by a separation by means of baffles (Veera and Joshi 2001).

Packed bed bioreactors are also known as fixed bed bioreactors. The bed is mostly made of ceramic, natural materials, glass and polymer of varying sizes and shapes (Gaikwad *et al.*, 2018). The packed bed bioreactor is an example of a plug flow reactor, and it is commonly used in wastewater treatment.

Fluidized bed bioreactor is another type of reactor which is developed for three phase biological systems in which has cells as biocatalyst (Gaikwad *et al.*, 2018). The fluidized bed bioreactor is operated in continuous state with temperature gradient and uniform particle mixing. The fluidized bed reactor is like bubble column reactor, but it has expanded top cross-sectional area which recirculate the liquid at a velocity that is satisfactory to maintain the suspension (Chistietal.2010). The bubble column reactor which generally has a gas provider at its bottom which sparges gas into a liquid-solid suspension (Borakb and Kutlu, 2005). According to Degaleesan *et al.* (2001), the bubble column reactor is widely used in the petrochemical, chemical, metallurgical and biochemical industry.

2.3.2 Bioreactor features

There are some basic features which makes the bioreactor fit for purpose, some of these features include Temperature control, pH control, Agitation, Gas control, Headspace volume and Sample point. Temperature control is used obtain and maintain the temperature require in the bioreactor.

Some reactions or processes are pH specific hence the pH control is used to obtain and maintain the required pH for the process. In processes where oxygen is required, aeration system or gas control is incorporated to ensure the level of oxygen is in check. The above stated features are made up of several components, according to Kaushik *et al.* (2014) and Jagani *et al.* (2010) some of these components are

1. Impellors which are used for stirring to maintain a uniform mixture and distribute oxygen
2. Baffles which used to prevent vortex formation in the bioreactor
3. Temperature probe which is used to monitor temperature in the bioreactor
4. Level sensor which is used to monitor level in the bioreactor
5. Sparger which is used to introduce oxygen (gas) into the bioreactor
6. Heating or cooling jacket which is used to control the temperature of the bioreactor
7. pH sensor to monitor the pH in the bioreactor
8. pressure gauge which is used for monitoring pressure in the bioreactor
9. Air filters which are used to filter air supplied and air exhaust from the bioreactor

The presence or absence of some of these components on a bioreactor is dependent on the intended use of the bioreactor.

2.3.3 Heat transfer

Heat transfer in a bioreactor is achieved by means of heating coils and/or jacket. The jacket is connected to a heat source or to a chill water source. The jacket is built around the entire surface of the bioreactor to allow a heating or cooling medium to circulate around the bioreactor surface and allow heat to be exchanged between the walls of the bioreactor, the water circulating in the jacket and the occupant of the bioreactor (Brain and man, 1989).

CHAPTER THREE

3.0 MATERIALS AND METHODS

Noni fruits were obtained from back yard gardens in Madina a suburb in Accra, from Ogbojo another suburb of Accra and from a noni farm at Akuse in the Eastern Region of Ghana. The fruits were harvested in the green yellow and the pale-yellow stages, transported immediately to the Food Process Engineering laboratory at the University of Ghana, Legon. They were washed under running tap water and were kept on a drip tray to dry.

3.1 Texture analysis (softening profile) of noni fruits after harvest

The texture of the noni fruit was monitored to study softening profile and to uncover how long it takes for the harvested fruits to reach the grey translucent stage required for processing. The cleaned fruits were sorted based on their ripeness, the fruits that were already in the grey-translucent stage as well as fruits outside the pale-yellow stage were set aside for the experiment. Six samples comprising five fruits each were obtained and kept enclosed in polyethene bags throughout the texture test period.

One sample was immediately subjected to texture analysis using CT3 texture analyzer (Model: CT-1000 with TA-BT-KIT fixture base table from Brookfield AMETEK, 11 commerce Blvd, Middleborough, MA 02346, United States) to mark time zero (0) but this time was equivalent to one hour after harvest. The remaining samples were kept in the laboratory for 24, 32, 46 and 54 hours respectively before subjecting the samples to texture analysis. The test parameters used in the texture analysis was trigger of 2g which is based on the minimum trigger required for 1000g internal load texture analyzer. The deformation setpoint was 20mm and the probe speed was set at 10mm/s, the TA17 cone with diameter of 24mm and angle of 30^o was used.

Each fruit was divided into three sections labelled a, b and c. see illustration 4 below. The fruits were set under the CT3 texture analyzer after the parameters were set on the CT3 texture analyzer and the test was run. For each fruit the test was run three times to measure the texture at three points on the fruit, the test was repeated for all the samples that were due for analysis.

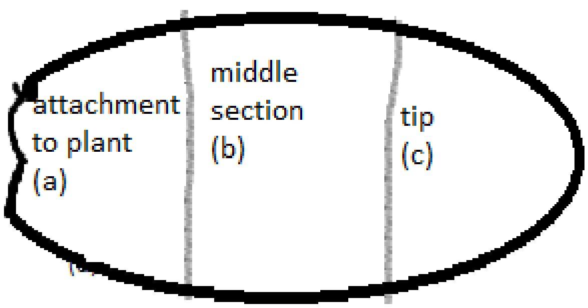

Illustration 4:Division of fruit for texture analysis

3.2 Temperature monitoring for drip extraction indoor and outdoor

The fruits were washed under running tap water and dried on a drip tray. After drying, the fruits were kept in polythene bag for three days to soften. Two 3L glass bottles with lid were washed, rinsed thoroughly and dried. The weight of the empty glass bottles was determined after which 0.62kg soft noni fruits were weighed into each glass bottles and the weight of the glass bottle and the fruits was determined.

Each glass bottle containing the fruits was fitted with a SUPCO LT300TH temperature humidity data logger and sealed. One setup was kept in the laboratory and the other was kept outside under the direct influence of the weather. The extraction set-up was left to stay at the designated location for five days. The exuded juice was collected and weighed. The pH of the exuded juice was measured using a pH meter (Oakton pH/ conductivity/ TDS meter, model: WD-35610-10.

Manufactured by Eutech Instruments Pte Ltd 7 Gul Circle, level 2M, Keppel Logistic Building, Singapore 629563). The total soluble solid (T.S.S) of the juice in terms of ^{o}Brix was measured with an abbe 60/DR refractometer (model no. A 10005 from Bellingham and Stanley Ltd, Longfield Rd, Royal Tunbridge Wells, Tunbridge Wells TN2 3EY, United Kingdom) at 28^{o}C.

Prior to the extraction set up the SUPCO LT300TH data logger was set up on a computer and validated using a liquid in glass thermometer.

3.2.1 pH and Total soluble solid

For each juice obtained throughout this thesis, the underlisted procedure was followed to analyse pH and total soluble solids.

1. For pH measurement, the pH meter was calibrated with buffer 4.01 and buffer 7.0 at 25^{o}C. The sample was tempered to 25^{o}C and pH was measured using pH meter (Oakton pH/ conductivity/ TDS meter, model: WD-35610-10. Manufactured by Eutech Instruments Pte Ltd 7 Gul Circle, level 2M, Keppel Logistic Building, Singapore 629563) by inserting the probe of the pH meter into the sample. At 25^{o}C, the pH reading on the pH meter was allowed to stabilize before the value was recorded.
2. For Total soluble solid measurement, abbe 60/DR refractometer (model no. A 10005 from Bellingham and Stanley Ltd, Longfield Rd, Royal Tunbridge Wells, Tunbridge Wells TN2 3EY, United Kingdom) was used. Prior to total soluble solid measurement in the juice, the refractometer was used to measure the total soluble solid content of distilled water to validate the accuracy of the refractometer. The total soluble solid measurement was done at room temperature rather than the 20^{o}C stated in the equipment manual. To measure the total soluble solid, the refractometer prisms are cleaned with soft tissue after which the refractometer was switched on and samples dropped at the center of the measurement

prism. The upper prism was lowered and locked onto the measurement prism with the toggle clamp, excess sample is wiped with a soft tissue. The light source is incident on the prism to illuminate the bottom of the upper prism, whiles looking into the field telescope rotate the control knob to adjust the borderline to align with the center of the cross hairs. The total soluble solids value is then read in the scale view via the scale view telescope.

The temperature of sample and refractometer prism is measured by the thermometer on the refractometer. This temperature varied between 28^{o}C and 30^{o}C; however, the refractometer manual provides a correction factor for calculation and correction of total soluble solids values measured at any temperature other than 20^{o}C. The correction factor is dependent on the measured total soluble solids value at any temperature except 20^{o}C. To correct total soluble solids values measured at any temperature except 20^{o}C, the difference between temperature at which measurement was done and 20^{o}C is multiplied by a correction factor and the results is added to the measured total soluble solids value. Thus

T.S.S value = measured T.S.S value + (measurement temp. – 20^{o}C) × correction factor.

For measured total soluble solids (T.S.S) value between 0 and 20, the correction factor is 0.005.

3.3 Equipment design

In attempt to drip extract noni juice at controlled temperature and ensure consistent noni juice is produced, a bioreactor was designed. The bioreactor was designed for laboratory scale extraction, it has 0.0015m^3 juice compartment and 0.0103m^3 fruit holding compartment which yields an internal volume of 0.0118m^3. The bioreactor has 0.0187m^3 of jacket space for heating water and the entire contraption has a volume of 0.031m^3.

The bioreactor was not design with an agitator since the drip extraction process does not require mixing in its operation. The bioreactor has a lid that closes it tightly and makes the bioreactor airtight, however, a pressure release valve is fixed to the lid to prevent over pressurization of the equipment by gases produced during drip extraction. Provision is made on the lid to fix a pressure gauge and thermometer. The juice chamber and the fruit chamber are separated by 355micron sieve. The bioreactor design is shown below

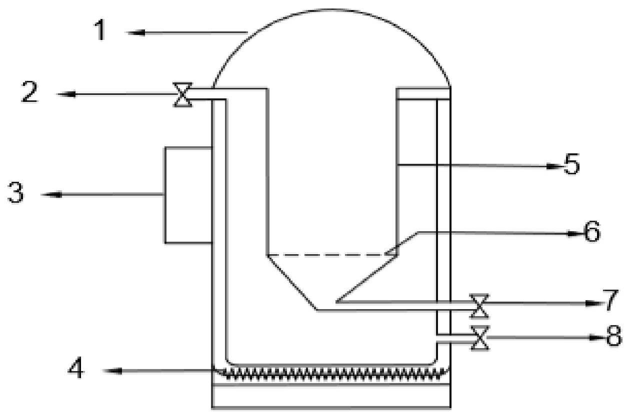

Figure 1: Sectional Diagram Bioreactor

PART	DESCRIPTION	MATERIAL	NUMBER
1	Lid	Stainless steel	1
2	Heating medium inlet	Stainless steel	1
3	Control box	Aluminium	1
4	Heating coil	Nichrome	1
5	Interial cylinder	Stainless steel	1
6	metal sieve	Stainless steel	1
7	Heating medium outlet	Stainless steel	1
8	Product Outlet	Stainless steel	1

Figure 2: Parts of the bioreactor

The bioreactor was designed with an electric heating element at the base to provide the heat required to raise the heating medium temperature and subsequently the extracting chamber temperature. Power supply to the heating coil was controlled by a proportional–integral–derivative (PID) temperature controller based on the temperature of the bioreactor and a setpoint temperature, this formed a temperature control system which made it possible to hold a temperature in the bioreactor over a long period of time.

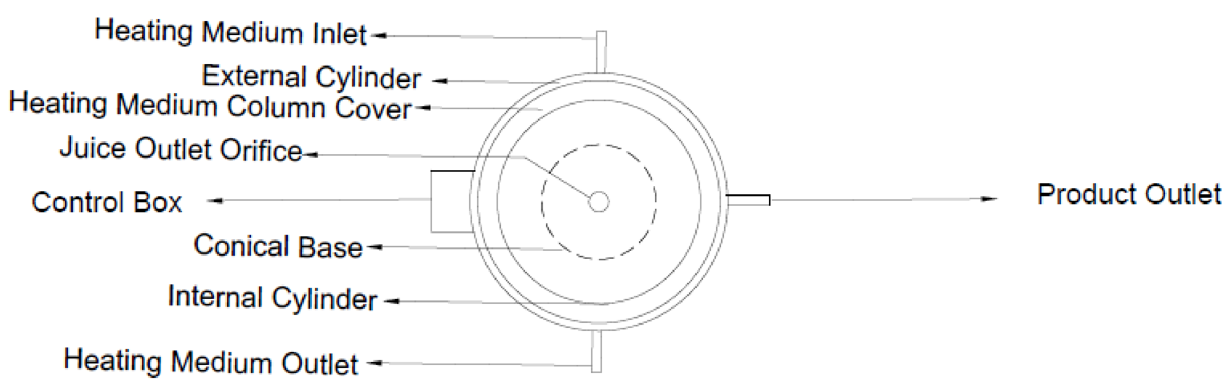

Figure 3: Cross-sectional (top) view of bioreactor

The fruit chamber and the juice chamber were separated with removable metal sieve of mesh size of 355 micron (45ASTM) which prevented the fruit and its exudate from being in contact during the extraction process.

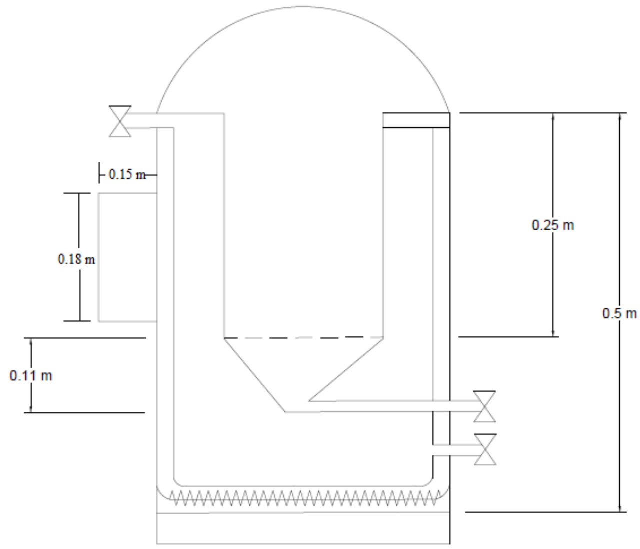

Figure 4: Dimensions of bioreactor

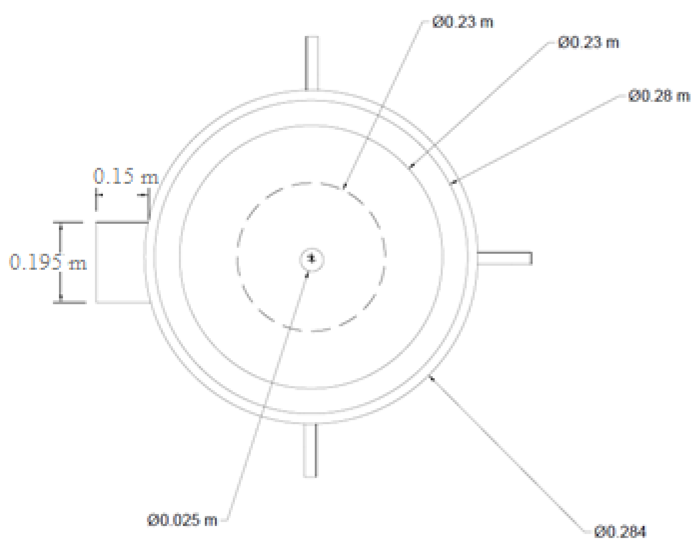

Figure 5: Cross sectional dimensions of bioreactor

3.3.1 Material for bioreactor construction

The bioreactor was fabricated with stainless-steel, because the metallic properties of stainless-steel prevents corrosion on the surface of the metal at the product and metal contact surface as well as the metal and heating medium surface. Stainless-steel has been used in fabrication of various food processing equipment for several years due to the inability of the metal to react to the food commodity coupled with its corrosion resistance and ability to withstand high and low temperatures. The corrosion resistance of stainless-steel is made possible by its chromium content, chromium oxide is formed at the surface of the steel which prevents chemical reaction with the bulk of the metal.

3.3.2 Temperature control

Temperature control in the bioreactor was achieved with the aid of a heating coil, thermocouple, proportional–integral–derivative (PID) temperature controller, contactor and a circuit breaker that were connected to electrical power supply as shown in the circuit diagram below.

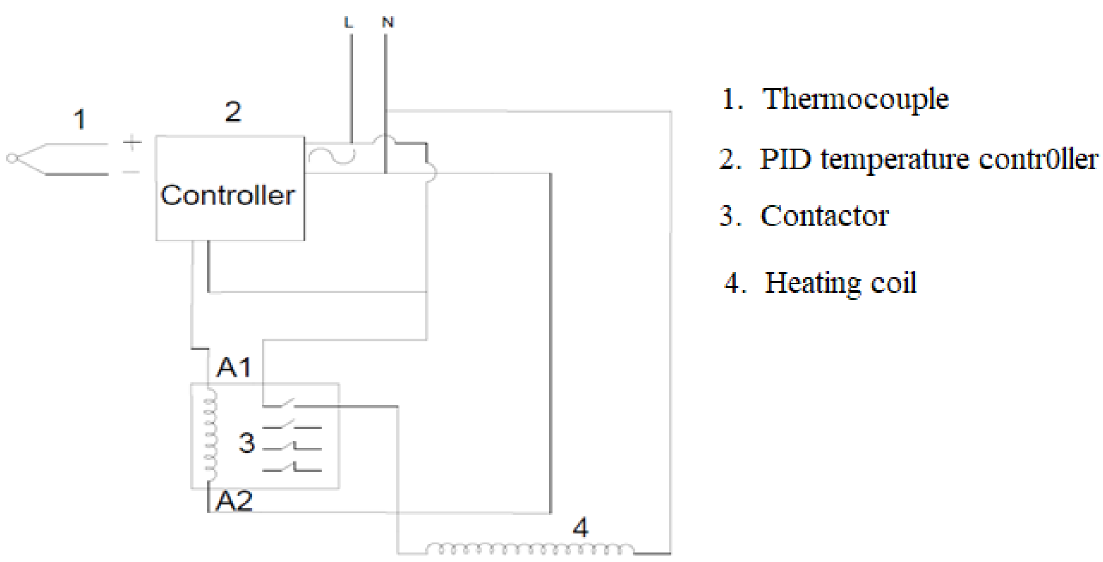

Figure 6: Temperature control circuit diagram

A thermocouple was linked to a controller for temperature generation in the bioreactor. The PID controller compared the temperature from the thermocouple to a setpoint temperature and opened or closed the power supply to the contactor. The contactor supplied or shut power supply to the heating coil based on the signal from the PID controller. The heating coil heat up the heating medium to increase the temperature in the bioreactor.

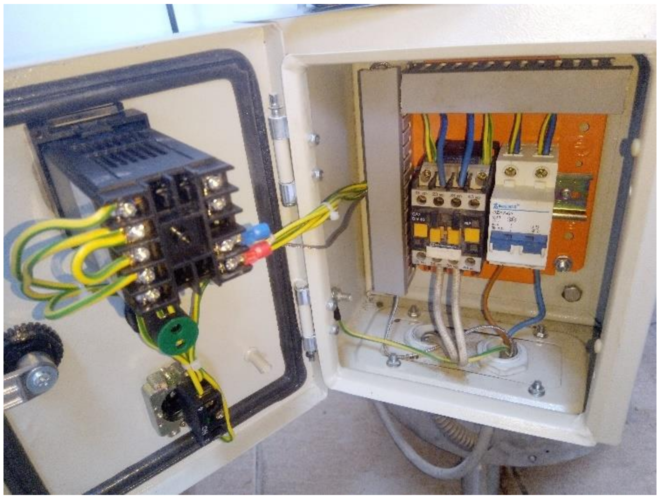

Illustration 5: Electrical connection

The PID controller controls loop feedback mechanism which compares actual temperature and setpoint temperature of the heating medium to signal the supply of power to the heating coil via a contactor. The contactor electrically-control switching of the electrical power circuit. The contactor was controlled by PID controller which had a much lower power requirement.

3.3.3 Energy balance for bioreactor

Considering a diagram below which depicts the transfer of heat from the heating medium through the walls of the equipment.

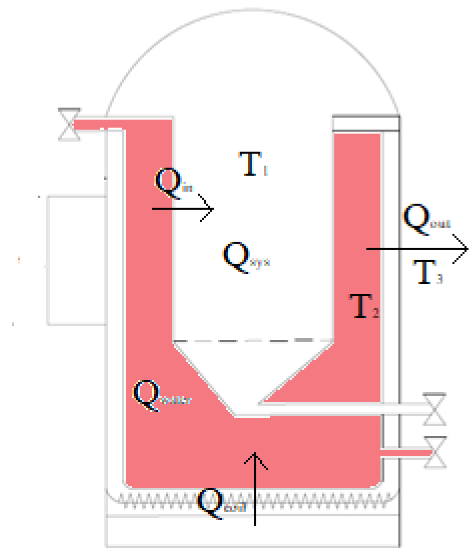

Illustration 6: Flow of heat in bioreactor

Assumptions

1. No heat losses from the heating coil
2. Temperature of the heating medium is uniform
3. No slip conditions exist.

In the diagram above: T_1 is temperature of the extraction chamber, T_2 is temperature of heating medium and T_3 the temperature of the surrounding air outside the bioreactor. Q_{coil} is the heat supplied by the heating coil, Q_{water} is the energy (heat) of the heating medium, Q_{in} is the heat transfer into the extraction chamber, Q_{sys} is the heat in the extraction chamber and Q_{out} is the heat transfer to the surrounding outside the reactor.

Energy balance for the heating medium (hot water) in the bioreactor is given by;

Energy input – Energy removed = Energy accumulated (energy in the system)

⇨ $Q_{coil} - Q_{in} - Q_{out} = Q_{water}$ ………… (1)

The heat gained by the heating water from the heating coil can be computed from

$Q_{med} = MCp(T_2-T_w)$ ………………... (2)

Where M is the mass of water, Cp is specific heat capacity of water (4.186j/g/^oC) and T_w is the initial temperature of the heating water (29^oC). The heating medium is water and it occupies the space between the outer housing and the inner chamber. Volume of space for water is 0.0187m^3, but the water will occupy two third ($\frac{2}{3}$) of this volume to leave room for vaporization of the water and expansion. Actual volume occupied by water is 0.0125m^3. therefore, the mass of water used is 0.0125m^3 × 1000kg/m^3 which is 12.5kg.

The heat transfer to the extraction chamber and the heat lost can be calculated from the heat conduction equation (Fouriers law).

$Q = \frac{kA}{L}(T_1 - T_2)$……………. (3)

Where Q is the heat conducted,

k is thermal conductivity of stainless steel (16.26 W/m.^oC),

L is the thickness of the material conducting the heat (0.002m) and

$(T_2 - T_1)$ is the temperature drop.

Heat transfer from hot water (heating medium) to extraction chamber

$Q_{cham} = \frac{kA_i}{L}[(T_2 - T_1)]$……………… (4)

heat transfer out of the bioreactor (heat lost)

$Q_{out} = \frac{kA_o}{L}[(T_2 - T_3)]$……………… (5)

⇨ A_i = heat transfer area to the chamber = 2πrh + πrl…………... (6)

⇨ r is radius, h is height of cylinder and l is length of slant side of the cone

⇨ $A_i = 0.242m^2$………… (7)

⇨ A_o= heat transfer area of the external bioreactor cylinder = 2πRH…………. (8)

⇨ R is radius and H is height of cylinder

⇨ $A_o = 0.44m^2$ …………. (9)

From inserting equations 2, 3, 5 and 6 into equation 1 yields

$$\frac{MCp(T2-Tw)}{t} = Q_{coil} - \frac{kA_i}{L}[(T_2 - T_1)] - \frac{kA_o}{L}[(T_2 - T_3)] \text{……… (10)}$$

From equation 10, T_w is the initial temperature of the heating water and t is the time taken to heat the water with the heating coil. For a lagged bioreactor in which heat transfer to the surrounding is negligible (Q_{ou} = 0), equation 10 becomes

$$\frac{MCp(T2-Tw)}{t} = Q_{coil} - \frac{kA_i}{L}(T_2 - T_1) \text{ … … … … … (11)}$$

Energy balance for the extraction chamber is given by

Q_{in} – energy lost from chamber = Q_{sys} ……. (12)

But the extraction chamber has negligible energy lost,

⇨ $Q_{in} = Q_{sys}$ ……………… (13)

⇨ $\frac{kA_i}{L}(T_2 - T_1) = \frac{mCpf(T1-To)}{t}$ …………. (14)

Where m is mass of fruit, C_{pf} is specific heat capacity of the fruit and T_o is the initial temperature of the fruit.

Inserting the heating coil is rated (2000w) and the bioreactor dimensional parameters into equation 10 yields

$$\frac{12500g*4.186j/gC(T2-Tw)}{t} = 2000\text{W} - \frac{\frac{16.26W}{mC}*0.242m2}{0.002n}(T_2 - T_1) - \frac{\frac{16.26W}{mC}*0.44m2}{0.002m}(T_2 - T_3) \text{ ...... (15)}$$

⇨ $\frac{52325j/C(T2-Tw)}{t} = 2000\text{W} - 1967.46W/C(T_2 - T_1) - 3577.2W/C(T_2 - T_3)$.... (16)

⇨ for a lagged Bioreactor, equation 16 becomes

⇨ $\frac{52325j/C(T2-Tw)}{t} = 2000\text{W} - 1967.46W/C(T_2 - T_1)$ …………….. (17)

For the extraction chamber equation 14 becomes

$$1967.46W/C(T_2 - T_1) = \frac{mCp(T1-To)}{t} \text{ .... (18)}$$

The equations above are required to calculate the energy consumption of the bioreactor during an extraction.

3.4 Validation of bioreactor

Two (2) kg of the ripe soft fruits were weighed into a 3L glass bottle and another 2 kg was weighed into the bioreactor. The fruits placed in the glass bottle were kept in the laboratory for six (6) days for the juice to leach out of the fruit.

The heating medium temperature was set to 70^{o}C in the bioreactor, this gave an internal temperature of 52 ± 1^{o}C. The fruits were kept in the bioreactor at this temperature for six days to extract the juice in the fruits. The temperature of the fruits in the bioreactor was measured at one-hour interval for 7 hours with a digi-sense dual jtek thermocouple thermometer (Cole-Parmer instrument company, Vernon Hill, IL 60061-1844 USA). A SUPCO SL300TH data logger was fixed into the bioreactor to measure the atmospheric temperature around the fruit. The temperature of the fruit throughout the extraction duration was checked to see if it remained constant.

Illustration 7: Fabricated bioreactor

The total soluble solids of the juice obtained was measured at temperatures 30.5^{o}C for the juice extracted in the bioreactor and 30.8^{o}C for the juice extracted in the glass bottle. Temperature compensation calculation was done to correct the total soluble solids value.

3.5 Effect of constant temperature on drip extraction

Ripe noni fruit weight of 1.32 kg was weighed into the bioreactor and the temperature of the heating medium (water) set to 53^{o}C which generated a temperature of 35 +/- 1 ^{o}C in the extraction chamber. The fruit were kept in the chamber at this temperature for 7 days, after which the juice exuded from the fruit was collected and weighed. The total soluble solid and pH of the juice were measured. Similarly, 1.32 kg of the soft ripe noni fruit were weighed and kept in 3L glass bottle, the fruit and the glass were kept outside the School of Engineering Building. This extraction therefore was done at an average temperature of 29.5^{o}C. The set up was kept there for seven (7) days, after which the juice exuded was collected and the pH, total soluble solid and mass of the juice was measured.

3.6 Effect of noni peels on juice extraction

A 5×3 factorial experiment was designed with five levels of time (5, 10,15,20 and 25 days) and three levels of treatment (unpeeled, peeled and peeled but peel kept in the extraction medium) was used. Each treatment and time combination involved the use of 800 g of noni fruits. Mature soft and clean noni fruits were weighed and either peeled or unpeeled, packed into 3 Liter plastic containers and sealed. One sample had the peels added to the peeled fruit in a container and sealed. An extraction was setup for each treatment and time combination.

The extraction set-ups for all the treatment and time combinations were kept in the laboratory at a temperature of 29.6^{o}C (room temperature). After the predetermined time for extraction, the juice yield was measured by carefully filtering the juice exuded from the fruit using a 355micron sieve and placing it on a balance to record the weight after which the total soluble solids and the pH were also measured.

3.7 Effect of extraction temperature and time on drip extraction

A 3×3 factorial experiment involving temperature (30, 40, 50^{o}C) and time of extraction (5, 10, 15days) was conducted to evaluate the effect of time and temperature on drip extracted noni juice. Each sample was prepared by weighing 1.5 kg of noni fruit into a 3L glass bottle after which a thermocouple was fixed into the bottle and the bottle sealed. A thermostatically-controlled oven (Binder GmbH, model ED56, P.O.Box 102, 78502 Tuttlingen, Germany) was used. The thermocouple running from the closed bottle was connected to a thermocouple thermometer (Cole-Parmer instrument company, Vernon Hill, IL 60061-1844 USA) to monitor and confirm that the temperature in the bottle during the extraction is equal to the set temperature. The thermocouple thermometer was kept outside, and the oven was closed for the predetermined extraction time to elapse, during the extraction thermocouple thermometer was checked and compared to the operating temperature of the oven to ensure there was no deviations. The samples were withdrawn from the oven when the predetermined extraction time of 5, 10 and 15days were attained. The extraction experiment was repeated for incubation temperatures of 40^{o}C and 50^{o}C.

At the end of the extraction duration, the juice produced was collected and weighed, the pH and total soluble solid were measured. Analysis of variance was carried out to determine the effect of time and temperature on pH, total soluble solids content and yield of resulting juice.

3.8 Effect of water addition to drip extraction

A 4×3 factorial experiment was designed with two factors, extraction time and quantity of water added. The times for extraction were 9, 18 and 27 days whilst the amount of water added were 0, 50, 75 and 100ml of water which are 0%, 5%, 7.5% and 10% of the fruit weight used for the extraction. 1 kg of noni fruit was weighed into 12 polypropylene containers, three containers were closed without any water addition. For the remaining 9 containers, 50, 75 and 100ml of distilled water of total soluble solids content of 0^{o}Brix was added to three containers each, with the containers already containing 1 kg of noni fruit. All the sample were kept at room temperature in the laboratory for predetermined times. One each of the samples with 0, 50, 75 and 100ml of water added was kept for 9 days, another set of samples of one each of the samples with 0, 50, 75 and 100ml of water added was kept for 18days and the last set of samples was kept for 27 days. The juice dripped off the fruit was filtered via a 355micron sieve after keeping it for the predetermined time. Yield, total soluble solids content and pH of the resulting juice was measured.

3.9 Optimization of juice extraction using central composite rotatable design for K=3

Following the preliminary studies, the Central Composite Rotatable Design for k =3 was used to study the effects of three critical variables on juice extraction. The factors were a) mash (fruit) weight (X_1), fermentation temperature (X_2) and fermentation time (X_3) using the bioreactor and an oven (Binder GmbH, model ED56, P.O.Box 102, 78502 Tuttlingen, Germany) for keeping the extraction setups at constant temperature simultaneously throughout the extraction period. The minimum and maximum values for these independent variables was set using preliminary extraction data and literature values and the intermediate variables were calculated and summarized as shown in Table 1.

Table 1. Independent variables for experiment

Levels	**-1.682**	**-1**	**0**	**1**	**1.682**
Fruit weight (kg), X_1	0.5	0.8	1.25	1.7	2
Temperature (^oC), X_2	30	36.08	45	53.92	60
Time (days), X_3	3	6.65	12	17.35	21

5 levels were used for all the independent variables, these levels were aligned with the coded values 1.682, 1, 0, -1 and -1.682 and matrix of variables was generated as follows:

Table 2. Design matrix for k=3

Runs	**Original matrix codes**			**Calculated matrix values**		
	X_1	**X_2**	**X_3**	**X_1**	**X_2**	**X_3**
1	-1	-1	-1	0.8	36.08	6.65
1	-1	1	1	0.8	53.92	17.35
1	1	-1	1	1.7	36.08	17.35
1	1	1	-1	1.7	53.92	6.65
1	0	0	0	1.25	45	12.00
1	0	0	0	1.25	45	12.00
2	-1	-1	1	0.8	36.08	17.35
2	-1	1	-1	0.8	53.92	6.65
2	1	-1	-1	1.7	36.08	6.65
2	1	1	1	1.7	53.92	17.35
2	0	0	0	1.25	45	12.00
2	0	0	0	1.25	45	12.00
3	1.6817	0	0	2	45	12.00
3	-1.6817	0	0	0.5	45	12.00
3	0	1.6817	0	1.25	60	12.00
3	0	-1.6817	0	1.25	30	12.00
3	0	0	1.6817	1.25	45	21.00
3	0	0	-1.6817	1.25	45	3.00

3	0	0	0	1.25	45	12.00
3	0	0	0	1.25	45	12.00

These represented 20 treatment combinations for this experiment. Multiple Regression Equations were generated to predict the effects of the independent variables selected on the dependent variable of interest (y = juice recovery, pH and total soluble solid).

The extraction was intended to be carried out in the bioreactor that was designed and built for this research by directly weighing the fruits into the fruit chamber for the juice to drip into the juice chamber. But upon validation of the bioreactor, it was not fit for purpose due to the presence of separate chambers for both fruits and juice even though the temperature control function was adequate. A simplified version was made in which the fruits were weighed into the 3L glass container and kept at constant predetermined temperature and time per the treatment combination in the matrix, the fruit-charged glass were placed in a temperature-controlled oven (Binder GmbH, model ED56, P.O.Box 102, 78502 Tuttlingen, Germany) for designated times according to the central composite rotatable design (CCRD) matrix.

After fermenting for the predetermined time, the juice obtained was sieved and weighed, the physiochemical characteristics of interest (pH and total soluble solid) were measured.

3.9.1 Drip extraction based on optimization results from CCRD experiment

Based on the central composite rotatable design experiment result, a response surface optimization was carried out to adjust the pH and total soluble solids as well as maximize yield of resulting drip extracted noni juice. Minitab software was used to run an optimization to produce noni juice with pH of 3.4 and total soluble solids of 7.5^{o}Brix with maximized yield. The pH and total soluble solid target values set for the optimization were based on the pH and total soluble solids content of noni juice on the Ghanaian market. From the optimization, 2 kg of noni fruit dripped extracted at 30.50^{o}C for 12days 10hours was required to produce noni juice with total soluble solid of 7.5^{o}Brix, pH of 3.4 and yield of 360 g. Four experiments were set up to confirm the prediction and validate the regressions equations as well as the models.

Two 3L glass bottles were cleaned and dried, after which 2 kg of cleaned noni fruits were weighed into each glass bottle and tightly closed with their lids. The bioreactor was powered, and the temperature was adjusted to obtain 30.50^{o}C in the extraction chamber, simultaneously an oven (Binder GmbH, model ED56, P.O.Box 102, 78502 Tuttlingen, Germany) was set to 30.50^{o}C. One glass bottle with the noni fruits was placed in the bioreactor and the other in the oven, a thermocouple was placed in the fruit and glass bottle setup before placing the setup in the bioreactor and the oven. The thermocouple was used to monitor the internal temperature of the extraction setup. The setup was dripped for 12days 10hours, after which the juice obtained was decanted through 355miron sieve and the pH, total soluble solids and yield of the juice was measured. The extraction was repeated to obtain a second pair of results. The results were averaged and compared to the predicted values of pH, total soluble solids content and yield.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Textural changes (softening profile) of noni fruit after harvest

To understand the softening of noni fruit after harvest the peak load and work were measured. The results showed that the peak load and the work reduced significantly over storage time (see illustration 8 below), this reduction in peak load and work characterized softening of the noni fruit. The fruit became soft enough to be subjected to drip extraction 46hours and became very soft after 54hours.

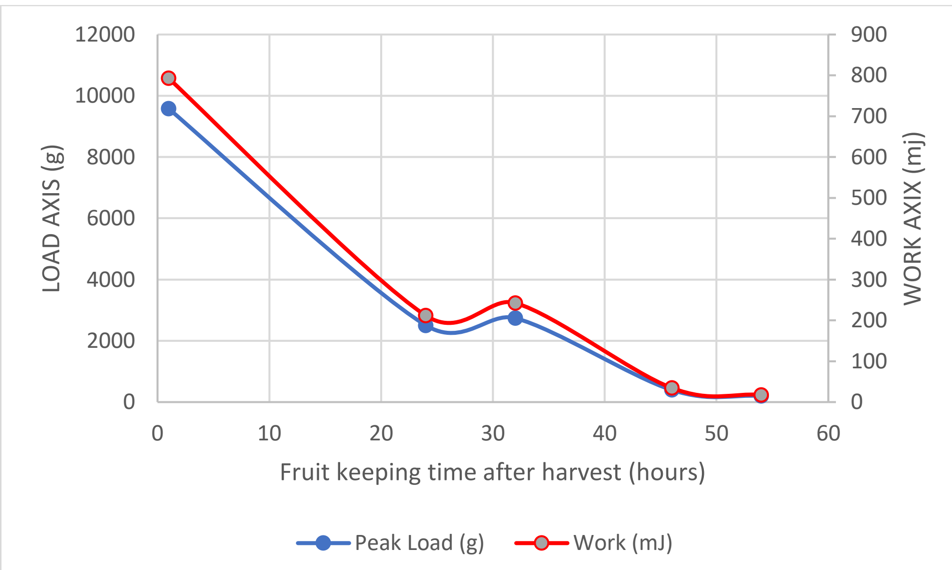

Illustration 8: The effects of incubation time after harvest on the texture of noni fruit

The time taken by the fruit to soften depended on how the fruits were kept. The fruits were kept in a polythene bag to conceal the foul odor. Keeping the fruits in the polythene bag also prevented the escape of respiratory heat, which facilitated the softening and ripening of the fruits. Noni fruits harvested in the grey-translucent stage or pale-yellow stage requires about 46 hours of storage to soften before subjecting them to drip extraction. After the 46 hours the fruit is soft enough for its juice to exude and the resulting juice is not darkened as compared to juice extracted from green hard fruits.

4.2 TEMPERTURE MONITORING FOR DRIP EXTRACTION

The extraction temperature was monitored for extraction in the laboratory and extraction in the sun, due to the different temperature profile of these locations throughout the day.

Table 3. Summary temperature and humidity changes for noni juice extraction

	Temperature (°C)	**Humidity (%RH)**	**Dew Point (°C)**	**Temperature (°C)**	**Humidity (%RH)**	**Dew Point (°C)**
	Indoor Extraction			Outdoor Extraction		
Average	27.94	103.96	28.53	31.51	91.09	29.77
Minimum	26.32	82.7	26.06	22.4	72.5	21.62
Maximum	29.6	116.42	32.19	52.96	95.94	48.61

The average temperature for the extraction indoor was 27.94°C, whereas the average temperature for the extraction outdoor was 31.51. the juice yield for the indoor extraction was lower than the juice yield for the outdoor extraction. The temperature, dew point and humidity profile in the extraction setups indoor and outdoor are illustrated below. The dependency of variations in dew point and humidity on temperature is iterated in this research experiment, dewpoint increases with increase in temperature whiles humidity reduces with increase in temperature and vice versa.

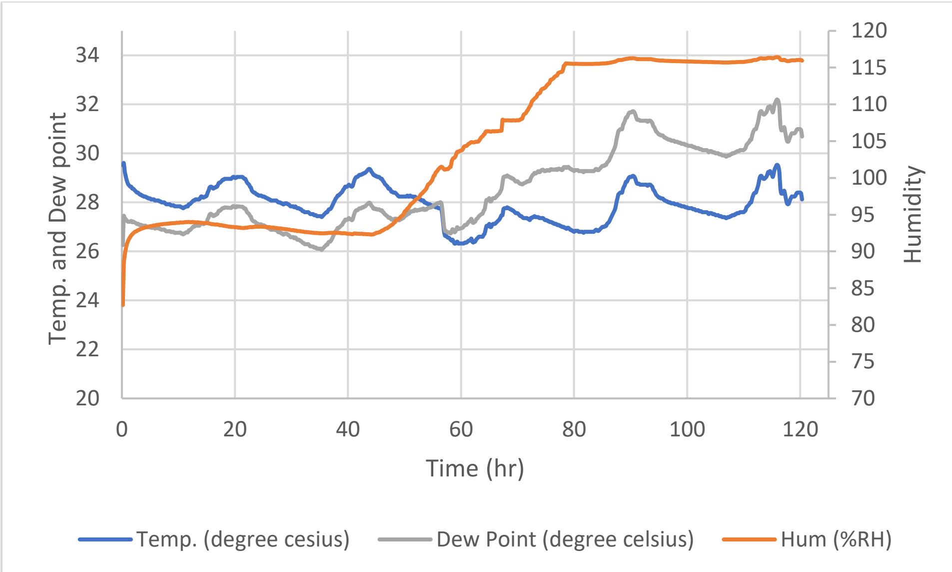

Illustration 9:Graph of temperature, humidity and dew point against time for indoor drip extraction

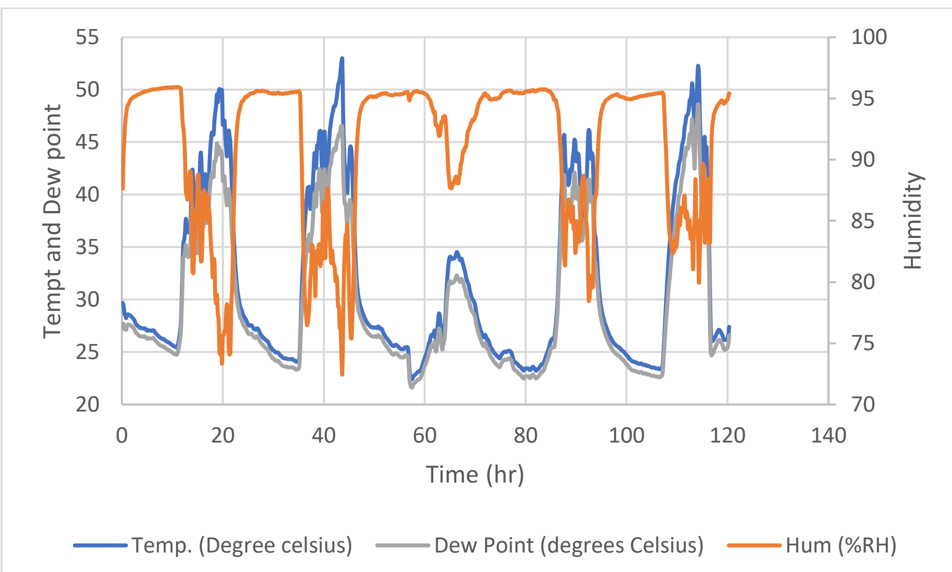

Illustration 10:Graph of temperature, humidity and dew point against time for outdoor extraction

The variations in humidity, temperature and dew point is relatively steady in the indoor extraction setup compared to outdoor extraction where the variations in dew point, temperature and humidity is sinusoidal due to the low temperatures at dawn and high temperatures at noon.

Table 4. Juice characteristic comparison for indoor and outdoor extracted juice

Location	**Fruit Weight (kg)**	**Juice quantity (g)**	**Juice quantity per kg (g/kg)**	**pH**	**T.S (%)**	**Total soluble solids (ºBrix)**	**Weight of residue (kg)**
Indoor	0.62	57.15	92.18	3.78	5.75	6.3	1.58
Outdoor	0.62	109.26	176.23	3.95	5.3	5.4	1.54

The outdoor extraction yielded almost twice as much juice as the indoor extraction, due to the higher rate of transpiration and condensation of water from the fruit at high temperatures experienced outside than the fairly constant temperature experienced indoor. Transpiration in the fruits outside was evident during the daytime and water droplets were seen on the interior surface of the glass bottle.

After the extraction, molds were found on the fruits dripped indoor whereas no mold was found on the fruit dripped outdoor. The extraction temperature indoor coupled with the rich nutrient content of the fruit favored the mold growth. Molds did not grow on the outdoor fruit basically because of the high temperature above 35^{o}C recorded during the day, temperature range of 10^{o}C to 35^{o}C favors growth of molds with their optimum growth temperature range being 15^{o}C to 30^{o}C.

The pH, total solids and total soluble solids of the indoor extracted juice was higher than that of the outdoor extracted juice. This further reiterates the transpiration effect on the juice extracted outdoor which improves the yield, increases pH and lowers the total soluble solids content. However, the increase in pH and the drop in total soluble solid content are not significant.

4.3 Validation of bioreactor

The major function of the bioreactor is to enable drip extraction at a constant temperature over the period of extraction. A summary of the bioreactor temperature during extraction is shown below. The minimum temperature was recorded immediately the SUPCO300TH data logger was fixed in the bioreactor.

Table 5. Summary of bioreactor temperature during extraction

	Temperature (ºC)	**Humidity (%RM)**	**Dew Point (ºC)**
Average	51.21	92.95	49.73
Minimum	28.96	80.49	25.74
Maximum	54.32	106.04	55.53

The trend of temperature, dewpoint and humidity during the extraction period is illustrated below.

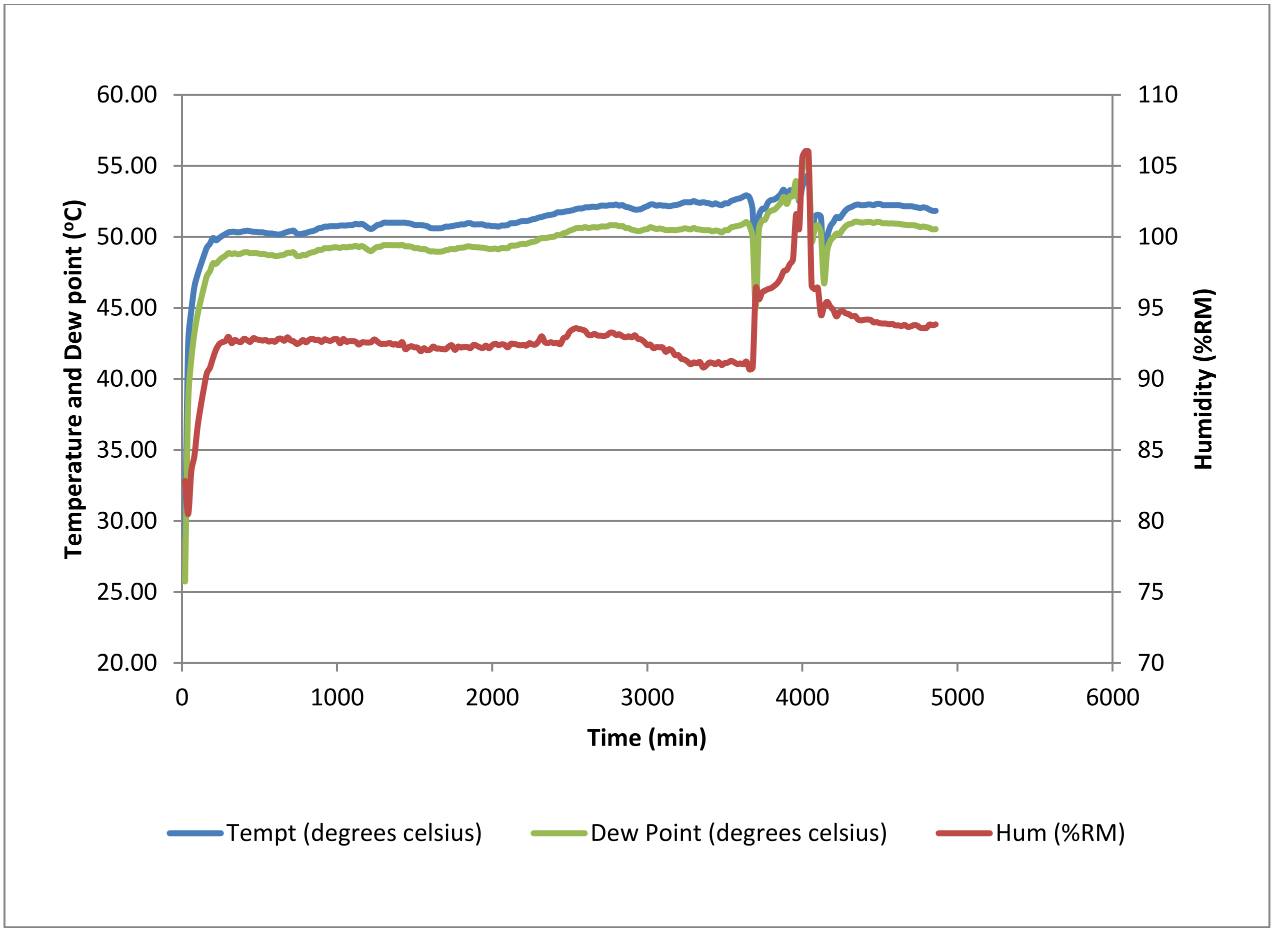

Illustration 11:Graph of temperature, dew point and humidity for extraction in bioreactor

From the trends above, it was seen that the variations in bioreactor temperature was not significant and that the bioreactor temperature was constant over the extraction period.

Table 6. Fruit Temperature Monitoring in Bioreactor

Bioreactor chamber temperature			Fruit temperature	
Time	Temperature (ºC)	Average atm. Temperature (ºC)	Time	Fruit Temperature (ºC)
12:41	53.32			
13:01	52.8	53.06	12:51	52.1
14:01	53.6			
14:21	52.52	53.06	14:10	52.1
15:01	54.12			
15:21	54.32	54.22	15:18	52.2
16:21	51.56			
16:41	51.4	51.48	16:36	52.1
17:21	49.92			
17:41	50.72	50.32	17:38	52.2
18:21	51.4			
18:41	51.32	51.36	18:37	52.1
19:21	51.88			
19:41	52.04	51.96	19:36	52.1

The temperature inside the chamber of the bioreactor varied between 49.92 ºC and 54.32ºC, this generated fruit temperature that varied between 52.1 ºC and 52.2 ºC with an average fruit temperature of 52.2ºC. The bioreactor was effective in keeping the fruits at a constant temperature, fruit temperature remained constant over time at 52ºC.

Table 7. Results for extraction at 29ºC and 52ºC

Sample	Weight of fruit (kg)	Juice Quantity (kg)	Total Soluble Solids (ºBrix)	Yield (%)	Color	Residue fruit weight (kg)
Glass Bottle (29°C)	2	0.242	7.3	12.1	Golden Brown	1.74
Bioreactor (52°C)	2	0.451	2.55	22.55	Black (dark)	1.32

The juice yield from the bioreactor (52ºC) was higher than the juice yield for the extraction at room temperature (29ºC). The total soluble solids of the juice extracted at 52ºC was lower (2.55ºBrix) than that of the juice extracted at 29ºC (7.1ºBrix) and the color was dark whereas the juice extracted at room temperature had a golden-brown color.

Illustration 12: Juice extracted at room temperature (A) and juice extracted at 52ºC (B)

In drip extraction of Noni juice, juice yield increases with increase in temperature and the total soluble solids of the juice reduces with increased temperature of extraction. Drip extraction at 52^{o}C darkened the resulting juice, possibly due to maillard reaction (browning) taking place in the juice at this temperature.

4.4 Effect of constant temperature on drip extraction

From the results obtained, it can be said that increased extraction temperature above room temperature improves juice yield for drip extraction. The juice yield for extraction at 35^{o}C was higher than the juice yield for extraction at room temperature, however the total soluble solid of the resulting juice is significantly lower than the total soluble solids of juice extracted at low temperature. The low total soluble solids exposed a flaw in the bioreactor. In the traditional drip extraction set-up, the fruits being dripped sits in the exudate during the dripping process, this improves the total soluble solids by giving the exudate enough contact time to absolve substances from the fruit. Therefore, the presence of separation between the fruits and exudate do not permit the uptake of substances by the exudate which has resulted in the low total soluble solids of the juice produced.

Table 8. Results of juice extraction at room temperature and juice extracted in bioreactor with separation between fruit and juice at 35^{o}C

Method	**Yield (%)**	**pH**	**Total Soluble Solids (^{o}Brix)**
35^{o}C in bioreactor	**17.74**	**3.47**	**0.25**
Room temperature (29^{o}C)	**10.68**	**3.66**	**6.8**

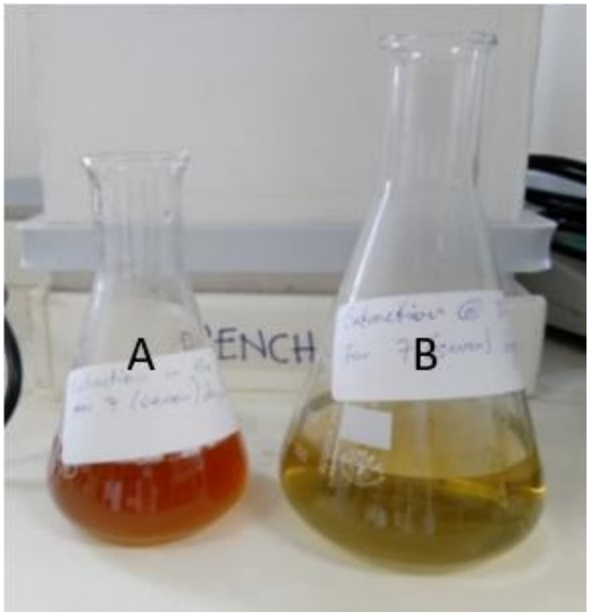

Illustration 13: Image of juice extracted at different temperatures

In illustration 13, A is juice extracted at room temperature for 7 days and B is juice extracted in a bioreactor with separation between fruits and juice for 7 days at 35^{o}C.

The juice produced from the bioreactor had golden colour while the juice extracted at ambient temperature had a golden amber colour, the colour difference indicates that the exudate from fruits in the bioreactor had less substances from the fruit dissolved in it compared to exudate from fruit that were dripped at ambient temperature where the fruit sat in the exudate during the extraction.

To improve the total soluble solid content of juice dripped with the bioreactor, the sieve creating the separation between the fruit chamber and the juice chamber would be removed, this will allow the fruit to sit in the exudate during extraction.

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4.5 Effect of noni fruit peel on noni juice extraction

From the experimental data, the presence or absence of peels on the fruit during drip extraction of the noni juice has no observable effect on the pH and total soluble solids content of the resulting juice. Samples that contained the peeled fruits only and peeled fruits plus peels followed similar trend. Noni juice extracted from whole noni fruits gave a slightly different trend. Generally, with increasing days of extraction the pH of the noni juice from the whole fruits was relatively higher. The resulting juice therefore will be less acidic and sour to taste. The variation in pH of the juices obtained for each treatment were not statistically significant ($p \leq 0.05$).

It is important to note that the yield recovered from the whole fruit is more than the yield recovered from the peeled fruit and peeled fruit plus set up. Extracting noni juice from unpeeled whole fruit appears to yield more juice, it is therefore not necessary to peel the fruit before juice extraction.

Analysis of variance on the effect of treatment and time combination on the total soluble solid content of juice produced, revealed that the total soluble solid content of the resulting juice is not significantly affected by the treatment and time combination. This is to say that the total soluble solids of noni juice dripped is not dependent on the presence or absence of noni fruit peels. However, the highest total soluble solids content of 7.7^{o}Brix was observed in the juice dripped from the whole fruit, whiles the total soluble solids content of the juice obtained from the peeled fruit and the peeled fruit plus peels was 7.5^{o}Brix as shown in the table for total soluble solids results. From the Duncan multiple test results, there is a significant difference between the mean total soluble solids content of the juice obtained from the peeled fruits plus peel and the unpeeled fruits. This implies that although there is no significant effect of the time and treatment combination on the total soluble solids content of juice obtained, the Duncan test proposes that the total soluble solids profile of the juice obtained from the peeled fruit and the whole fruit over the dripping period were significantly different.

The yield for all treatments increased with increase in time. however, the highest yield was obtained from dripping the whole fruit for 25days whiles dripping the peeled fruits for 25days had the lowest yield. Analysis of variance showed that time of extraction and the treatment given to the noni fruit before extraction both significantly affected the yield of juice extracted. From the yield results obtained for each time level, the highest juice yield was obtained from the unpeeled (whole) fruits followed by the peeled fruits plus peels setup and the peeled fruits dripped the lowest juice quantity.

From the results shown in appendix 3, the unpeeled (whole) fruits produced noni juice with better result in terms of yield and total soluble solids content. It is therefore not necessary to peel the fruit before noni juice extraction. See below analysis of variance of the results obtained for the effects of noni fruit peels on drip extraction of noni juice shown in appendix 3.

Table 9. ANOVA Table for effect of peels on pH of juice produced

source of variance	**SS**	**Df**	**MS**	**F**	**p-value**
Time	0.0202	4	0.0051	3.0982	0.0813
Treatment	0.0061	2	0.0030	1.8691	0.2157
Error	0.0130	8	0.0016		
Total	0.0393	14			

Table 10. ANOVA table for effect of peels on total soluble solids content of produced juice

source of variance	**SS**	**Df**	**MS**	**F**	**p-value**
Time	0.2307	4	0.0577	1.5412	0.2789
Treatment	0.3023	2	0.1512	4.0401	0.0613
Error	0.2993	8	0.0374		
Total	0.8323	14			

Table 11. ANOVA table for effect of peels on yield of produced juice

source of variance	SS	Df	MS	F	p-value
Time	15027.07	4	3756.768	11.5696	0.0021
Treatment	5159.207	2	2579.604	7.9443	0.0126
Error	2597.684	8	324.7106		
Total	22783.96	14			

4.6 Effect of temperature and time on drip extraction

It was observed that higher temperature of extraction tended to give noni juice with relatively high pH. This explains why noni juice extracted in the sun where the temperature can go up to 52^{o}C at mid-day have higher pH than juice extracted indoor around 29^{o}C.

Analysis of variance for the effect of temperature and time on drip extraction indicates that, extracting noni juice at different temperatures has significant effect on the pH of the resulting juice. Time on the other hand has no significant effect on the pH of the resulting juice.

Table 12. ANOVA table for effect of temperature and time on pH

source of variance	**SS**	**Df**	**MS**	**F**	**p-value**
Time	0.005267	2	0.002633	1.244094	0.380078
Treatment	0.047267	2	0.023633	11.16535	0.023078
Error	0.008467	4	0.002117		
Total	0.061	8			

The total soluble solids content of the resulting juice for extraction at 30^{o}C decreased with increase in extraction time whiles the total soluble solids content for extraction at 40^{o}C remained constant with increase in time of extraction and the total soluble solids content of juice extracted at 50^{o}C tends to increase with increase in extraction time. However, for a given extraction time, the total soluble solids content of resulting juice increases with increase in extraction temperature.

Analysis of variance for the effect of temperature and time on total soluble solids content, shows that the treatment has significant effect on the total soluble solids content thus the total soluble solids content increased with increase in extraction temperature, however time of extraction did not affect the total soluble solids content significantly.

Table 13. ANOVA table for the effect of temperature and time on total soluble solids content

Source of variance	SS	Df	MS	F	p-value
Time	0.111	2	0.055	0.409	0.689
Treatment	10.804	2	5.402	39.932	0.002
Error	0.541	4	0.135		
Total	11.456	8			

The yield of extracted noni juice increases with increase in extraction time temperature. High temperature and long extraction time improve the yield of noni juice.

Analysis of variance on the effect of temperature and time on juice yield, indicates that both temperature and time significantly affects the juice yield. The analysis of variance table is shown below.

Table 14. ANOVA Table for effect of temperature and time on yield

Source of variance	SS	Df	MS	F	p-value
Time	14823.59	2	7411.797	13.24382	0.017214
Treatment	21814.57	2	10907.29	19.48976	0.008662
Error	2238.568	4	559.6419		
Total	38876.73	8			

4.7 Effect of water addition on drip extraction

From analysing the data shown in appendix 5, it was noticed that adding water to drip extraction of noni juice equivalent to 10% of the fruit weight increases the yield slightly. However, the pH and total soluble solids content results obtained shows that, the water addition does not affect the pH and total soluble solids content of the resulting juice significantly. Analysis of variance on the data produced the ANOVA tables below.

Table 15: ANOVA table for effect of water addition to drip extraction on pH

Source of Variation	**SS**	**df**	**MS**	**F**	**p-value**
Time	0.088317	2	0.044158	0.767193	0.505022
Treatment	0.263625	3	0.087875	1.526712	0.301133
Error	0.34535	6	0.057558		
Total	0.697292	11			

The effect of water addition on pH of the resulting juice during drip extraction was not significant, that is the experiment shows that adding water up to 10% of the weight of the fruit being drip extracted does not affect the pH of the resulting juice significantly. Time effect on the extraction set up was not significant either.

Table 16 ANOVA table for effect of water addition to drip extraction on total soluble solids content

Source of Variation	**SS**	**df**	**MS**	**F**	**p-value**
Time	0.287917	2	0.143958	0.363876	0.709323
Treatment	5.135625	3	1.711875	4.327014	0.060303
Error	2.37375	6	0.395625		
Total	7.797292	11			

The addition of water (10% of fruit weight) to drip extraction of noni juice and the duration of the extraction does not significantly affect the total soluble solids content of the resulting juice. It is important to note that even though the total soluble solids content is affected by the quantity of water, the effect is not statistically significant. This presuppose that to shorten the extraction, water can be added to the drip extraction. However, further research needs to be done on the maximum quantity of water and the extraction duration to obtain a desired juice.

Table 17 ANOVA table for effect of water addition to drip extraction on juice yield

Source of Variation	**SS**	**df**	**MS**	**F**	**p-value**
Time	1041.6	2	520.8	11.55197	0.008762
Treatment	959.7036	3	319.9012	7.095793	0.021244
Error	270.4993	6	45.08322		
Total	2271.803	11			

The yield increased with increase in time and with increase in quantity of water added, thus both water addition to and duration of extraction significantly affected the yield of the resulting juice as shown in table 20, ANOVA table for yield above. Duncan multiple comparison test carried out on the results for all dependent parameters (pH, total soluble solids content and yield) indicates that adding varying quantity of water (not more than 10% of the fruit weight) to the drip extraction set up does not affect the extraction process significantly.

4.8 Results for optimization of juice extraction using central composite rotatable design for K=3

4.8.1 Effect of mass, temperature and time on pH of resulting juice

Generally, the CCRD results obtained indicate that pH of the resulting juice does not depend on the mass of fruit used for the extraction. However, when the mass is kept constant, pH of the resulting juice reduces with increase in extraction time for extraction temperature of 45^{o}C and below. pH generally increases for extraction at temperatures above 45^{o}C due to a relatively higher water content of juice obtained as a result of increased transpiration in the fruit during extraction at high temperature. Low extraction temperature and long extraction time results in juice with low pH, thus the pH of the resulting juice is favoured by extraction at low temperature for a long time, but the reverse is true for extraction at low temperature for a short time. Analysis of variance for the effect of mass, temperature, and time on pH of the resulting juice is shown below.

Table 18. Analysis of Variance for effect of mass, temperature, and time on pH of resulting juice

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.935042	0.103894	18.89	0
Linear	3	0.448751	0.149584	27.19	0
Mass	1	0.009802	0.009802	1.78	0.219
Temperature	1	0.291357	0.291357	52.96	0
Time	1	0.041125	0.041125	7.48	0.026
Square	3	0.344732	0.114911	20.89	0
Mass*Mass	1	0.005432	0.005432	0.99	0.349
Temperature*Temperature	1	0.300159	0.300159	54.56	0
Time*Time	1	0.017624	0.017624	3.2	0.111
2-Way Interaction	3	0.109222	0.036407	6.62	0.015
Mass*Temperature	1	0.000052	0.000052	0.01	0.925
Mass*Time	1	0.003756	0.003756	0.68	0.433
Temperature*Time	1	0.094115	0.094115	17.11	0.003
Error	8	0.044008	0.005501		
Lack-of-Fit	3	0.030124	0.010041	3.62	0.1
Pure Error	5	0.013883	0.002777		
Total	17	0.97905			

Table 19. Model Summary for pH

S	R-sq	R-sq(adj)	R-sq(pred)
0.074168	95.51%	90.45%	45.37%

Regression Model

$$pH = 0.997 - 0.280X_1 + 0.1536X_2 - 0.1129X_3 + 0.100X_1^2 - 0.001863X_2^2 - 0.00184X_3^2 - 0.00079X_1X_2 + 0.0111X_1X_3 + 0.002815X_2X_3$$

Where X_1 is mass of fruit

X_2 is temperature of extraction

X_3 is time of extraction

The model and analysis of variance for pH is shown above, the high R^2 value (90.45%) indicates that the data explained 90.45% of the variation in pH. The lack of-fit was not significant ($p>0.05$) for the pH response. Model of the parameters showed that they fit the model well and thus represented the experimental data adequately. The model shows that analysis of variance for linear, square and two-way interaction of the independent parameters significantly affects the pH of the resulting juice. From the analysis, temperature and time significantly affects the pH of the resulting juice whereas the mass does not.

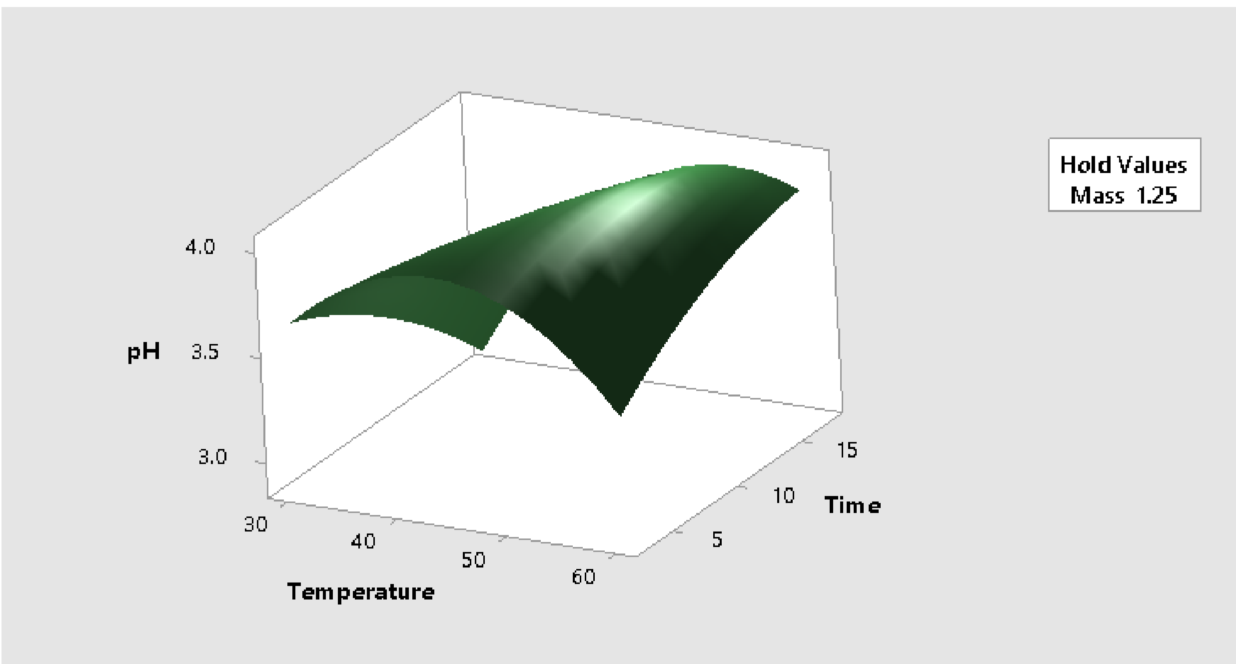

Illustration 14: Surface Plot of pH vs Time, Temperature

It is observed from the surface plot of pH vs Time and Temperature (illustration 14), that at high temperature and short time, pH is low but increases with increase in time. At low temperature, time has negative linear effect on pH that is, the pH decreases with increase in time at low temperature. At high temperature the negative linearity of time on pH changes to positive as pH increases with increase in time at high temperature, this is possibly due to increase transpiration rate which results in more water in the exudate. Temperature and the interaction of temperature and time has a significant effect on the pH of the resulting juice. From the response surface above, the pH of the resulting juice is lowest at two points which translate to low temperature long extraction time and high temperature short extraction time for a constant mass of fruit.

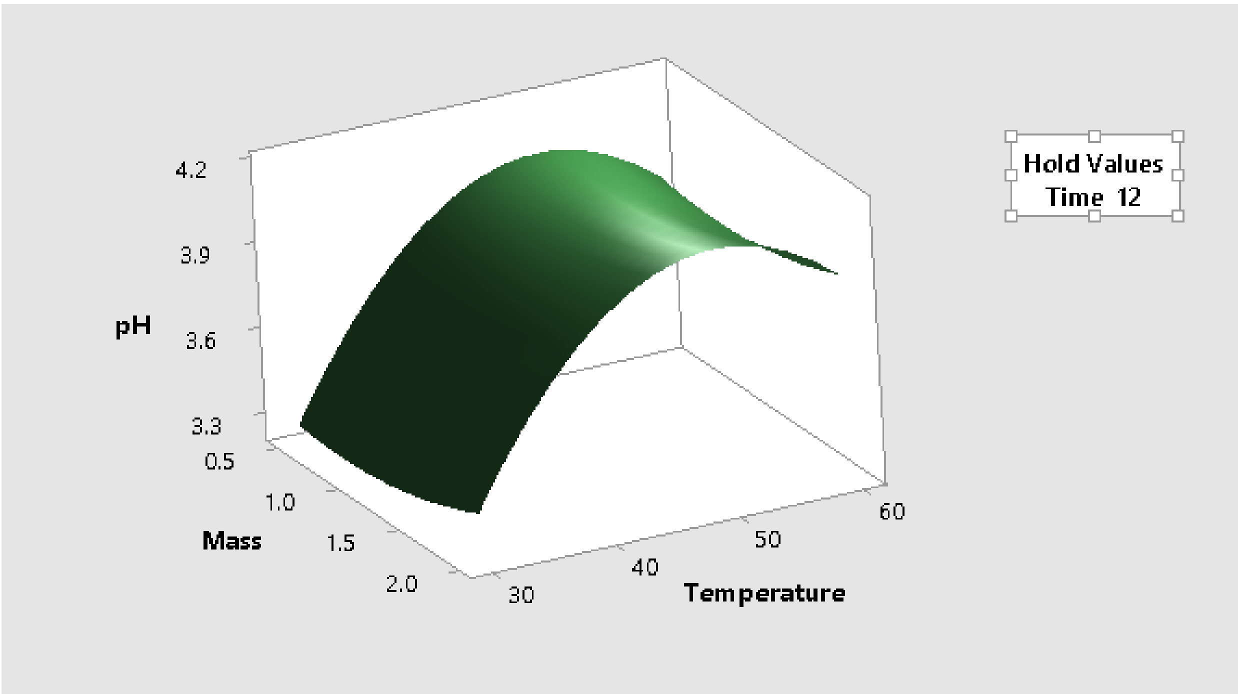

Illustration 15: Surface Plot of pH vs Temperature, Mass

From Surface Plot of pH vs Temperature and Mass (illustration 15), pH of the extracted noni juice was predicted to be low at low temperature and mass but increased steadily with gradual increase in temperature and mass. At high mass and low temperature, the pH was low but relatively higher than the pH at low mass and low temperature. Increasing temperature irrespective of the mass, will cause the pH to increase when the extraction (aging) time is increased as reported by Hafiza *et al.* (2013). It is prudent to note that since the pH of the resulting juice is expected to be low, the best pH results for a constant time extraction is observed at low temperature and is independent of the mass of fruit used for the extraction.

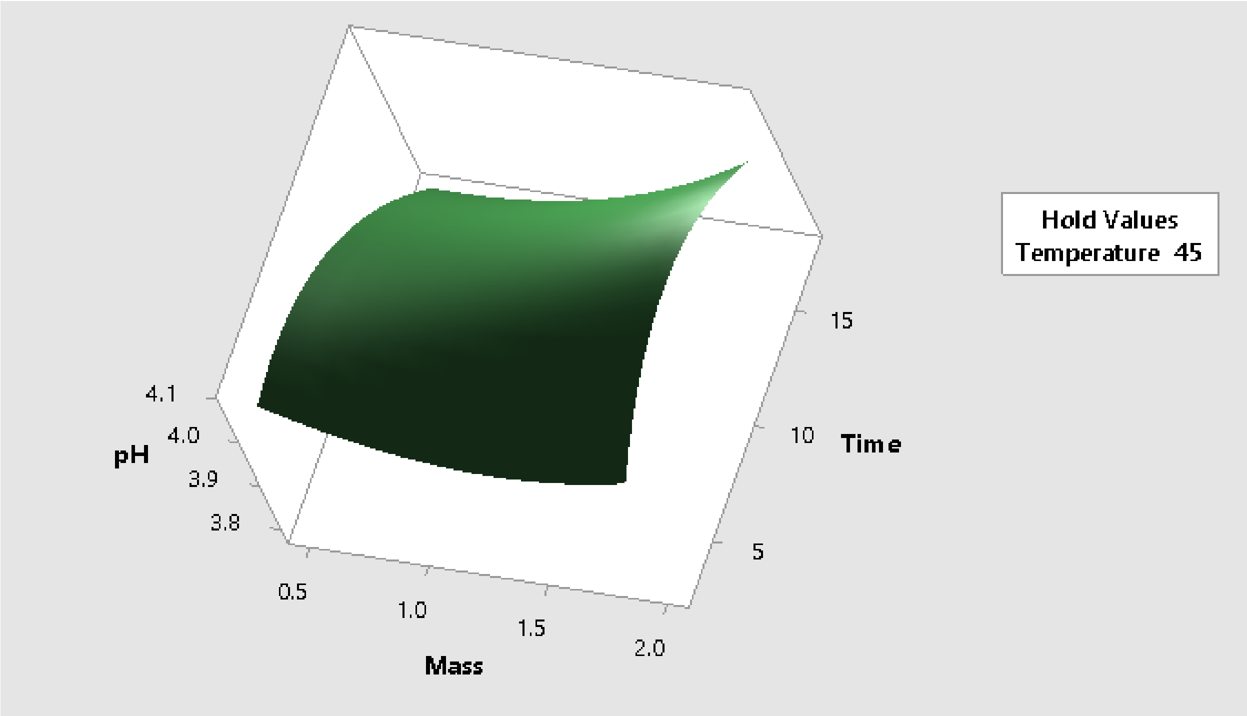

Illustration 16: Surface Plot of pH vs Time, Mass

The time effect on pH of resulting juice is shown in the Surface Plot of pH vs Time and Mass (illustration 16), the plot shows that at constant temperature and varying mass and time, the pH of the resulting juice is low when the extraction is done with a small mass for a long time or with a large mass for a short time. During extraction with small mass the pH of the resulting juice is initially high but drops as the extraction progresses for days or weeks. However, extraction with large mass has the pH of the resulting juice low in the initial stage and increases over the period of extraction. It is important to note that the pH of the resulting juice for large mass long time extraction is lower than the pH of the resulting juice for a small mass short time extraction.

Considering the finding from the surface plots for pH, low temperature is a requirement to obtain low pH of the resulting juice.

4.8.2 Effect of mass, temperature and time on total soluble solids content of resulting juice

From the CCRD results obtained, the effect of mass, time and temperature on the total soluble solids content of the resulting juice does not follow a general rule like the pH mention above. However, analysis of variance on the effect of mass, temperature and time on the total soluble solids content of the resulting juice is shown below.

Table 20. Analysis of Variance for the effect of mass, temperature and time on total soluble solids content of resulting juice

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	3.95852	0.5655	8.72	0.002
Linear	3	0.84088	0.28029	4.32	0.038
Mass	1	0.11915	0.11915	1.84	0.208
Temperature	1	0.45158	0.45158	6.96	0.027
Time	1	0.48071	0.48071	7.41	0.024
Square	2	2.19767	1.09884	16.94	0.001
Mass*Mass	1	1.7826	1.7826	27.48	0.001
Time*Time	1	0.64499	0.64499	9.94	0.012
2-Way Interaction	2	1.29515	0.64758	9.98	0.005
Mass*Temperature	1	0.90188	0.90188	13.9	0.005
Mass*Time	1	0.04876	0.04876	0.75	0.408
Error	9	0.58381	0.06487		
Lack-of-Fit	4	0.11287	0.02822	0.3	0.867
Pure Error	5	0.47094	0.09419		
Total	16	4.54233			

Table 21. Model Summary for total soluble solids content

S	R-sq	R-sq(adj)	R-sq(pred)
0.254691	87.15%	77.15%	59.93%

Regression Model

$$T.S.S = 17.50 - 10.03X_1 - 0.1367X_2 - 0.0682X_3 + 1.790X_1^2 + 0.00749X_3^2 + 0.1316 - 0.0510X_1X_3$$

Where T.S.S is total soluble solids.

X_1 is mass of fruit

X_2 is temperature of extraction

X_3 is time of extraction

The model shows a good agreement with the theoretical predicted total soluble solids values and the experimentally measured total soluble solids values characterized by the high R^2 (77.15%) value. The lack-of-fit was not significant ($p > 0.05$). Temperature, time and the interaction of temperature and mass had significant effect on the total soluble solids content. From the analysis of variance table above, the linear, square and two-way interaction of the independent parameters significantly affects the total soluble solids content of the resulting juice. The total soluble solids content of the resulting juice per the analysis above is significantly affected by temperature and time only. The surface response for total soluble solids (Brix) against the independent variables (time, mass and temperature) is shown below.

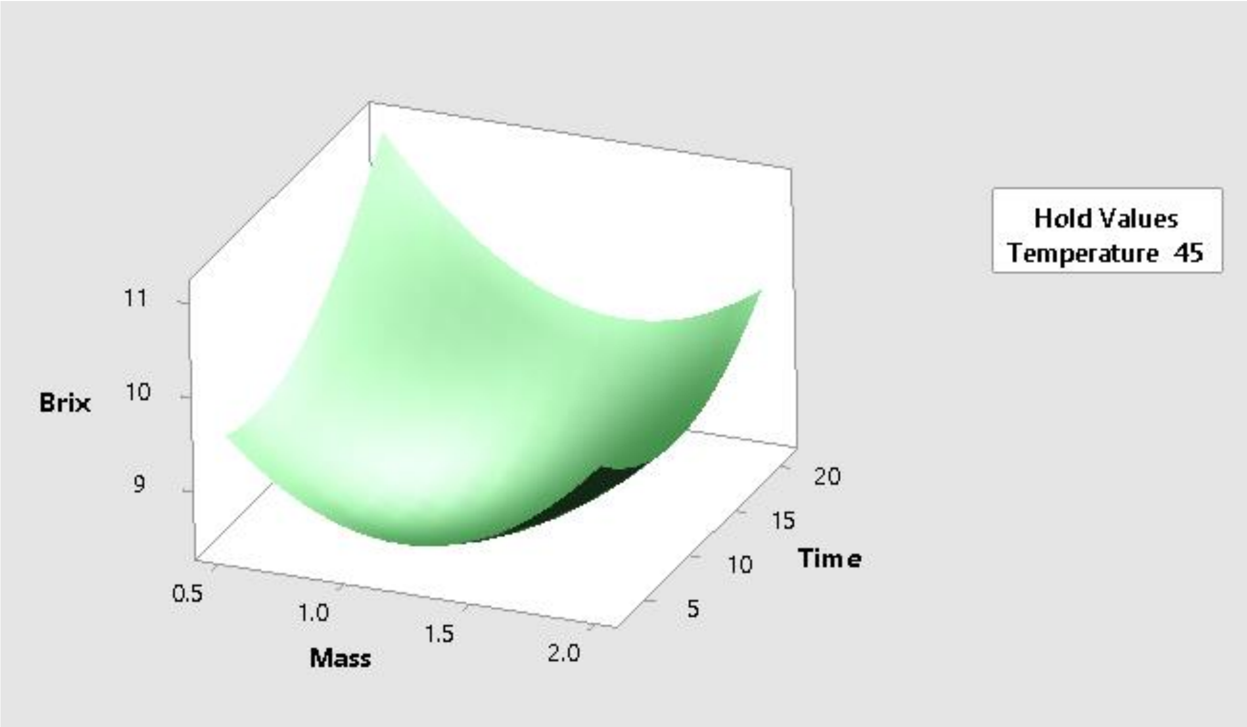

Illustration 17:Surface Plot of Brix vs Time, Mass

At constant temperature (45^{o}C), the highest total soluble solids content was observed at long extraction time of a small fruit mass as shown in illustration 17. The extraction of large quantity of noni fruits at a constant temperature for a long time primarily results in high juice yield which reduces the soluble solid content in the juice as compared to extraction of small fruit quantity for the same time duration, the possible reason for which the total soluble solids content of the later is higher than the former. From the surface plot of Brix vs Time and Mass (illustration 17), the highest total soluble solids content was obtained for extracting low mass for a long time. However, extracting large quantity of fruit for a long time also result in juice with high total soluble solids content but lower than the total soluble solids content for small mass long time extraction. This indicates that irrespective of the mass, for extraction at constant temperature, time is required to obtain high total soluble solids content of the resulting juice.

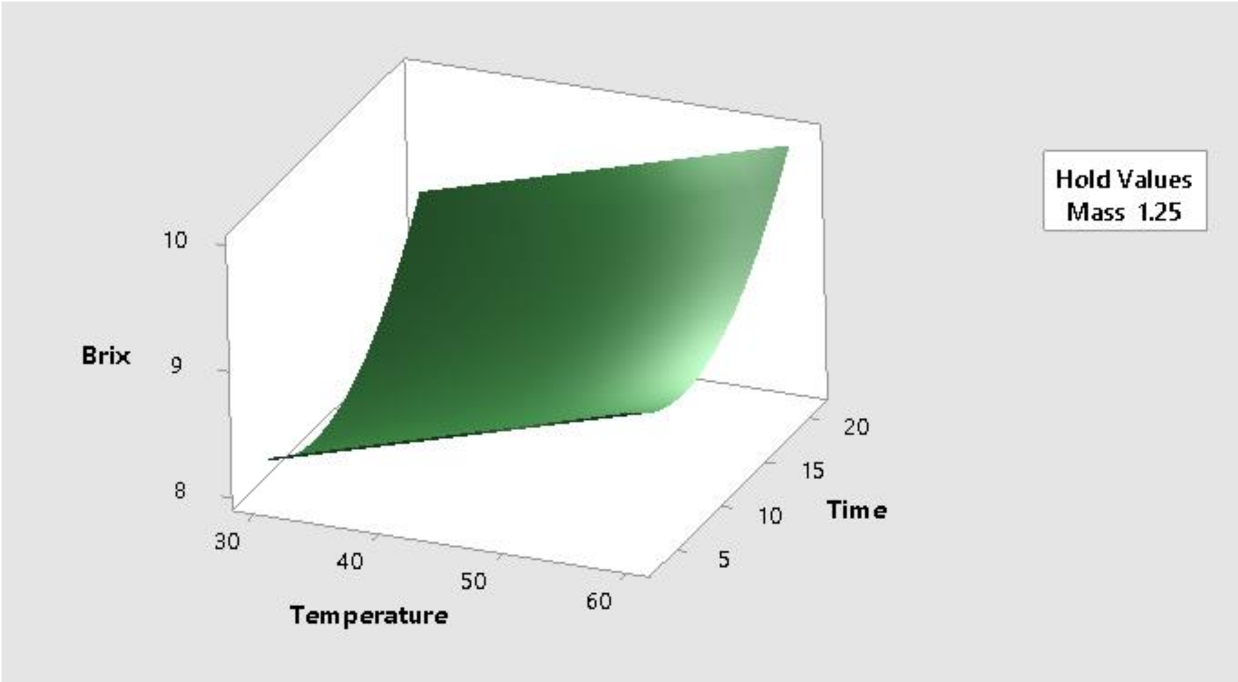

Illustration 18: Surface Plot of Brix vs Time, Temperature

For constant mass extraction, the total soluble solids content of the resulting juice increases with increase in temperature and time. From the surface plot of Brix against temperature and time (illustration 18) whiles mass of fruit is kept constant; the highest total soluble solids content is obtained for high temperature and long-time extraction. This indicates that time and temperature are critical parameters that affect the total soluble solids content of the resulting juice from drip extraction of noni.

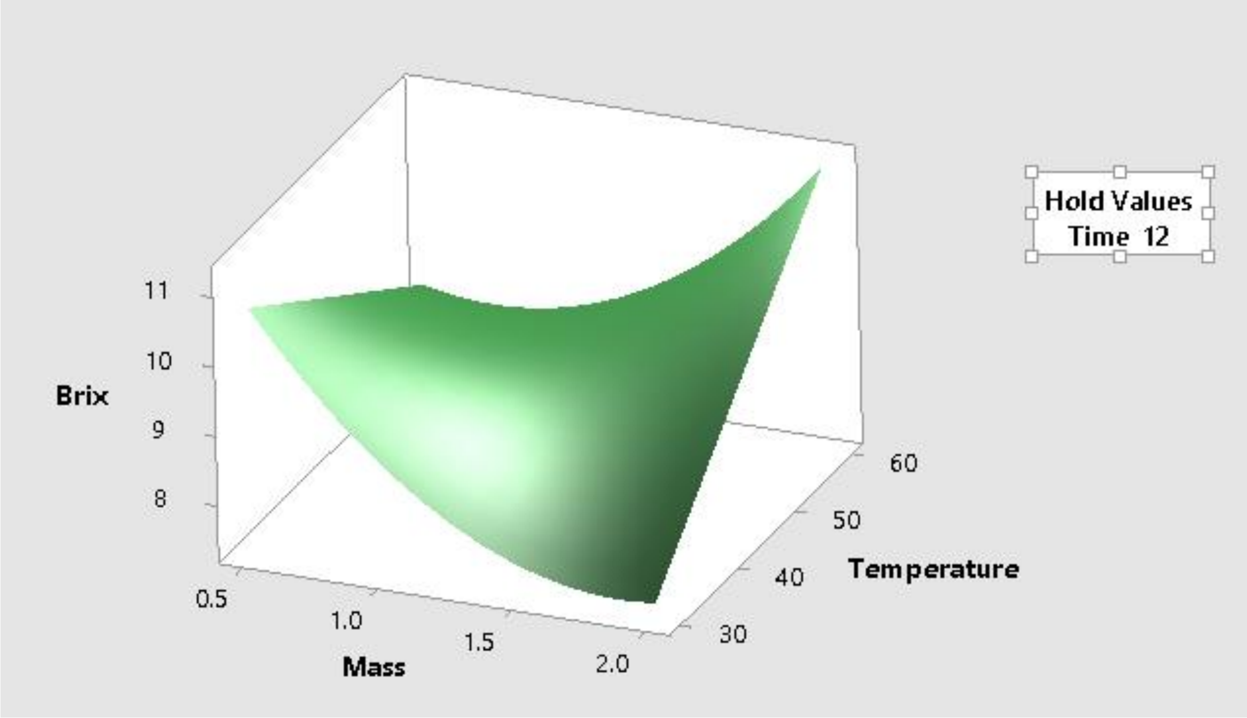

Illustration 19:Plot of Brix vs Temperature, Mass

From the surface plot of Brix against temperature and mass (illustration 19) whiles time is kept constant; it is seen that the total soluble solids content is high for juice extracted from low mass at low temperature. The total soluble solids content of the resulting juice drops as the quantity of fruit (mass) used for the extraction increased for low temperature extraction. However, for high temperature extraction at constant time the total soluble solids content of the resulting juice for small fruit mass is low but increases as the quantity of fruits for the extraction is increased at the high temperature. This implies that at constant time and low temperature total soluble solids content of resulting juice decreases with increase in mass, whereas the total soluble solids content of resulting juice extracted at high temperature increases with increase in mass of fruit used for the extraction at constant time.

4.8.3 Effect of mass, temperature and time on yield of resulting juice

According to the CCRD results, the yield of juice obtained after drip extraction increases with increase in temperature when time and mass of fruit used for the extraction are kept constant. Generally, the yield increases with increase in mass of fruit used for the extraction, the extraction temperature and the extraction time. However, analysis of variance for the effect of mass, temperature and time indicates that, the increase in as a result of time effect is statistically not significant. The analysis of variance for the effect of mass, temperature and time is shown below.

Table 22. Analysis of Variance for effect of mass, temperature and time on juice yield

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	109151	12127.9	11.81	0
Linear	3	86169	28723	27.96	0
Mass	1	80167	80167.1	78.04	0
Temperature	1	3993	3993	3.89	0.077
Time	1	2009	2008.9	1.96	0.192
Square	3	20425	6808.3	6.63	0.01
Mass*Mass	1	14043	14043.4	13.67	0.004
Temperature*Temperature	1	7287	7286.9	7.09	0.024
Time*Time	1	118	117.5	0.11	0.742
2-Way Interaction	3	2558	852.5	0.83	0.507
Mass*Temperature	1	899	899.1	0.88	0.372
Mass*Time	1	824	824.4	0.8	0.391
Temperature*Time	1	834	834.2	0.81	0.389
Error	10	10272	1027.2		
Lack-of-Fit	5	4269	853.9	0.71	0.641
Pure Error	5	6003	1200.6		
Total	19	119424			

Table 23. Model Summary for yield

S	R-sq	R-sq(adj)	R-sq(pred)
32.0505	91.40%	83.66%	65.50%

Regression Model

Yield (g) = $709 – 389X_1 - 24.2X_2 + 9.0X_3 + 156.4X_1^2 + 0.283X_2^2 - 0.100X_3^2 + 2.64X_1X_2$

$+ 4.22X_1X_3 - 0.214X_2X_3$

Where X_1 is mass of fruit

X_2 is temperature of extraction

X_3 is time of extraction

The high R^2 (83.66) value indicates that the model shows a good agreement between the theoretically predicted values of yield and the experimentally measured values of yield. From the analysis of variance table above, the linear and square interactions significantly affect the yield of the resulting juice. The temperature of extraction and the mass of fruit extracted also significantly affects the yield of the resulting juice. From the analysis of variance, the lack of fit is not significant ($p>0.05$) which further indicates that the model is acceptable. The Regression equation for juice yield is shown above. The surface plot for juice yield is shown below.

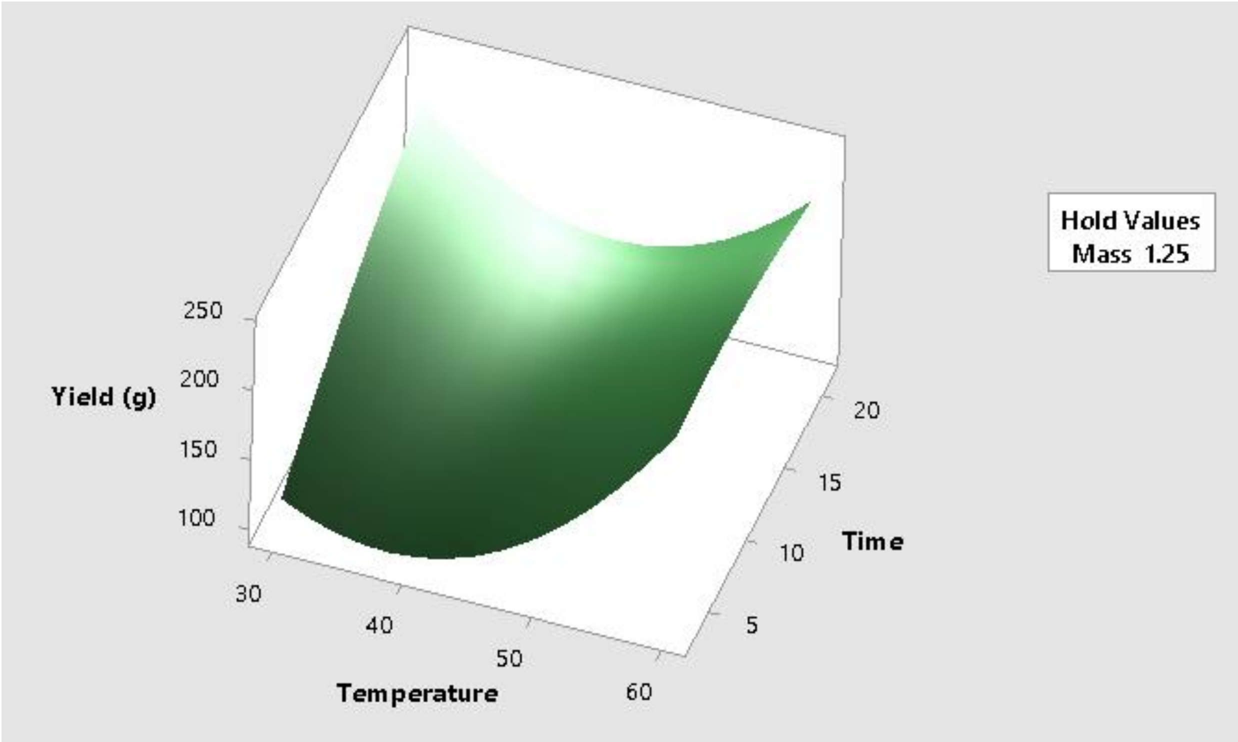

Illustration 20: Surface Plot of Yield (g) vs Time, Temperature

From the surface plot of yield against time and temperature where mass is kept constant above, the yield of juice increased with increase in extraction time and temperature. However, the highest yield was obtained for extraction at low temperature for long time.

It is important to note that the second highest yield was obtained for high temperature extraction for long time. This implies that for maximum yield time and temperature of extraction are critical.

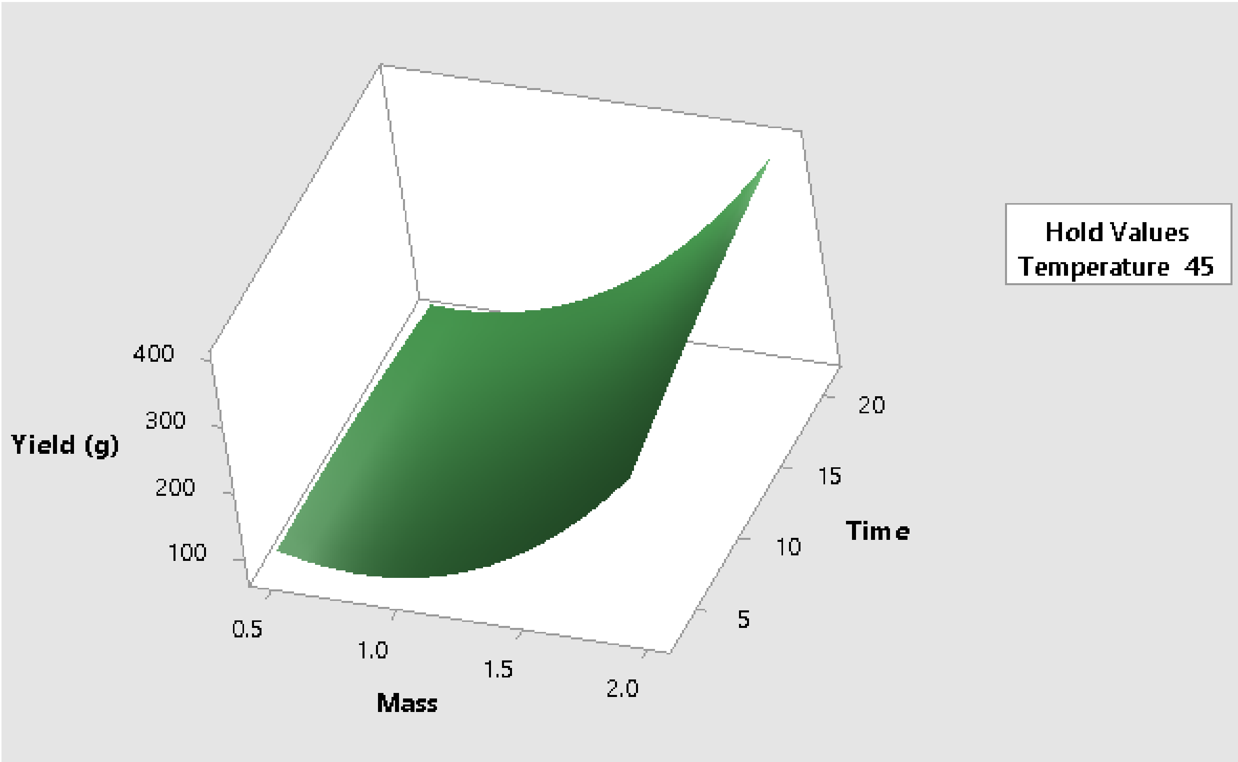

Illustration 21: Surface Plot of Yield (g) vs Time, Mass

For constant temperature extraction, the yield increases with increase in mass and time. The highest yield was obtained for the highest mass and highest time combination extraction whiles keeping the temperature constant. For high mass and short time extraction, the yield was high but relatively lower than the yield for long time extraction. Long extraction time gives the fruit more time for its content to exude as compared to short time extraction, this explains the lower yield in short time extraction when mass and temperature are constant.

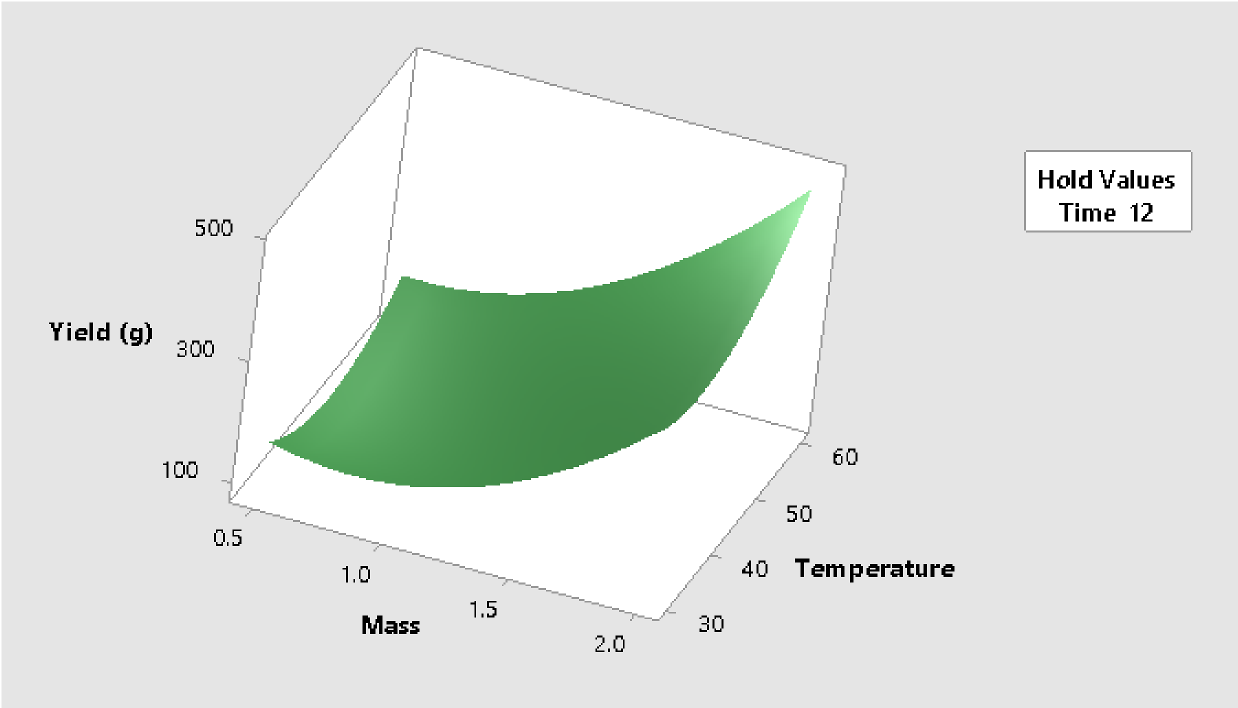

Illustration 22: Surface Plot of Yield (g) vs Temperature, Mass

High temperature increases the rate of transpiration in fruits which in turn improves the juice yield for juice extracted at high temperature, this explains the high yield of juice obtained from high extraction temperature and high mass as shown on the surface plot of yield against mass and temperature whiles time was kept constant. At low temperature and mass, the yield of the resulting juice was low but increased with increase in temperature and mass of fruit used for the extraction. From the diagram above, it can be said that the high temperature, mass of fruit and prolong extraction time are critical to maximizing the yield of the resulting juice of drip extraction.

From the analysis of the results, it was seen that different combinations of mass of fruit, temperature and time of extraction affects the yield, pH and total soluble solids content of resulting juice differently. However, a general observation that long extraction time of more or equal to 12 days and a complimentary low temperature of extraction is critical for obtaining low pH of the resulting juice.

It was also observed that, the combination of mass, temperature and time in each of the extractions yielded a juice with total soluble solids value greater than 7^{o}Brix. Therefore, the total soluble solids values obtained are higher than the total soluble solids content for the noni juice products on the Ghanaian market now, which has an average total soluble solids content of 7^{o}Brix. Finally, it was observed that the juice yield for all mass, time and temperature combination increased with increase in mass, time and temperature. This observation give room for manipulating any of the independent parameters to customise the dependent parameters of the resulting juice.

However, the aim of this research is to minimize the time required to drip juice out of the noni fruit. In view of this mass and temperature combinations that reduces the time required for extraction to obtain a desired juice is required. Based on the results obtained, a response optimization was run to maximize yield and produce a pH of 3.4 in the resulting juice. total soluble solids content of the resulting juice was set to 7.5^{o}Brix in the optimization due to the fact that, irrespective of the mass, time and temperature combination the total soluble solids content obtained is higher than the average total soluble solids content of the juice on the Ghanaian market. The response optimisation is shown below.

4.8.4 Response Optimization: Yield (g), total soluble solids content (^{o}Brix) and pH

The response optimization is aimed at maximizing yield and producing juice from noni fruit with a pH and total soluble solids content of 3.40 and 7.5^{o}Brix respectively. Minitab software was used to optimize the response.

Response	Goal	Lower	Target	Upper	Weight	Importance
Yield (g)	Maximum	82.56	342.23		1	1
Total soluble solids	Target	6.75	7.5	9.649	1	1
pH	Target	3.17	3.4	4.04	1	1

Table 24: Target of dependent parameters for optimized extraction

In order to obtain the required setpoints for the responses, the independent parameters below were predicted.

Variable	Setting
Mass (kg)	2
Temperature (**^{o}C)**	30.508
Time (day)	12.4089

Table 25: Independent parameter setting for optimization extraction

The predicted independent parameters correlate to a yield of 360g in addition to the predicted 3.4 pH and 7.5^{o}Brix (total soluble solids content) of the resulting juice.

Response	Fit	SE Fit	95% CI	95% PI
Yield (g)	360.3	45.3	(259.3, 461.3)	(236.6, 484.0)
Total soluble solids	7.5	0.497	(6.376, 8.624)	(6.237, 8.763)
pH	3.4	0.116	(3.134, 3.666)	(3.083, 3.717)

Table 26: Expected dependent parameters for optimized extraction

Based on the optimization result, four extractions were setup with a mass of 2 kg each and kept at 30.5 **^{o}C** for 12days 10 hours. After which the juice yield, total soluble solids content and pH of the resulting juice of all the setups was measured.

Setup	Yield (g)	Total soluble solids (°Brix)	pH
1	366.12	8.9	3.76
2	227.47	7.4	3.72
3	319.58	7	3.65
4	281.35	7.2	3.71
Average	**298.63**	**7.625**	**3.71**

Table 27: Experimental results for optimization extraction

Comparing the results of the actual extraction to the predicted optimization values of 3.4 pH, 7.5°Brix (total soluble solids content) and yield of 360g. it was seen that out of four extractions carried out with 2 kg of fruit for 12days 10 hours at 30.50°C, three of the total soluble solids content values of the resulting juices were comparable to the predicted total soluble solids content value from the optimization and two yield results were also comparable to the predicted yield value from the optimization. The average yield of the four extractions is 298 kg with a standard deviation of ±58.75 kg. The average yield compares to the predicted yield with a standard deviation of ±43.40 kg, the closeness of the experimental value to the predicted optimization values iterates the significance of CCRD to this research. The average total soluble solids content for the four experimental extraction is 7.625±0.866 and the average for the pH is 3.71±0.045. The average total soluble solids content of the experiment compares to the predicted total soluble solids content value with a standard deviation of ±0.09. The Average experimental pH value compares to the predicted pH value with a standard deviation of ±0.22. The experimental results of pH, total soluble solids and yield for drip extracting 2 kg of Noni fruit for 12days and 10hours at 30.5°C agree with the predicted pH, total soluble solids content and yield values. The deviations between the experimental values and the expected values of pH, total soluble solids content and yield are tolerable since the experimentally obtained values of total soluble solids content and pH fall within the range of total soluble solids content and pH of the noni juice on the local Ghanaian market. These results show that the regression equations are accurate and therefore the models are valid and reliable.

4.9 **Modification of Bioreactor Design**

The bioreactor that was initially designed for the drip extraction of noni juice at controlled temperature had separate chambers for the juice and the noni fruit during extraction, this separation was a flaw in the design which resulted in the production of noni juice with very low total soluble solids content. The fruit surface dried up during extraction at high temperature (45^{o}C and above) due to the presence of the separate chambers, this had made it necessary to redesign the bioreactor for the extraction.

It was reported by Nelson and Elevitch, in 2006 that the juice recovery for drip extraction of noni juice for 2 months is between 40% to 50%, however this juice recovery percentage was not realized in the experiment. The juice recovery for drip extraction of noni juice for 13days varied between 14.1% to 18.3%, introducing a press at this point will improve the juice recovery. In order to retain the properties of fermented noni juice and improve the juice recovery, it is important to press the fermented fruit and its exudate after 12 to 13days of drip extraction. Therefore, the new bioreactor design will incorporate a pressing accessory to press the fruits after the period of fermentation or dripping to improve the juice recovery to 60% of the fruit weight which close to the highest extractable juice from the noni fruit (65% of the fruit weight). It is important to note that without employing a press, drip extraction alone will not yield a more than 50% juice recovery.

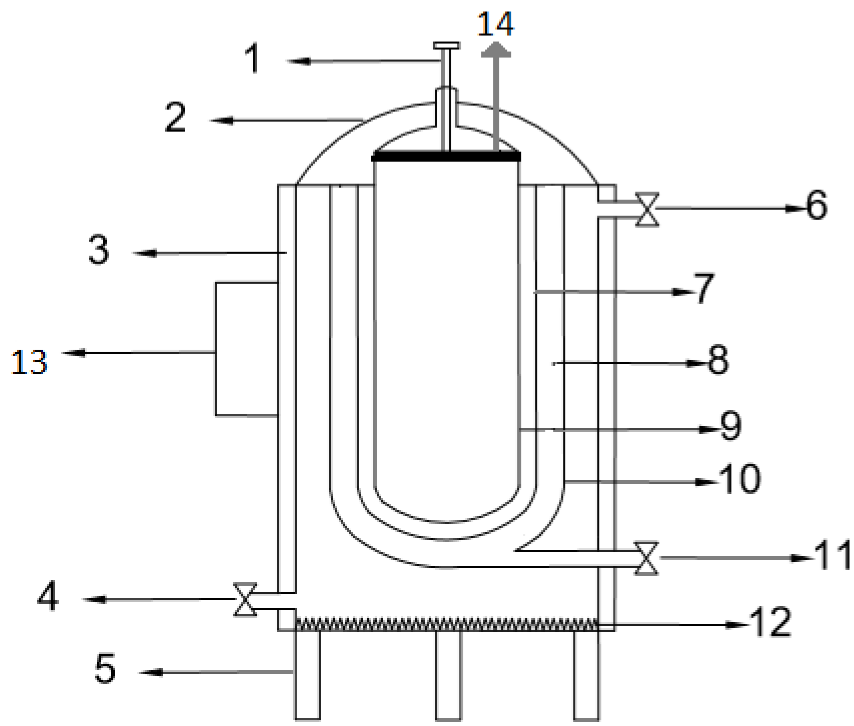

Figure 7: Bioreactor design with a press accessory

PART	DESCRIPTION	MATERIAL
1	Press rod	Stainless steel
2	Lid	Stainless steel
3	Insulation	Mineral wool
4	Heating medium outet	Stainless steel
5	Support	Stainless steel
6	Heating medium inlet	Stainless steel
7	Cloth sieve	Nylon
8	Juice holding space	
9	Metal sieve	Stainless steel
10	Internal surface	Stainless steel
11	Product outlet	Stainless steel
12	Heating Coil	Nichrome
13	Control box	Aluminium
14	Press plate	Stainless steel

Figure 8: Parts of modified bioreactor design

The design incorporates a threaded rod and press plate to press the fruits after fermentation. Pressing the fruits is achieved by turning the threaded rod to press down the fruits within the inner walls of a 355micron metal sieve in the bioreactor to expel the juice. The juice goes through a 250micron cloth sieve before entering the juice holding area. The juice holding area allows the fruit to sit in the juice during the drip extraction (fermentation) period, this improves the total soluble solids content of the resulting juice.

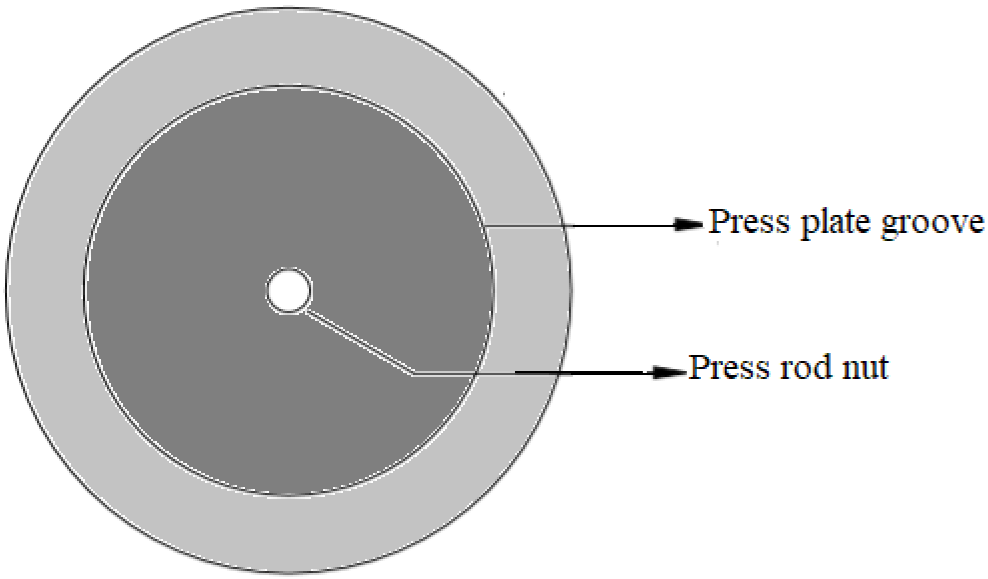

Figure 9: Modified Bioreactor lid

The main structural differences between the first design and the modified design are the absence of the conical base of the interior chamber that opens to the product outlet, absence of separation in the extraction chamber and the presence of the press accessories. The press accessories comprise of a stainless-steel press plate, a threaded rod and a 355micron metal sieve. There is an optional 250micron cloth sieve which can be placed in the bioreactor before the 355micron sieve to further remove particles in the resulting juice.

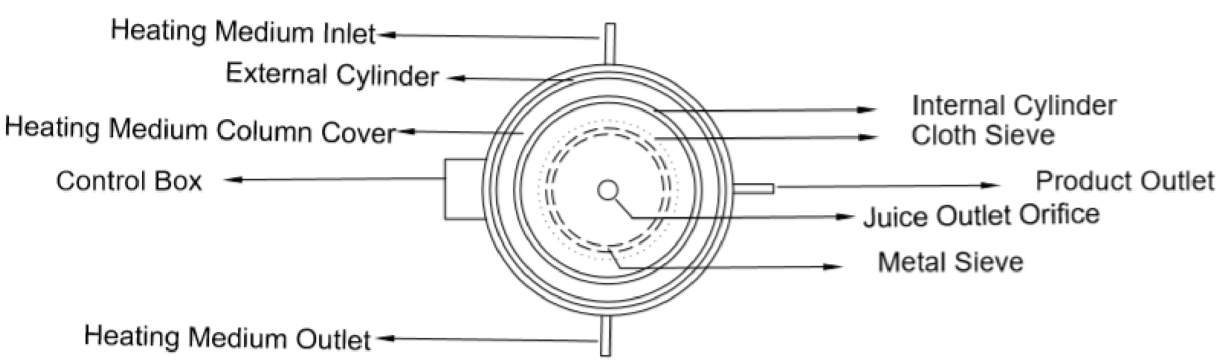

Figure 10: Cross-sectional view of modified bioreactor design

Temperature control is achieved by means of electrical energy via a heating coil connected to a contactor which is also connected to PID controller just as in the first design.

The improved bioreactor works by first setting the extraction temperature on the PID controller for the empty bioreactor before charging the assembled bioreactor without lid and pressing rod and plate with noni fruits, after which the clean and dry press plate is place on the fruits in the 355micron metal sieve inside the bioreactor and covered with the lid. The fruits and the bioreactor are then left for the juice to drip off the fruit for a pre-determined period after which the product outlet tap is opened to collect the dripped juice. Whiles collecting the dripped juice the screw rod is fixed to the lid and turned to press the drip extracted fruits in the bioreactor to extract juice that would otherwise remain in the fruit.

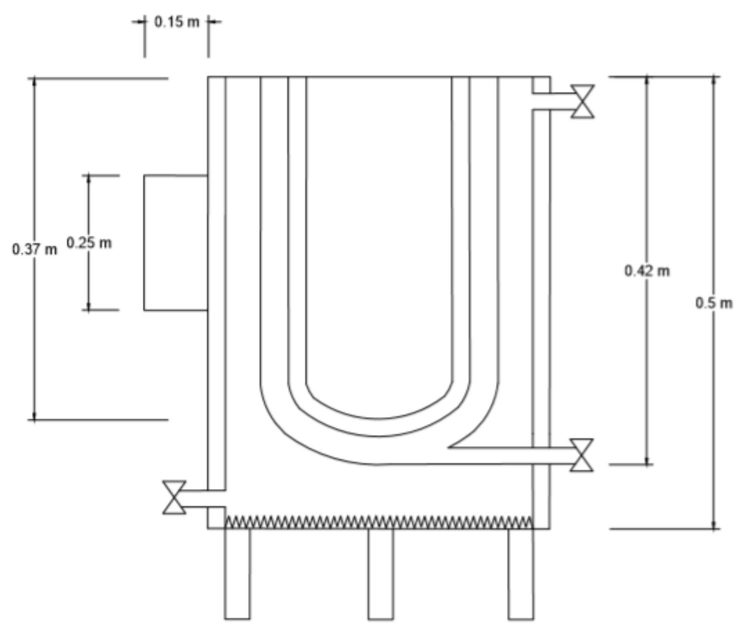

Figure 11:Dimensions of modified bioreactor

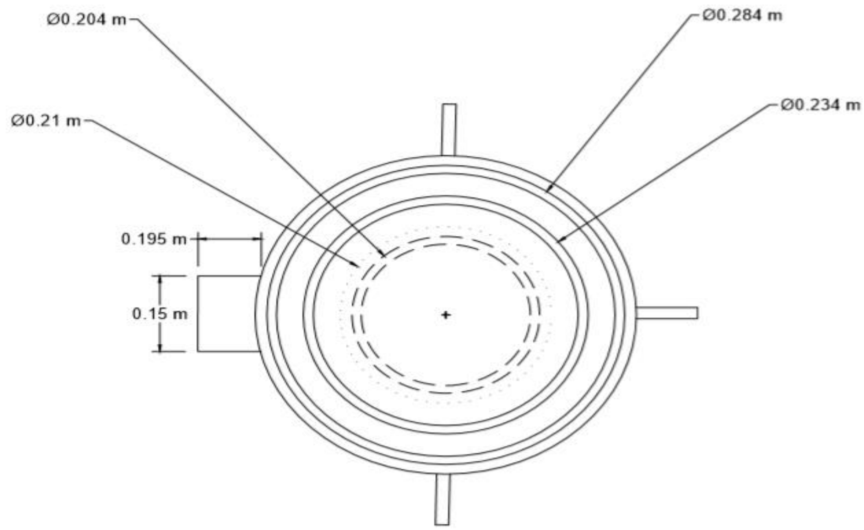

Figure 12: Cross-sectional dimension of modified bioreactor

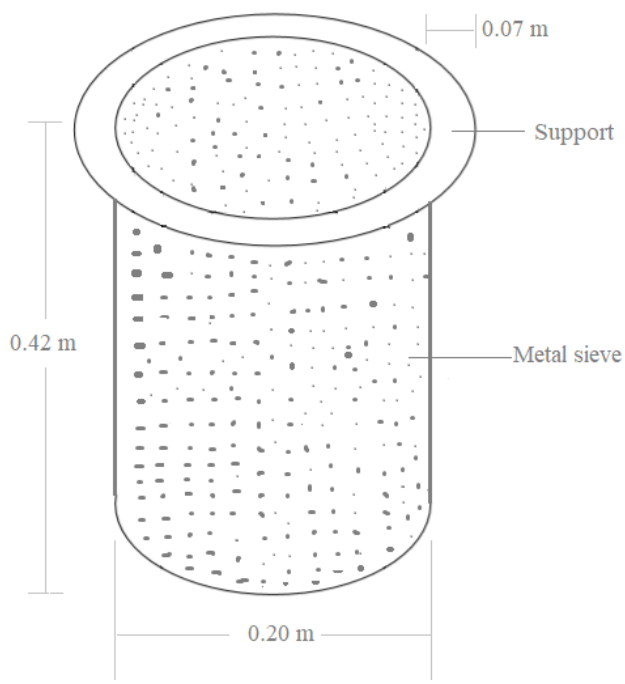

Figure 13: Metal sieve with dimensions

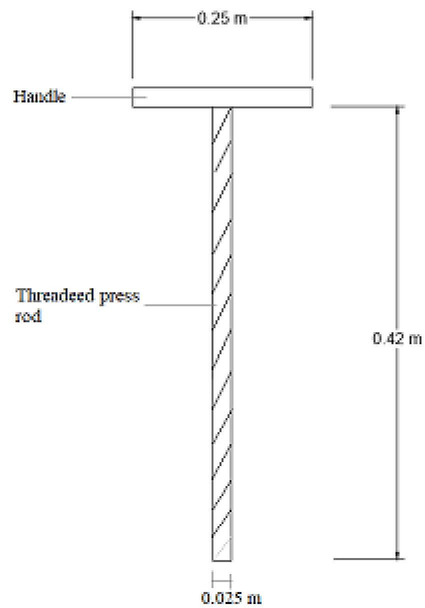

Figure 14: Press rod with dimensions

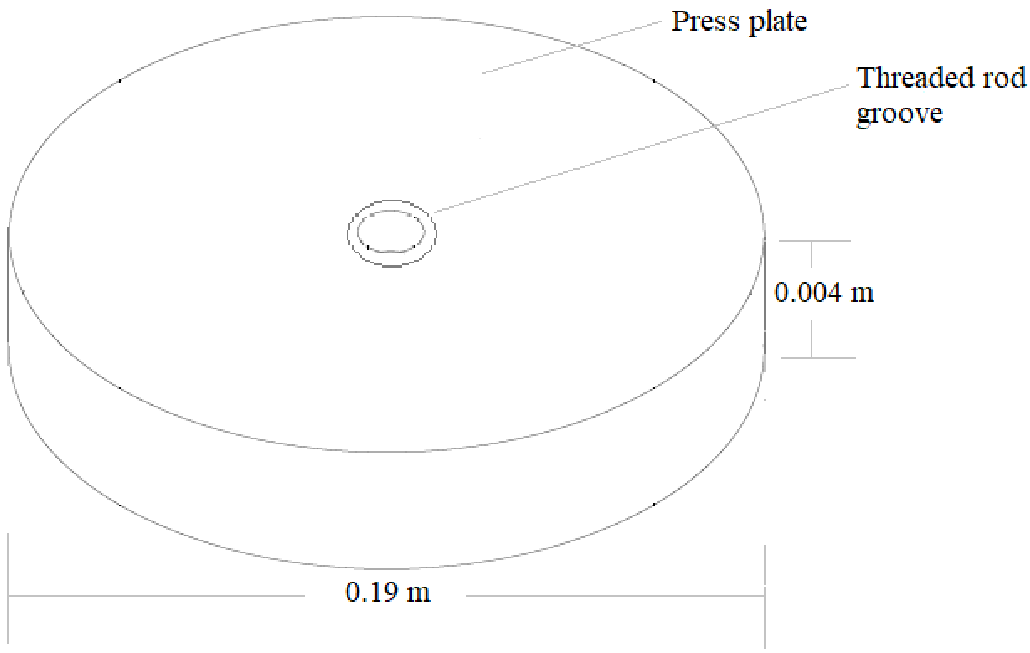

Figure 15: Press plate with dimension

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

The idea behind design and fabrication of a bioreactor and the drip extraction of noni juice at a controlled temperature was to help reduce the time taken for drip extraction of noni juice as well as increase the extraction efficiency. The study showed that temperature, time and mass affect the quality parameters of noni juice of which total soluble solids content and pH were considered in this study. The pH of drip extracted noni juice is dependent mainly on the temperature of extraction and duration of extraction, that is extraction at temperature of 30±2^{o}C favors the production of low pH noni juice. However, extraction at low temperature does not favor yield and the extraction efficiency but extraction at high temperature improves the yield of the extraction and subsequently the extraction efficiency. The improvement in yield for high temperature extraction can be attributed to increase rate of transpiration in the fruit at such temperatures, also this increase in rate of transpiration basically increases the amount of water in the extraction system which directly increases the pH of the resulting juice. Extraction at high temperature increases the pH of the resulting juice due to the fact that high temperature reduces the activities of microorganisms or perhaps even destroys the organisms that are possibly fermenting the fruit in addition to the high water content of the juice due to increased transpiration rate. It is reported that the microflora of the noni juice during drip extraction consist mainly of yeast and lactic acid bacteria (Kantachote *et al.,* 2009). The optimum temperature for yeast varies between 32^{o}C and 35^{o}C whiles that of lactic acid bacteria varies between 20^{o}C and 45^{o}C hence extraction at temperatures above 45^{o}C significantly reduce their activity.

From the study, total soluble solids content is affected visibly by temperature and time of extraction. High extraction temperature (60^{o}C) and prolong extraction time results in juice with high total soluble solids content, thus total soluble solids content in the resulting juice increases with increase in extraction time and temperature. Yield of juice also increase with increase in time of extraction and temperature of extraction.

For a constant mass extraction different time and temperature combinations result in juice with different yield, pH and total soluble solids content. However, the objective of this research is to shorten the time required to drip a batch of noni juice and to obtain juice with acceptable quality parameters. Reducing the extraction time will produce low yield juice with acceptable total soluble solids content and pH when the extraction is carried out at low temperature. For high temperature extraction for a reduced time, the yield is higher than that for low temperature extraction. The increase in yield results in increase of pH in the resulting juice.

Having control of the noni juice extraction temperature and extracting the juice at a constant temperature produces more consistent juice in terms of quality compared to the traditional extraction of the noni juice where temperature of extraction is not controlled. Dripping noni juice at a constant temperature ensures that the rate of deterioration of the noni fruit is constant throughout the extraction period. However, the deterioration of the noni fruit requires temperature below 45^{o}C. Drip extraction at constant temperatures below 45^{o}C causes the deterioration of the noni fruit to be steady but not fast enough to significantly reduce the extraction time and improve the juice recovery. Extraction above 45^{o}C damages the microorganisms which reduces or stops the deterioration of the noni juice and prevents production of consistent fermented noni juice.

Drip extraction of noni juice for two months results in a juice recovery of 40% to 50% of the fruit weight, but the noni fruit has 65% extractable juice. Reducing the extraction time and extracting the juice at 30±2^{o}C further reduces the juice recovery to 14% to 18.30% of the fruit weight, therefore incorporating a press into the drip extracting process will increase the juice recovery. Drip extraction cannot be 60% efficient because the noni mass after ageing withholds some of the juice except with the application of a press, to press the juice out of the remains of the noni fruit after drip extraction period. A combined bioreactor and press system will significantly improve drip extraction of noni juice. A bioreactor designed with a press accessory to produce noni juice with improved juice yield and retained properties of a fermented juice.

5.1 Recommendations

Based on the results and observations of research work carried out, it is recommended that.

1. Drip extraction of noni juice should be carried out at temperatures below 45^{o}C to ensure the pH of the resulting juice is right.
2. In drip extraction setups where water is added before the onset of the extraction, the water added should not be more than 10% of the fruit weight. This will ensure that the physiochemical properties of the resulting juice are not significantly affected by the added water.
3. The time required to obtain a fermented noni juice should be reduced by employing a press to press the noni fruit after dripping or fermenting the fruit and exuded juice for a minimum of 14days.

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APPENDICES

Appendix 1: Texture analysis of harvested noni fruits prior to extraction

Fruits analyzed after one (1) hour of harvest

Sample No.	Peak Load (g)	Peak Deformation (mm)	Work (mJ)	Final Load (g)	ADH Force(g)	Adhesion (mJ)
1a	8677	20	838.6	8677	114	5430.6
1b	10066	20	851.8	10066	207	8403.6
1c	7983	15.5	690	7065	98	7339.4
2a	8995	19.4	752.5	8946	89	4345.7
2b	8299	18.9	598.9	7978	103	6322.4
2c	7811	20	597.2	7811	100	14007
3a	11878	19.9	1021.4	10741	263	26332.8
3b	10891	20	960.2	10886	291	11133.4
3c	11730	20	692.1	11631	65	1627.9
4a	8453	19.2	691.9	8132	252	44228.8
4b	11054	19.7	930.2	10990	306	40800.3
4c	10493	19.6	817.1	10356	89	4138.3
5a	8063	19.6	822.5	7886	180	10860.9
5b	9461	20	825.6	9461	172	11203.6
5c	9801	20	801.4	9801	120	110434.9
AVERAGE	**9577**	**19.45333333**	**792.76**	**9361.8**	**163.2666667**	**20440.64**

Fruits analyzed after 24 hours

Sample No.	Peak Load (g)	Peak Deformation (mm)	Work (mJ)	Final Load (g)	ADH Force(g)	Adhesion (mJ)

1a	223	20	15.5	214	5	192.5
1b	186	20	18.8	177	6	277.3
1c	186	19.1	13.6	110	5	211.8
2a	892	19.7	66.6	891	6	460.3
2b	734	20	62.2	734	13	500.2
2c	718	20	59.9	718	25	1074.1
3a	1226	20	76.8	1226	12	296.8
3b	231	20	20.3	220	7	266.4
3c	98	20	7.3	87	6	203.2
4a	5848	20	620.6	5848	150	6452
4b	323	20	23	315	3	29.3
4c	206	17	13.3	150	7	1523.3
5a	7772	19.2	690.1	7564	84	2850.6
5b	9517	20	747.7	9517	121	25821.3
5c	9441	20	741.8	9441	77	4641.5
AVERAGE	**2506.733333**	**19.66666667**	**211.83333**	**2480.8**	**35.13333333**	**2986.706667**

fruits analyzed after 32 hours

Sample No.	**Peak Load (g)**	**Peak Deformation (mm)**	**Work (mJ)**	**Final Load (g)**	**ADH Force(g)**	**Adhesion (mJ)**
1a	514	19.9	37.4	514	5	93.7
1b	509	20	46.5	509	7	253.3
1c	220	18.4	26	217	7	344.6
2a	988	15.8	104.7	949	13	583.5
2b	487	20	35.1	487	11	63.9
2c	453	20	36.5	434	4	233.6
3a	3424	20	247	3398	8	302.6
3b	500	20	36.3	500	9	517.6

3c	207	20	14.2	207	7	471
4a	724	20	70.9	719	13	772.1
4b	1028	20	73	1024	12	622.1
4c	2216	15.8	222.4	2049	27	1151.3
5a	10561	20	937.3	10561	101	4458.1
5b	10415	20	993.4	10415	148	13569.9
5c	8866	19.4	761.1	8606	266	45892.8
AVERAGE	**2740.8**	**19.28666667**	**242.78667**	**2705.933333**	**42.53333333**	**4622.006667**

Fruits analyzed after 46 hours

Sample No.	**Peak Load (g)**	**Peak Deformation (mm)**	**Work (mJ)**	**Final Load (g)**	**ADH Force(g)**	**Adhesion (mJ)**
1a	507	18.1	35.7	358	5	176.1
1b	523	20	52.1	505	23	1435.7
1c	345	20	33.8	337	4	250.6
2a	307	19.6	25.5	290	5	70.3
2b	228	20	20.3	228	6	363.4
2c	127	20	10.6	127	3	160.5
3a	844	20	70.6	844	6	705.9
3b	451	20	44.7	451	20	1639.1
3c	215	20	18.7	207	3	51.3
4a	521	16.8	41.8	411	9	240.9
4b	434	20	34.5	424	5	138.1
4c	169	18.8	13.5	150	5	299.5
5a	444	20	44	437	6	248.6
5b	498	20	43.6	488	9	1205
5c	329	18.8	30.3	309	12	410.5
AVERAGE	**396.1333**	**19.4733**	**34.6467**	**371.0667**	**8.0667**	**493.0333**

Fruits analyzed after 54 hours

Sample No.	Peak Load (g)	Peak Deformation (mm)	Work (mJ)	Final Load (g)	ADH Force(g)	Adhesion (mJ)
1a	193	20	18.2	183	8	373.2
1b	103	19.3	7.9	101	7	436.3
1c	80	20	7.9	80	7	453.6
2a	151	20	14.2	151	12	741.4
2b	102	19.5	7.9	91	8	835.5
2c	63	20	5.8	63	7	9495
3a	469	20	45.1	469	11	536.3
3b	292	20	29.7	279	10	763.5
3c	158	16.7	11.5	84	5	176.2
4a	240	20	23.6	240	7	292.1
4b	173	20	14.1	164	6	356.2
4c	150	20	11.4	140	6	268.2
5a	354	20	28	339	12	702.2
5b	339	20	29	339	13	714.5
5c	114	13.3	9.7	94	8	673.1
AVERAGE	**198.7333**	**19.2533**	**17.6**	**187.8**	**8.4667**	**1121.153**

Texture analysis summary table

Time after harvest (H)	Peak Load (g)	Work (mJ)	Final Load (g)	ADH Force(g)	Adhesion (mJ)
1	9577	792.76	9361.8	163.27	20440.64

24	2506.73	211.83	2480.8	35.13	2986.71
32	2740.8	242.79	2705.93	42.53	4622.01
46	396.13	34.647	371.07	8.07	493.03
54	198.73	17.6	187.8	8.47	1121.15

Appendix 2: Temperature monitoring for indoor and outdoor extraction

Indoor extraction temperature monitoring

Time (hr)	Temp. (ºC)	Hum (%RH)	Dew Point (ºC)
0.17	29.52	82.7	26.26
0.33	29.60	88.25	27.44
0.50	29.28	89.43	27.36
0.67	29.08	90.25	27.32
0.83	28.92	90.85	27.27
1.00	28.80	91.24	27.22
1.17	28.72	91.56	27.21
1.33	28.68	91.79	27.21
1.50	28.64	92	27.21
1.67	28.64	92.2	27.24
1.83	28.56	92.32	27.19
2.00	28.56	92.47	27.22
2.17	28.52	92.58	27.19
2.33	28.48	92.67	27.17
2.50	28.44	92.73	27.14
2.67	28.40	92.79	27.12
2.83	28.40	92.89	27.13
3.00	28.36	92.92	27.10
3.17	28.32	92.99	27.07
3.33	28.32	93.06	27.09
3.50	28.28	93.1	27.06
3.67	28.28	93.14	27.06
3.83	28.24	93.18	27.03
4.00	28.24	93.23	27.04
4.17	28.24	93.28	27.05
4.33	28.20	93.29	27.01
4.50	28.20	93.32	27.02

4.67	28.16	93.35	26.98
4.83	28.16	93.4	26.99
5.00	28.16	93.42	26.99
5.17	28.12	93.44	26.96
5.33	28.12	93.46	26.96
5.50	28.12	93.49	26.97
5.67	28.12	93.53	26.98
5.83	28.08	93.52	26.93
6.00	28.08	93.57	26.94
6.17	28.08	93.6	26.95
6.33	28.08	93.62	26.95
6.50	28.08	93.62	26.95
6.67	28.04	93.66	26.92
6.83	28.04	93.66	26.92
7.00	28.00	93.69	26.88
7.17	28.00	93.69	26.88
7.33	28.00	93.72	26.89
7.50	28.00	93.74	26.89
7.67	27.96	93.73	26.86
7.83	27.92	93.75	26.82
8.00	27.92	93.77	26.82
8.17	27.92	93.77	26.82
8.33	27.92	93.77	26.82
8.50	27.92	93.82	26.83
8.67	27.88	93.81	26.79
8.83	27.88	93.83	26.79
9.00	27.88	93.83	26.79
9.17	27.88	93.85	26.79
9.33	27.84	93.84	26.76
9.50	27.84	93.87	26.76
9.67	27.84	93.89	26.76
9.83	27.84	93.89	26.76
10.00	27.84	93.89	26.76
10.17	27.84	93.92	26.77
10.33	27.84	93.94	26.77
10.50	27.80	93.93	26.73
10.67	27.80	93.93	26.73
10.83	27.76	93.94	26.69
11.00	27.80	93.95	26.73
11.17	27.80	93.98	26.74
11.33	27.84	93.99	26.78

11.50	27.84	93.99	26.78
11.67	27.84	93.99	26.78
11.83	27.92	94.01	26.86
12.00	27.92	93.98	26.86
12.17	27.96	93.97	26.89
12.33	28.00	93.98	26.94
12.50	28.04	93.99	26.98
12.67	28.08	94	27.02
12.83	28.08	93.95	27.01
13.00	28.12	93.96	27.06
13.17	28.12	93.96	27.06
13.33	28.12	93.94	27.05
13.50	28.12	93.96	27.06
13.67	28.12	93.91	27.04
13.83	28.16	93.92	27.09
14.00	28.24	93.9	27.16
14.17	28.24	93.87	27.16
14.33	28.20	93.86	27.12
14.50	28.20	93.86	27.12
14.67	28.24	93.85	27.15
14.83	28.24	93.85	27.15
15.00	28.28	93.84	27.19
15.17	28.40	93.84	27.31
15.33	28.48	93.82	27.38
15.50	28.60	93.77	27.49
15.67	28.64	93.76	27.53
15.83	28.64	93.71	27.52
16.00	28.60	93.7	27.48
16.17	28.56	93.69	27.44
16.33	28.60	93.68	27.48
16.50	28.60	93.65	27.47
16.67	28.64	93.66	27.52
16.83	28.64	93.66	27.52
17.00	28.72	93.64	27.59
17.17	28.80	93.61	27.66
17.33	28.80	93.56	27.66
17.50	28.84	93.57	27.69
17.67	28.88	93.56	27.73
17.83	28.92	93.52	27.77
18.00	28.92	93.5	27.76
18.17	28.96	93.46	27.79

18.33	28.96	93.46	27.79
18.50	28.96	93.43	27.79
18.67	28.96	93.41	27.78
18.83	28.96	93.39	27.78
19.00	28.96	93.36	27.78
19.17	28.96	93.36	27.78
19.33	28.96	93.34	27.77
19.50	29.00	93.32	27.81
19.67	29.04	93.33	27.85
19.83	29.04	93.31	27.84
20.00	29.00	93.28	27.80
20.17	29.00	93.28	27.80
20.33	29.04	93.29	27.84
20.50	29.04	93.24	27.83
20.67	29.04	93.24	27.83
20.83	29.04	93.24	27.83
21.00	29.04	93.21	27.83
21.17	29.04	93.19	27.82
21.33	29.04	93.19	27.82
21.50	29.00	93.18	27.78
21.67	28.96	93.19	27.74
21.83	28.96	93.22	27.75
22.00	28.88	93.22	27.67
22.17	28.80	93.23	27.59
22.33	28.76	93.26	27.56
22.50	28.72	93.28	27.52
22.67	28.64	93.31	27.45
22.83	28.60	93.32	27.41
23.00	28.48	93.29	27.29
23.17	28.44	93.33	27.26
23.33	28.40	93.32	27.22
23.50	28.40	93.37	27.22
23.67	28.36	93.36	27.18
23.83	28.32	93.35	27.14
24.00	28.32	93.35	27.14
24.17	28.28	93.36	27.10
24.33	28.28	93.36	27.10
24.50	28.28	93.38	27.11
24.67	28.28	93.36	27.10
24.83	28.24	93.37	27.07
25.00	28.24	93.35	27.06

25.17	28.24	93.35	27.06
25.33	28.20	93.34	27.02
25.50	28.20	93.32	27.02
25.67	28.16	93.31	26.97
25.83	28.16	93.31	26.97
26.00	28.12	93.3	26.93
26.17	28.12	93.3	26.93
26.33	28.08	93.24	26.88
26.50	28.08	93.24	26.88
26.67	28.08	93.24	26.88
26.83	28.08	93.24	26.88
27.00	28.08	93.21	26.88
27.17	28.08	93.19	26.87
27.33	28.08	93.19	26.87
27.50	28.04	93.16	26.83
27.67	28.00	93.15	26.78
27.83	28.00	93.12	26.78
28.00	28.00	93.12	26.78
28.17	27.96	93.11	26.74
28.33	27.96	93.09	26.73
28.50	27.92	93.05	26.69
28.67	27.92	93.05	26.69
28.83	27.96	93.04	26.73
29.00	27.96	93.02	26.72
29.17	27.96	93.02	26.72
29.33	27.92	92.98	26.68
29.50	27.92	92.96	26.67
29.67	27.88	92.95	26.63
29.83	27.84	92.91	26.58
30.00	27.84	92.89	26.58
30.17	27.84	92.89	26.58
30.33	27.84	92.89	26.58
30.50	27.80	92.83	26.53
30.67	27.84	92.84	26.57
30.83	27.80	92.83	26.53
31.00	27.76	92.77	26.48
31.17	27.76	92.77	26.48
31.33	27.76	92.77	26.48
31.50	27.72	92.76	26.44
31.67	27.72	92.72	26.43
31.83	27.68	92.71	26.39

32.00	27.64	92.7	26.35
32.17	27.64	92.67	26.34
32.33	27.60	92.64	26.29
32.50	27.60	92.64	26.29
32.67	27.60	92.64	26.29
32.83	27.60	92.61	26.29
33.00	27.60	92.61	26.29
33.17	27.56	92.58	26.24
33.33	27.52	92.57	26.21
33.50	27.52	92.57	26.21
33.67	27.52	92.55	26.20
33.83	27.52	92.55	26.20
34.00	27.48	92.51	26.16
34.17	27.48	92.51	26.16
34.33	27.48	92.51	26.16
34.50	27.44	92.5	26.11
34.67	27.44	92.5	26.11
34.83	27.44	92.48	26.11
35.00	27.44	92.45	26.11
35.17	27.44	92.48	26.11
35.33	27.40	92.45	26.06
35.50	27.44	92.45	26.11
35.67	27.48	92.46	26.14
35.83	27.52	92.47	26.19
36.00	27.56	92.46	26.22
36.17	27.60	92.49	26.27
36.33	27.60	92.49	26.27
36.50	27.68	92.51	26.36
36.67	27.72	92.52	26.39
36.83	27.72	92.52	26.39
37.00	27.76	92.53	26.44
37.17	27.84	92.51	26.51
37.33	27.92	92.53	26.59
37.50	28.00	92.55	26.68
37.67	28.08	92.57	26.76
37.83	28.16	92.54	26.83
38.00	28.20	92.52	26.87
38.17	28.28	92.54	26.96
38.33	28.28	92.52	26.95
38.50	28.32	92.53	26.99
38.67	28.36	92.49	27.02

38.83	28.40	92.48	27.06
39.00	28.44	92.46	27.09
39.17	28.52	92.48	27.18
39.33	28.56	92.47	27.22
39.50	28.64	92.46	27.29
39.67	28.64	92.44	27.29
39.83	28.64	92.42	27.28
40.00	28.68	92.38	27.32
40.17	28.72	92.39	27.36
40.33	28.68	92.38	27.32
40.50	28.68	92.38	27.32
40.67	28.64	92.34	27.27
40.83	28.68	92.35	27.31
41.00	28.80	92.41	27.44
41.17	28.92	92.44	27.57
41.33	29.00	92.43	27.64
41.50	29.04	92.42	27.68
41.67	29.04	92.39	27.68
41.83	29.08	92.4	27.72
42.00	29.12	92.39	27.76
42.17	29.12	92.39	27.76
42.33	29.12	92.39	27.76
42.50	29.16	92.4	27.80
42.67	29.16	92.35	27.79
42.83	29.20	92.36	27.83
43.00	29.20	92.36	27.83
43.17	29.24	92.35	27.87
43.33	29.28	92.33	27.91
43.50	29.32	92.34	27.94
43.67	29.36	92.33	27.98
43.83	29.36	92.33	27.98
44.00	29.32	92.29	27.93
44.17	29.24	92.3	27.86
44.33	29.20	92.31	27.82
44.50	29.12	92.32	27.74
44.67	29.12	92.39	27.76
44.83	29.08	92.43	27.72
45.00	29.08	92.52	27.74
45.17	29.04	92.54	27.71
45.33	29.04	92.56	27.71
45.50	29.04	92.61	27.72

45.67	29.00	92.63	27.68
45.83	28.96	92.74	27.66
46.00	28.96	92.83	27.68
46.17	28.88	92.84	27.60
46.33	28.84	92.95	27.58
46.50	28.76	93.02	27.52
46.67	28.72	93.11	27.49
46.83	28.68	93.12	27.46
47.00	28.64	93.19	27.43
47.17	28.56	93.31	27.37
47.33	28.56	93.38	27.38
47.50	28.52	93.49	27.37
47.67	28.44	93.57	27.30
47.83	28.44	93.64	27.31
48.00	28.40	93.77	27.29
48.17	28.40	93.91	27.32
48.33	28.40	93.99	27.33
48.50	28.36	94.21	27.34
48.67	28.32	94.3	27.31
48.83	28.28	94.38	27.29
49.00	28.24	94.47	27.27
49.17	28.24	94.56	27.28
49.33	28.24	94.73	27.31
49.50	28.24	94.8	27.32
49.67	28.24	94.94	27.35
49.83	28.24	95.08	27.37
50.00	28.24	95.36	27.43
50.17	28.24	95.52	27.46
50.33	28.24	95.62	27.47
50.50	28.28	95.82	27.54
50.67	28.24	95.92	27.53
50.83	28.24	96.08	27.56
51.00	28.28	96.3	27.63
51.17	28.24	96.43	27.62
51.33	28.24	96.57	27.64
51.50	28.24	96.66	27.66
51.67	28.20	96.79	27.64
51.83	28.24	96.94	27.71
52.00	28.20	97.07	27.69
52.17	28.16	97.15	27.66
52.33	28.16	97.24	27.68

52.50	28.16	97.33	27.69
52.67	28.12	97.48	27.68
52.83	28.12	97.69	27.72
53.00	28.08	97.84	27.71
53.17	28.08	97.93	27.72
53.33	28.08	98.09	27.75
53.50	28.00	98.2	27.69
53.67	28.00	98.36	27.72
53.83	27.96	98.51	27.70
54.00	27.96	98.8	27.76
54.17	27.92	99.09	27.76
54.33	27.92	99.18	27.78
54.50	27.92	99.27	27.79
54.67	27.88	99.48	27.79
54.83	27.88	99.61	27.81
55.00	27.84	99.91	27.83
55.17	27.84	100.27	27.89
55.33	27.84	100.36	27.90
55.50	27.80	100.7	27.92
55.67	27.80	100.83	27.94
55.83	27.80	101.01	27.97
56.00	27.76	101.19	27.96
56.17	27.76	101.3	27.98
56.33	27.76	101.44	28.01
56.50	27.72	101.51	27.98
56.67	27.52	101.46	27.77
56.83	27.16	101.31	27.38
57.00	26.80	101.17	27.00
57.17	26.64	101.12	26.83
57.33	26.64	101.17	26.84
57.50	26.60	101.2	26.80
57.67	26.56	101.19	26.76
57.83	26.56	101.3	26.78
58.00	26.52	101.48	26.77
58.17	26.48	101.51	26.73
58.33	26.44	102.19	26.81
58.50	26.48	102.54	26.91
58.67	26.40	102.69	26.85
58.83	26.32	102.75	26.78
59.00	26.32	102.92	26.81
59.17	26.36	103.28	26.91

59.33	26.40	103.54	26.99
59.50	26.32	103.58	26.92
59.67	26.32	103.6	26.92
59.83	26.32	103.69	26.93
60.00	26.32	103.73	26.94
60.17	26.32	103.77	26.95
60.33	26.32	103.94	26.98
60.50	26.32	104.21	27.02
60.67	26.36	104.31	27.08
60.83	26.36	104.33	27.08
61.00	26.36	104.37	27.09
61.17	26.40	104.5	27.15
61.33	26.44	104.64	27.21
61.50	26.44	104.68	27.22
61.67	26.48	104.8	27.28
61.83	26.52	104.87	27.33
62.00	26.40	104.84	27.21
62.17	26.36	104.83	27.16
62.33	26.40	104.84	27.21
62.50	26.40	104.88	27.21
62.67	26.48	104.92	27.30
62.83	26.52	104.91	27.34
63.00	26.56	104.93	27.38
63.17	26.60	105.04	27.44
63.33	26.60	105.23	27.47
63.50	26.60	105.43	27.50
63.67	26.60	105.58	27.53
63.83	26.60	105.68	27.54
64.00	26.68	105.87	27.66
64.17	26.72	105.96	27.71
64.33	26.88	106.26	27.92
64.50	27.04	106.35	28.09
64.67	27.04	106.32	28.09
64.83	27.04	106.35	28.09
65.00	27.12	106.33	28.17
65.17	27.00	106.29	28.04
65.33	27.00	106.29	28.04
65.50	27.08	106.34	28.13
65.67	27.12	106.35	28.17
65.83	27.12	106.33	28.17
66.00	27.12	106.33	28.17

66.17	27.16	106.36	28.22
66.33	27.20	106.35	28.26
66.50	27.24	106.36	28.30
66.67	27.28	106.38	28.34
66.83	27.32	106.39	28.38
67.00	27.40	106.41	28.47
67.17	27.48	106.44	28.55
67.33	27.48	107.9	28.79
67.50	27.72	107.85	29.02
67.67	27.76	107.82	29.06
67.83	27.76	107.82	29.06
68.00	27.76	107.82	29.06
68.17	27.80	107.83	29.10
68.33	27.76	107.82	29.06
68.50	27.76	107.82	29.06
68.67	27.72	107.81	29.02
68.83	27.72	107.81	29.02
69.00	27.68	107.8	28.97
69.17	27.68	107.84	28.98
69.33	27.64	107.82	28.94
69.50	27.60	107.81	28.89
69.67	27.56	107.8	28.85
69.83	27.56	107.84	28.86
70.00	27.56	107.84	28.86
70.17	27.52	107.83	28.82
70.33	27.48	107.86	28.78
70.50	27.44	107.96	28.76
70.67	27.44	108	28.76
70.83	27.40	108.07	28.73
71.00	27.36	108.46	28.76
71.17	27.36	108.66	28.79
71.33	27.36	108.74	28.80
71.50	27.36	108.86	28.82
71.67	27.36	109.09	28.86
71.83	27.32	109.26	28.84
72.00	27.32	109.51	28.88
72.17	27.28	109.72	28.87
72.33	27.36	109.92	28.99
72.50	27.36	110.34	29.06
72.67	27.40	110.51	29.12
72.83	27.40	110.65	29.14

73.00	27.44	110.79	29.21
73.17	27.40	110.9	29.18
73.33	27.40	111.01	29.20
73.50	27.40	111.28	29.24
73.67	27.40	111.47	29.27
73.83	27.36	111.5	29.23
74.00	27.36	111.61	29.25
74.17	27.36	111.95	29.31
74.33	27.36	112.07	29.32
74.50	27.36	112.14	29.33
74.67	27.32	112.17	29.29
74.83	27.28	112.27	29.27
75.00	27.28	112.38	29.29
75.17	27.28	112.57	29.32
75.33	27.24	112.7	29.30
75.50	27.24	112.81	29.32
75.67	27.20	112.95	29.29
75.83	27.20	113.32	29.35
76.00	27.20	113.36	29.36
76.17	27.16	113.45	29.33
76.33	27.16	113.53	29.34
76.50	27.12	113.7	29.33
76.67	27.12	113.81	29.34
76.83	27.12	113.88	29.36
77.00	27.08	113.94	29.32
77.17	27.08	114.23	29.37
77.33	27.08	114.31	29.38
77.50	27.04	114.36	29.35
77.67	27.04	114.4	29.36
77.83	27.00	114.42	29.32
78.00	27.00	114.6	29.34
78.17	27.00	115.21	29.44
78.33	26.96	115.31	29.41
78.50	26.96	115.56	29.44
78.67	26.92	115.54	29.41
78.83	26.96	115.56	29.44
79.00	26.96	115.56	29.44
79.17	26.92	115.54	29.41
79.33	26.88	115.53	29.36
79.50	26.88	115.53	29.36
79.67	26.84	115.52	29.32

79.83	26.84	115.52	29.32
80.00	26.80	115.5	29.28
80.17	26.84	115.52	29.32
80.33	26.84	115.52	29.32
80.50	26.84	115.52	29.32
80.67	26.84	115.52	29.32
80.83	26.80	115.5	29.28
81.00	26.80	115.5	29.28
81.17	26.80	115.5	29.28
81.33	26.80	115.5	29.28
81.50	26.80	115.5	29.28
81.67	26.76	115.49	29.23
81.83	26.80	115.5	29.28
82.00	26.80	115.5	29.28
82.17	26.80	115.5	29.28
82.33	26.80	115.5	29.28
82.50	26.80	115.5	29.28
82.67	26.80	115.5	29.28
82.83	26.80	115.5	29.28
83.00	26.80	115.5	29.28
83.17	26.80	115.5	29.28
83.33	26.80	115.5	29.28
83.50	26.80	115.5	29.28
83.67	26.84	115.52	29.32
83.83	26.88	115.53	29.36
84.00	26.88	115.53	29.36
84.17	26.84	115.52	29.32
84.33	26.84	115.52	29.32
84.50	26.88	115.53	29.36
84.67	26.92	115.54	29.41
84.83	26.96	115.56	29.44
85.00	27.00	115.57	29.49
85.17	27.00	115.57	29.49
85.33	27.00	115.57	29.49
85.50	27.04	115.58	29.53
85.67	27.04	115.58	29.53
85.83	27.12	115.61	29.62
86.00	27.16	115.62	29.66
86.17	27.20	115.64	29.71
86.33	27.28	115.66	29.79
86.50	27.36	115.69	29.87

86.67	27.44	115.72	29.96
86.83	27.52	115.74	30.04
87.00	27.60	115.77	30.13
87.17	27.68	115.8	30.22
87.33	27.80	115.84	30.34
87.50	28.00	115.91	30.56
87.67	28.16	115.96	30.73
87.83	28.32	116.02	30.90
88.00	28.36	116.03	30.94
88.17	28.40	116.04	30.99
88.33	28.40	116.04	30.99
88.50	28.40	116.04	30.99
88.67	28.56	116.1	31.16
88.83	28.64	116.12	31.24
89.00	28.72	116.15	31.33
89.17	28.84	116.19	31.46
89.33	28.84	116.19	31.46
89.50	28.92	116.22	31.54
89.67	29.00	116.24	31.63
89.83	29.04	116.26	31.67
90.00	29.04	116.26	31.67
90.17	29.04	116.26	31.67
90.33	29.08	116.27	31.72
90.50	29.08	116.27	31.72
90.67	29.04	116.26	31.67
90.83	28.96	116.23	31.59
91.00	28.84	116.19	31.46
91.17	28.76	116.16	31.37
91.33	28.76	116.16	31.37
91.50	28.76	116.16	31.37
91.67	28.72	116.15	31.33
91.83	28.72	116.15	31.33
92.00	28.72	116.15	31.33
92.17	28.72	116.15	31.33
92.33	28.72	116.15	31.33
92.50	28.72	116.15	31.33
92.67	28.72	116.15	31.33
92.83	28.72	116.15	31.33
93.00	28.68	116.14	31.29
93.17	28.72	116.15	31.33
93.33	28.72	116.15	31.33

93.50	28.72	116.15	31.33
93.67	28.68	116.14	31.29
93.83	28.64	116.12	31.24
94.00	28.52	116.08	31.12
94.17	28.48	116.07	31.07
94.33	28.40	116.04	30.99
94.50	28.32	116.02	30.90
94.67	28.28	116	30.86
94.83	28.24	115.99	30.82
95.00	28.20	115.97	30.77
95.17	28.20	115.97	30.77
95.33	28.16	115.96	30.73
95.50	28.16	115.96	30.73
95.67	28.16	115.96	30.73
95.83	28.12	115.95	30.69
96.00	28.08	115.93	30.64
96.17	28.08	115.93	30.64
96.33	28.04	115.92	30.60
96.50	28.04	115.92	30.60
96.67	28.00	115.91	30.56
96.83	28.00	115.91	30.56
97.00	28.00	115.91	30.56
97.17	27.96	115.89	30.52
97.33	27.96	115.89	30.52
97.50	27.96	115.89	30.52
97.67	27.96	115.89	30.52
97.83	27.92	115.88	30.47
98.00	27.92	115.88	30.47
98.17	27.92	115.88	30.47
98.33	27.92	115.88	30.47
98.50	27.88	115.87	30.43
98.67	27.88	115.87	30.43
98.83	27.88	115.87	30.43
99.00	27.84	115.85	30.39
99.17	27.84	115.85	30.39
99.33	27.84	115.85	30.39
99.50	27.84	115.85	30.39
99.67	27.80	115.84	30.34
99.83	27.80	115.84	30.34
100.00	27.80	115.84	30.34
100.17	27.76	115.83	30.31

100.33	27.76	115.83	30.31
100.50	27.76	115.83	30.31
100.67	27.76	115.83	30.31
100.83	27.76	115.83	30.31
101.00	27.72	115.81	30.26
101.17	27.72	115.81	30.26
101.33	27.72	115.81	30.26
101.50	27.68	115.8	30.22
101.67	27.68	115.8	30.22
101.83	27.68	115.8	30.22
102.00	27.68	115.8	30.22
102.17	27.64	115.79	30.17
102.33	27.64	115.79	30.17
102.50	27.64	115.79	30.17
102.67	27.60	115.77	30.13
102.83	27.60	115.77	30.13
103.00	27.60	115.77	30.13
103.17	27.60	115.77	30.13
103.33	27.60	115.77	30.13
103.50	27.60	115.77	30.13
103.67	27.56	115.76	30.09
103.83	27.52	115.74	30.04
104.00	27.56	115.76	30.09
104.17	27.56	115.76	30.09
104.33	27.56	115.76	30.09
104.50	27.52	115.74	30.04
104.67	27.52	115.74	30.04
104.83	27.52	115.74	30.04
105.00	27.48	115.73	30.01
105.17	27.48	115.73	30.01
105.33	27.48	115.73	30.01
105.50	27.48	115.73	30.01
105.67	27.44	115.72	29.96
105.83	27.44	115.72	29.96
106.00	27.44	115.72	29.96
106.17	27.40	115.7	29.92
106.33	27.40	115.7	29.92
106.50	27.40	115.7	29.92
106.67	27.40	115.7	29.92
106.83	27.36	115.69	29.87
107.00	27.36	115.69	29.87

107.17	27.40	115.7	29.92
107.33	27.40	115.7	29.92
107.50	27.40	115.7	29.92
107.67	27.44	115.72	29.96
107.83	27.44	115.72	29.96
108.00	27.48	115.73	30.01
108.17	27.48	115.73	30.01
108.33	27.48	115.73	30.01
108.50	27.52	115.74	30.04
108.67	27.52	115.74	30.04
108.83	27.56	115.76	30.09
109.00	27.56	115.76	30.09
109.17	27.56	115.76	30.09
109.33	27.60	115.77	30.13
109.50	27.60	115.77	30.13
109.67	27.60	115.77	30.13
109.83	27.60	115.77	30.13
110.00	27.60	115.77	30.13
110.17	27.64	115.79	30.17
110.33	27.68	115.8	30.22
110.50	27.80	115.84	30.34
110.67	27.84	115.85	30.39
110.83	27.88	115.87	30.43
111.00	27.92	115.88	30.47
111.17	28.00	115.91	30.56
111.33	28.00	115.91	30.56
111.50	28.16	115.96	30.73
111.67	28.28	116	30.86
111.83	28.36	116.03	30.94
112.00	28.40	116.04	30.99
112.17	28.40	116.04	30.99
112.33	28.52	116.08	31.12
112.50	28.64	116.12	31.24
112.67	28.80	116.18	31.42
112.83	29.00	116.24	31.63
113.00	29.08	116.27	31.72
113.17	29.08	116.27	31.72
113.33	29.00	116.24	31.63
113.50	28.96	116.23	31.59
113.67	28.96	116.23	31.59
113.83	29.00	116.24	31.63

114.00	29.04	116.26	31.67
114.17	29.12	116.29	31.76
114.33	29.24	116.33	31.89
114.50	29.20	116.31	31.84
114.67	29.28	116.34	31.93
114.83	29.20	116.31	31.84
115.00	29.12	116.29	31.76
115.17	29.04	116.26	31.67
115.33	29.20	116.31	31.84
115.50	29.36	116.37	32.02
115.67	29.44	116.39	32.10
115.83	29.52	116.42	32.19
116.00	29.52	116.42	32.19
116.17	29.44	116.39	32.10
116.33	29.20	116.31	31.84
116.50	28.56	116.1	31.16
116.67	28.36	116.03	30.94
116.83	28.40	116.04	30.99
117.00	28.36	116.03	30.94
117.17	28.48	116.07	31.07
117.33	28.32	116.02	30.90
117.50	28.12	115.95	30.69
117.67	27.96	115.89	30.52
117.83	27.92	115.88	30.47
118.00	27.96	115.89	30.52
118.17	28.08	115.93	30.64
118.33	28.16	115.96	30.73
118.50	28.24	115.99	30.82
118.67	28.24	115.99	30.82
118.83	28.24	115.99	30.82
119.00	28.24	115.99	30.82
119.17	28.28	116	30.86
119.33	28.36	116.03	30.94
119.50	28.40	116.04	30.99
119.67	28.40	116.04	30.99
119.83	28.40	116.04	30.99
120.00	28.40	116.04	30.99
120.17	28.36	116.03	30.94
120.33	28.12	115.95	30.69

OUTDOOR EXTRACTION TEMPERATURE MONITORING

Tme (hr)	Temp. (°C)	Hum (%RH)	Dew Point (°C)
0.17	29.68	87.63	27.41
0.33	29.44	90.41	27.70
0.50	28.64	91.83	27.18
0.67	28.56	93.07	27.33
0.83	28.24	93.66	27.12
1.00	28.48	94.22	27.46
1.17	28.60	94.46	27.62
1.33	28.56	94.55	27.59
1.50	28.52	94.7	27.58
1.67	28.48	94.86	27.57
1.83	28.40	94.93	27.51
2.00	28.32	95.01	27.44
2.17	28.24	95.08	27.37
2.33	28.12	95.14	27.27
2.50	28.00	95.14	27.14
2.67	27.80	95.18	26.96
2.83	27.64	95.23	26.81
3.00	27.56	95.28	26.73
3.17	27.48	95.31	26.66
3.33	27.40	95.33	26.58
3.50	27.32	95.36	26.51
3.67	27.32	95.4	26.52
3.83	27.28	95.44	26.48
4.00	27.28	95.49	26.49
4.17	27.24	95.5	26.46
4.33	27.24	95.52	26.46
4.50	27.28	95.58	26.51
4.67	27.20	95.56	26.43
4.83	27.12	95.58	26.35
5.00	27.04	95.59	26.27
5.17	27.08	95.62	26.32
5.33	27.08	95.64	26.32
5.50	27.04	95.66	26.28
5.67	27.04	95.7	26.29
5.83	27.04	95.7	26.29
6.00	27.04	95.73	26.30
6.17	27.08	95.76	26.34
6.33	27.04	95.75	26.30
6.50	26.92	95.74	26.18
6.67	26.80	95.73	26.06

6.83	26.72	95.76	25.98
7.00	26.64	95.78	25.91
7.17	26.56	95.79	25.83
7.33	26.48	95.79	25.75
7.50	26.40	95.79	25.67
7.67	26.36	95.8	25.63
7.83	26.32	95.84	25.60
8.00	26.24	95.84	25.52
8.17	26.24	95.84	25.52
8.33	26.24	95.86	25.53
8.50	26.12	95.86	25.41
8.67	26.08	95.87	25.37
8.83	26.04	95.9	25.33
9.00	25.96	95.88	25.25
9.17	25.92	95.87	25.21
9.33	25.92	95.9	25.21
9.50	25.84	95.9	25.13
9.67	25.76	95.88	25.05
9.83	25.72	95.91	25.02
10.00	25.68	95.9	24.98
10.17	25.60	95.88	24.89
10.33	25.52	95.91	24.82
10.50	25.52	95.93	24.82
10.67	25.48	95.94	24.78
10.83	25.44	95.93	24.74
11.00	25.56	95.92	24.86
11.17	25.84	95.94	25.14
11.33	26.28	95.92	25.58
11.50	26.88	95.87	26.16
11.67	27.60	95.8	26.87
11.83	29.84	94.71	28.89
12.00	32.76	93.24	31.52
12.17	35.32	92.62	33.94
12.33	35.68	91.86	34.14
12.50	36.36	90.31	34.51
12.67	37.68	87.41	35.22
12.83	37.12	87.12	34.61
13.00	36.92	86.76	34.34
13.17	36.40	87.8	34.04
13.33	36.68	88.39	34.44
13.50	36.40	89.06	34.30

13.67	38.36	88.93	36.20
13.83	41.60	86.32	38.83
14.00	42.40	80.84	38.40
14.17	41.08	80.72	37.09
14.33	40.12	82.95	36.66
14.50	39.52	83.93	36.28
14.67	38.56	85.33	35.64
14.83	37.16	86.07	34.43
15.00	37.08	88.59	34.87
15.17	38.08	88.79	35.89
15.33	40.40	87.03	37.81
15.50	43.20	83.6	39.80
15.67	44.00	81.68	40.14
15.83	42.12	81.78	38.34
16.00	40.04	84.78	36.98
16.17	39.52	87.07	36.96
16.33	41.68	87.47	39.16
16.50	41.96	85.22	38.95
16.67	41.80	85.95	38.95
16.83	40.28	85.21	37.31
17.00	40.76	87.13	38.18
17.17	40.92	85.05	37.89
17.33	42.68	85.87	39.79
17.50	44.24	84.29	40.97
17.67	45.28	82.88	41.67
17.83	45.92	82.01	42.09
18.00	45.92	80.4	41.72
18.17	45.72	81.09	41.68
18.33	47.08	81.79	43.17
18.50	47.80	78.79	43.15
18.67	48.48	78.24	43.67
18.83	49.56	78.95	44.89
19.00	48.80	77.44	43.78
19.17	49.76	76.91	44.58
19.33	50.08	74.3	44.22
19.50	49.80	74.1	43.89
19.67	49.72	75.48	44.17
19.83	49.96	73.33	43.84
20.00	46.68	75.67	41.30
20.17	46.92	75.66	41.52
20.33	47.04	76.01	41.73

20.50	45.52	75.99	40.26
20.67	44.40	77.63	39.58
20.83	43.68	78.19	39.02
21.00	45.40	77.33	40.47
21.17	46.12	74.7	40.52
21.33	45.56	74.08	39.82
21.50	44.92	74.21	39.24
21.67	42.44	78.01	37.78
21.83	40.24	79.5	35.99
22.00	38.40	82.29	34.83
22.17	36.04	85.85	33.28
22.33	34.56	88.11	32.29
22.50	33.12	90.51	31.36
22.67	32.04	91.68	30.51
22.83	31.16	92.72	29.84
23.00	30.52	93.37	29.32
23.17	30.04	93.82	28.93
23.33	29.56	94.09	28.51
23.50	29.24	94.39	28.24
23.67	29.08	94.63	28.13
23.83	28.84	94.76	27.91
24.00	28.60	94.79	27.68
24.17	28.40	94.93	27.51
24.33	28.28	95.04	27.41
24.50	28.16	95.11	27.30
24.67	28.00	95.16	27.15
24.83	27.80	95.15	26.95
25.00	27.64	95.25	26.81
25.17	27.52	95.29	26.70
25.33	27.52	95.36	26.71
25.50	27.52	95.39	26.72
25.67	27.56	95.42	26.76
25.83	27.44	95.43	26.64
26.00	27.32	95.43	26.52
26.17	27.20	95.47	26.41
26.33	27.16	95.5	26.38
26.50	27.12	95.54	26.34
26.67	27.24	95.62	26.48
26.83	27.24	95.62	26.48
27.00	27.20	95.61	26.43
27.17	27.00	95.58	26.23

27.33	26.84	95.58	26.07
27.50	26.68	95.59	25.92
27.67	26.56	95.6	25.80
27.83	26.48	95.63	25.72
28.00	26.36	95.62	25.60
28.17	26.32	95.61	25.56
28.33	26.20	95.58	25.43
28.50	26.16	95.57	25.39
28.67	26.08	95.55	25.31
28.83	26.04	95.54	25.27
29.00	25.92	95.48	25.14
29.17	25.72	95.45	24.94
29.33	25.56	95.43	24.77
29.50	25.44	95.43	24.66
29.67	25.36	95.43	24.57
29.83	25.20	95.39	24.41
30.00	25.16	95.44	24.38
30.17	25.12	95.43	24.34
30.33	25.00	95.4	24.21
30.50	24.96	95.39	24.17
30.67	24.96	95.44	24.18
30.83	24.96	95.46	24.18
31.00	24.92	95.47	24.14
31.17	24.80	95.4	24.01
31.33	24.72	95.42	23.94
31.50	24.64	95.4	23.86
31.67	24.56	95.38	23.77
31.83	24.48	95.38	23.69
32.00	24.44	95.37	23.65
32.17	24.40	95.41	23.62
32.33	24.40	95.43	23.62
32.50	24.40	95.43	23.62
32.67	24.36	95.42	23.58
32.83	24.32	95.43	23.54
33.00	24.32	95.45	23.54
33.17	24.32	95.45	23.54
33.33	24.32	95.48	23.55
33.50	24.32	95.5	23.56
33.67	24.32	95.5	23.56
33.83	24.32	95.5	23.56
34.00	24.24	95.52	23.48

34.17	24.20	95.51	23.44
34.33	24.16	95.53	23.40
34.50	24.08	95.53	23.32
34.67	24.08	95.53	23.32
34.83	24.12	95.56	23.37
35.00	24.16	95.55	23.40
35.17	24.44	95.58	23.68
35.33	26.20	95.21	25.37
35.50	28.88	92.04	27.46
35.67	31.24	89.26	29.26
35.83	33.12	85.17	30.29
36.00	35.04	82.38	31.58
36.17	36.68	79.85	32.62
36.33	37.80	78.05	33.30
36.50	38.96	77.36	34.26
36.67	39.80	76.49	34.87
36.83	40.68	76.77	35.78
37.00	40.44	77.3	35.68
37.17	40.72	78.28	36.18
37.33	38.64	80.19	34.60
37.50	39.88	81.01	35.99
37.67	39.76	83.02	36.32
37.83	41.00	82.86	37.49
38.00	42.60	81.9	38.83
38.17	43.96	81.9	40.16
38.33	43.36	78.83	38.86
38.50	42.56	82.32	38.89
38.67	44.68	82.56	41.01
38.83	44.40	81.59	40.52
39.00	45.16	83	41.58
39.17	46.00	83.09	42.42
39.33	46.08	81.33	42.09
39.50	44.32	82.14	40.56
39.67	42.08	81.82	38.31
39.83	41.64	85.7	38.74
40.00	44.04	86.47	41.26
40.17	46.00	82.83	42.36
40.33	42.80	82.03	39.06
40.50	40.36	86.02	37.56
40.67	39.96	87.65	37.51
40.83	41.68	87.61	39.19

41.00	44.28	86.47	41.49
41.17	45.88	84.11	42.53
41.33	46.56	82.49	42.82
41.50	47.16	81.55	43.19
41.67	47.64	82.57	43.89
41.83	47.96	81.62	43.98
42.00	48.40	81.45	44.37
42.17	48.40	81.13	44.29
42.33	48.60	80.09	44.24
42.50	49.04	80.5	44.77
42.67	49.64	79.86	45.19
42.83	50.36	77.98	45.43
43.00	50.72	78.02	45.78
43.17	51.04	76.24	45.64
43.33	51.76	76.28	46.34
43.50	52.60	74.11	46.58
43.67	52.96	72.5	46.49
43.83	47.88	76.43	42.64
44.00	44.44	80.57	40.32
44.17	42.76	82.53	39.13
44.33	42.44	83.86	39.12
44.50	41.28	83.78	37.97
44.67	40.16	84.7	37.07
44.83	42.36	82.53	38.74
45.00	42.56	79.45	38.23
45.17	44.36	77.33	39.47
45.33	44.60	75.52	39.26
45.50	44.12	75.4	38.77
45.67	42.16	77.09	37.29
45.83	39.40	79.47	35.17
46.00	37.72	82.17	34.14
46.17	35.64	85.44	32.81
46.33	33.48	88.74	31.36
46.50	32.04	90.61	30.31
46.67	31.08	91.87	29.60
46.83	30.36	92.74	29.05
47.00	29.92	93.41	28.74
47.17	29.56	93.82	28.46
47.33	29.28	94.11	28.23
47.50	29.04	94.34	28.03
47.67	28.80	94.51	27.83

47.83	28.56	94.64	27.61
48.00	28.40	94.74	27.47
48.17	28.16	94.8	27.24
48.33	28.04	94.89	27.14
48.50	27.88	94.94	26.99
48.67	27.76	95.03	26.89
48.83	27.64	95.09	26.78
49.00	27.56	95.14	26.71
49.17	27.48	95.14	26.63
49.33	27.40	95.17	26.56
49.50	27.36	95.18	26.52
49.67	27.36	95.13	26.51
49.83	27.32	95.12	26.47
50.00	27.32	95.15	26.47
50.17	27.36	95.18	26.52
50.33	27.32	95.12	26.47
50.50	27.28	95.16	26.43
50.67	27.40	95.26	26.57
50.83	27.44	95.29	26.62
51.00	27.36	95.27	26.53
51.17	27.20	95.3	26.38
51.33	27.24	95.38	26.43
51.50	27.20	95.4	26.40
51.67	27.00	95.37	26.19
51.83	26.80	95.41	26.00
52.00	26.64	95.41	25.84
52.17	26.52	95.43	25.73
52.33	26.40	95.44	25.61
52.50	26.32	95.4	25.52
52.67	26.20	95.35	25.39
52.83	26.08	95.31	25.27
53.00	26.00	95.32	25.19
53.17	25.84	95.28	25.02
53.33	25.76	95.28	24.94
53.50	25.64	95.25	24.82
53.67	25.60	95.26	24.78
53.83	25.56	95.27	24.74
54.00	25.60	95.31	24.79
54.17	25.68	95.35	24.88
54.33	25.68	95.35	24.88
54.50	25.64	95.34	24.84

54.67	25.56	95.32	24.76
54.83	25.48	95.32	24.67
55.00	25.40	95.32	24.59
55.17	25.32	95.35	24.52
55.33	25.28	95.34	24.48
55.50	25.28	95.38	24.49
55.67	25.28	95.38	24.49
55.83	25.28	95.38	24.49
56.00	25.40	95.48	24.62
56.17	25.44	95.47	24.66
56.33	25.44	95.47	24.66
56.50	25.48	95.53	24.71
56.67	25.40	95.51	24.63
56.83	24.56	95.08	23.72
57.00	23.20	94.84	22.33
57.17	22.68	95.21	21.87
57.33	22.44	95.26	21.64
57.50	22.40	95.36	21.62
57.67	22.56	95.47	21.80
57.83	22.72	95.53	21.97
58.00	22.80	95.56	22.05
58.17	22.88	95.58	22.13
58.33	22.96	95.6	22.22
58.50	23.04	95.57	22.29
58.67	23.12	95.59	22.38
58.83	23.12	95.53	22.37
59.00	23.20	95.52	22.44
59.17	23.28	95.5	22.52
59.33	23.44	95.5	22.68
59.50	23.68	95.49	22.92
59.67	23.92	95.46	23.15
59.83	24.20	95.45	23.42
60.00	24.44	95.39	23.66
60.17	24.64	95.35	23.84
60.33	24.84	95.31	24.04
60.50	25.12	95.25	24.31
60.67	25.44	95.13	24.60
60.83	25.84	95	24.98
61.00	26.00	94.9	25.12
61.17	26.40	94.79	25.49
61.33	26.64	94.43	25.67

61.50	26.52	94.26	25.52
61.67	26.56	93.99	25.51
61.83	26.92	93.8	25.83
62.00	27.04	93.9	25.97
62.17	26.32	92.84	25.07
62.33	26.44	92.87	25.19
62.50	27.12	92.71	25.83
62.67	28.00	92.38	26.64
62.83	28.68	91.94	27.24
63.00	28.48	91.99	27.05
63.17	27.56	92.53	26.24
63.33	26.96	93.1	25.74
63.50	26.44	93.06	25.23
63.67	26.80	93.49	25.66
63.83	27.12	93.54	25.99
64.00	27.64	93.56	26.51
64.17	29.12	93.16	27.90
64.33	30.88	91.94	29.41
64.50	32.16	90.71	30.44
64.67	33.12	89.25	31.11
64.83	33.80	88.4	31.61
65.00	34.08	87.72	31.74
65.17	34.04	87.71	31.71
65.33	33.88	87.67	31.54
65.50	33.88	88.06	31.62
65.67	33.92	87.97	31.64
65.83	33.92	88.23	31.69
66.00	34.04	88.43	31.85
66.17	34.24	88.61	32.08
66.33	34.52	88.29	32.29
66.50	34.44	88.09	32.17
66.67	34.24	88.07	31.97
66.83	34.00	88.58	31.84
67.00	33.76	88.99	31.68
67.17	33.84	89.67	31.90
67.33	33.88	89.81	31.97
67.50	33.52	90.38	31.72
67.67	33.28	90.75	31.56
67.83	32.92	90.69	31.19
68.00	32.64	91.03	30.98
68.17	32.20	91.05	30.55

68.33	31.84	91.48	30.28
68.50	31.68	92.21	30.26
68.67	31.48	92.38	30.09
68.83	31.12	92.52	29.76
69.00	30.72	92.76	29.41
69.17	30.40	93.02	29.14
69.33	30.16	93.03	28.91
69.50	30.00	93.28	28.79
69.67	29.92	93.22	28.70
69.83	29.72	93.31	28.52
70.00	29.44	93.53	28.28
70.17	28.92	93.66	27.79
70.33	28.44	94	27.38
70.50	28.08	94.31	27.08
70.67	27.76	94.53	26.80
70.83	27.48	94.7	26.55
71.00	27.20	94.86	26.30
71.17	26.96	94.94	26.08
71.33	26.72	95.06	25.86
71.50	26.56	95.16	25.72
71.67	26.40	95.26	25.58
71.83	26.56	95.39	25.76
72.00	26.64	95.41	25.84
72.17	26.44	95.27	25.62
72.33	26.16	95.2	25.33
72.50	26.20	95.25	25.38
72.67	26.04	95.12	25.19
72.83	25.76	94.95	24.89
73.00	25.52	94.92	24.64
73.17	25.40	94.91	24.52
73.33	25.28	94.92	24.41
73.50	25.12	94.95	24.25
73.67	25.00	94.94	24.13
73.83	24.88	94.96	24.02
74.00	24.80	95.01	23.94
74.17	24.72	94.94	23.86
74.33	24.60	95	23.74
74.50	24.56	95.01	23.71
74.67	24.48	95.04	23.63
74.83	24.40	95.06	23.56
75.00	24.52	95.19	23.70

75.17	24.72	95.33	23.92
75.33	24.80	95.4	24.01
75.50	24.92	95.47	24.14
75.67	25.00	95.49	24.23
75.83	25.04	95.55	24.28
76.00	25.00	95.54	24.24
76.17	25.00	95.59	24.24
76.33	25.08	95.61	24.33
76.50	25.08	95.63	24.33
76.67	25.12	95.66	24.38
76.83	25.12	95.66	24.38
77.00	25.04	95.64	24.29
77.17	24.96	95.62	24.21
77.33	24.72	95.56	23.96
77.50	24.40	95.47	23.63
77.67	24.16	95.46	23.39
77.83	24.08	95.46	23.31
78.00	24.00	95.46	23.23
78.17	23.96	95.5	23.19
78.33	23.88	95.48	23.11
78.50	23.80	95.45	23.03
78.67	23.68	95.42	22.91
78.83	23.64	95.46	22.87
79.00	23.56	95.44	22.79
79.17	23.52	95.43	22.74
79.33	23.36	95.43	22.59
79.50	23.28	95.45	22.51
79.67	23.24	95.44	22.47
79.83	23.40	95.53	22.64
80.00	23.44	95.54	22.68
80.17	23.44	95.59	22.69
80.33	23.44	95.59	22.69
80.50	23.44	95.59	22.69
80.67	23.36	95.57	22.61
80.83	23.28	95.55	22.53
81.00	23.32	95.62	22.58
81.17	23.44	95.66	22.71
81.33	23.56	95.66	22.83
81.50	23.60	95.68	22.87
81.67	23.48	95.6	22.73
81.83	23.36	95.57	22.61

82.00	23.24	95.58	22.49
82.17	23.24	95.63	22.50
82.33	23.36	95.68	22.63
82.50	23.40	95.67	22.67
82.67	23.48	95.69	22.75
82.83	23.60	95.72	22.88
83.00	23.72	95.75	23.00
83.17	23.84	95.74	23.12
83.33	23.84	95.74	23.12
83.50	23.92	95.71	23.19
83.67	24.08	95.76	23.36
83.83	24.32	95.73	23.59
84.00	24.56	95.72	23.83
84.17	24.80	95.69	24.07
84.33	25.00	95.65	24.26
84.50	25.24	95.6	24.48
84.67	25.48	95.62	24.73
84.83	25.84	95.58	25.08
85.00	26.08	95.5	25.31
85.17	26.20	95.37	25.40
85.33	26.28	95.32	25.47
85.50	26.32	95.05	25.46
85.67	26.36	94.85	25.47
85.83	26.92	94.93	26.04
86.00	27.80	94.83	26.89
86.17	28.72	94.45	27.74
86.33	29.92	94.13	28.87
86.50	32.04	93.79	30.91
86.67	34.20	92.5	32.81
86.83	36.08	91.4	34.45
87.00	38.76	90.43	36.90
87.17	40.80	88.38	38.49
87.33	42.72	86.21	39.91
87.50	45.16	84.35	41.88
87.67	45.68	81.91	41.83
87.83	43.48	81.4	39.58
88.00	42.12	83.96	38.83
88.17	41.76	85.67	38.85
88.33	41.12	86.1	38.32
88.50	40.92	86.74	38.26
88.67	41.36	86.16	38.57

88.83	42.40	85.97	39.54
89.00	42.24	84.95	39.17
89.17	42.28	85.34	39.29
89.33	43.48	86.18	40.65
89.50	44.00	84.33	40.74
89.67	45.24	84.98	42.11
89.83	45.04	82.43	41.33
90.00	43.20	82.98	39.67
90.17	43.16	84.93	40.06
90.33	43.92	84.64	40.74
90.50	43.80	83.25	40.31
90.67	42.28	83.96	38.98
90.83	40.48	83.91	37.22
91.00	38.68	85.97	35.90
91.17	37.92	88.12	35.60
91.33	38.12	88.51	35.88
91.50	39.88	88.67	37.64
91.67	40.04	87.4	37.53
91.83	39.80	85.68	36.93
92.00	40.96	84.95	37.91
92.17	42.20	84.28	38.98
92.33	45.04	82.03	41.24
92.50	46.16	78.47	41.48
92.67	45.96	78.67	41.34
92.83	43.84	79.99	39.60
93.00	43.40	80.5	39.29
93.17	43.96	80.16	39.76
93.33	43.40	79.61	39.08
93.50	39.44	83.39	36.09
93.67	36.40	86.43	33.76
93.83	36.00	86.95	33.47
94.00	35.08	87.29	32.64
94.17	33.80	89.02	31.73
94.33	32.32	90.85	30.63
94.50	31.16	92.08	29.72
94.67	30.32	92.93	29.04
94.83	29.64	93.48	28.47
95.00	29.20	93.93	28.12
95.17	28.72	94.14	27.68
95.33	28.40	94.41	27.41
95.50	28.12	94.58	27.17

95.67	27.80	94.68	26.87
95.83	27.56	94.81	26.65
96.00	27.36	94.88	26.47
96.17	27.12	94.93	26.23
96.33	26.92	94.97	26.04
96.50	26.72	95.02	25.86
96.67	26.52	95.1	25.67
96.83	26.40	95.12	25.56
97.00	26.24	95.17	25.41
97.17	26.08	95.2	25.25
97.33	25.96	95.24	25.14
97.50	25.84	95.25	25.02
97.67	25.76	95.28	24.94
97.83	25.68	95.3	24.87
98.00	25.60	95.33	24.79
98.17	25.56	95.34	24.76
98.33	25.48	95.25	24.66
98.50	25.44	95.19	24.61
98.67	25.40	95.18	24.57
98.83	25.28	95.13	24.44
99.00	25.20	95.13	24.36
99.17	25.12	95.11	24.28
99.33	25.08	95.1	24.24
99.50	25.00	95.08	24.16
99.67	24.88	95.03	24.03
99.83	24.80	94.98	23.94
100.00	24.68	94.97	23.82
100.17	24.64	94.99	23.78
100.33	24.52	94.96	23.66
100.50	24.40	94.95	23.54
100.67	24.32	94.95	23.46
100.83	24.24	94.93	23.37
101.00	24.16	94.95	23.30
101.17	24.12	94.97	23.26
101.33	24.08	95.03	23.23
101.50	24.08	95.03	23.23
101.67	24.04	95.04	23.19
101.83	24.00	95.05	23.16
102.00	24.00	95.1	23.17
102.17	23.92	95.1	23.08
102.33	23.88	95.11	23.05

102.50	23.88	95.16	23.06
102.67	23.88	95.16	23.06
102.83	23.92	95.21	23.11
103.00	23.88	95.2	23.07
103.17	23.84	95.19	23.02
103.33	23.76	95.19	22.94
103.50	23.76	95.22	22.95
103.67	23.76	95.26	22.96
103.83	23.76	95.26	22.96
104.00	23.68	95.24	22.87
104.17	23.68	95.29	22.88
104.33	23.68	95.31	22.88
104.50	23.64	95.32	22.84
104.67	23.60	95.31	22.81
104.83	23.56	95.3	22.76
105.00	23.52	95.34	22.73
105.17	23.52	95.34	22.73
105.33	23.52	95.38	22.74
105.50	23.52	95.38	22.74
105.67	23.48	95.37	22.69
105.83	23.44	95.41	22.66
106.00	23.44	95.41	22.66
106.17	23.44	95.41	22.66
106.33	23.44	95.45	22.67
106.50	23.36	95.43	22.59
106.67	23.40	95.44	22.63
106.83	23.44	95.47	22.67
107.00	23.52	95.47	22.76
107.17	23.84	95.47	23.07
107.33	25.12	95.23	24.30
107.50	26.64	93.82	25.56
107.67	28.28	91.94	26.84
107.83	29.76	90.68	28.07
108.00	31.20	88.42	29.05
108.17	32.60	86.68	30.08
108.33	33.96	85.18	31.11
108.50	35.00	83.99	31.88
108.67	36.00	83.61	32.78
108.83	37.04	83.15	33.69
109.00	38.00	82.7	34.53
109.17	38.80	82.37	35.24

109.33	39.40	82.47	35.84
109.50	40.08	82.67	36.55
109.67	40.88	83.45	37.51
109.83	41.36	82.82	37.83
110.00	41.68	83.45	38.28
110.17	42.08	84.2	38.84
110.33	42.80	85.4	39.81
110.50	43.16	84.62	39.99
110.67	43.40	85.03	40.32
110.83	43.96	86.07	41.09
111.00	44.64	85.74	41.69
111.17	45.04	85.75	42.08
111.33	45.44	86.66	42.67
111.50	46.44	87.02	43.73
111.67	46.80	85.31	43.71
111.83	47.44	85.81	44.44
112.00	47.56	85.64	44.52
112.17	47.72	84.32	44.38
112.33	48.12	85.06	44.94
112.50	48.96	85.07	45.76
112.67	49.12	83.56	45.57
112.83	49.56	83.94	46.09
113.00	50.60	84.12	47.14
113.17	48.96	81.04	44.82
113.33	47.52	84	44.11
113.50	45.60	85.34	42.54
113.67	48.80	88.42	46.36
113.83	49.24	84.44	45.89
114.00	50.68	85.06	47.44
114.17	52.28	83.37	48.61
114.33	51.48	79.95	47.00
114.50	47.68	82.26	43.86
114.67	45.12	84.17	41.81
114.83	42.44	86.69	39.74
115.00	40.44	88.69	38.20
115.17	40.76	89.67	38.72
115.33	45.00	88.1	42.56
115.50	45.48	83.23	41.94
115.67	42.08	83.48	38.68
115.83	44.56	84.11	41.24
116.00	41.00	84.08	37.76

116.17	38.12	87.88	35.75
116.33	35.72	88.38	33.49
116.50	31.56	83.19	28.35
116.67	27.36	87.47	25.09
116.83	26.20	91.43	24.69
117.00	26.08	92.81	24.82
117.17	26.08	93.26	24.91
117.33	26.32	93.79	25.24
117.50	26.40	93.9	25.34
117.67	26.56	94.13	25.54
117.83	26.72	94.24	25.72
118.00	26.88	94.4	25.90
118.17	27.08	94.5	26.12
118.33	27.12	94.6	26.18
118.50	27.04	94.68	26.11
118.67	26.92	94.74	26.01
118.83	26.76	94.84	25.86
119.00	26.60	94.8	25.69
119.17	26.36	94.6	25.42
119.33	26.16	94.59	25.22
119.50	26.16	94.64	25.23
119.67	26.16	94.73	25.24
119.83	26.24	94.85	25.34
120.00	26.28	94.9	25.39
120.17	26.60	95.17	25.76
120.33	27.40	95.42	26.60

Appendix 3: Results of effect of peels on extraction

Time (days)	Treatment								
	Peeled Fruit			Peeled Fruit and Peels			Whole Fruit		
	pH	T.S.S (°Brix)	Yield (g)	pH	T.S.S (°Brix)	Yield (g)	pH	T.S.S (°Brix)	Yield (g)
5	3.79	7.2	116.65	3.78	7.4	94.32	3.71	7.4	114.26
10	3.7	7.5	137.23	3.72	7.2	120.7	3.76	7.6	171.1

15	3.65	7.4	149.46	3.69	7.5	166.7	3.73	8.2	188.5
20	3.68	7.25	157.49	3.67	7.6	182.9	3.77	7.6	212.1
25	3.61	7.5	157.78	3.64	7.5	189.93	3.7	7.7	244.85

For the Duncan multiple test whole fruit, peeled fruit and peeled fruit plus peel are represented with a, b and c respectively.

Analysis of variance for pH

	TREATMENT			
TIME	**1**	**2**	**3**	**Mean time**
5	3.79	3.78	3.71	**3.76**
10	3.7	3.72	3.76	**3.726666 7**
15	3.65	3.69	3.73	**3.69**
20	3.68	3.67	3.77	**3.706666 7**
25	3.61	3.64	3.7	**3.65**
Mean Treatment	**3.686**	**3.7**	**3.734**	**3.706666 7**

source of variance	**SS**	**df**	**MS**	**F**	**p-value**	**f critical**
Time	0.0202	4	0.00505	3.098159 5	0.08125732 1	3.8379
Treatment	0.00609333 3	2	0.00304666 7	1.869120 7	0.21574851 5	4.459
Error	0.01304	8	0.00163			
Total	0.03933333 3	14				

Duncan multiple comparism test						
	a	b	c	aa	bb	cc
	3.79	3.78	3.71	14.3641	14.2884	13.7641

	3.7	3.72	3.76	13.69	13.8384	14.1376
	3.65	3.69	3.73	13.3225	13.6161	13.9129
	3.68	3.67	3.77	13.5424	13.4689	14.2129
	3.61	3.64	3.7	13.0321	13.2496	13.69
Sum	18.43	18.5	18.67	67.9511	68.4614	69.7175
Mean						
sum of squares	0.01812					
	0.0114					
	0.00372					
Standard error	0.05263078 9		df	12		
		no. of groups				
significance		2		3		
0.05		3.082		3.225		
0.01		4.32		4.604		
	a	b	c			
Mean	3.686	3.7	3.734			
mean difference		Rp at 0.05 SIG	Interactions			
AB	0.014	0.07254166 5	NOT SIG			
BC	0.034	0.07254166 5	NOT SIG			
AC	0.048	0.07590748 5	NOT SIG			

Analysis of variance for total soluble solids (ºBrix)

	TREATMENT			
TIME	**1**	**2**	**3**	**Mean time**
5	7.2	7.4	7.4	**7.333333**
10	7.5	7.2	7.6	**7.433333**
15	7.4	7.5	8.2	**7.7**
20	7.25	7.6	7.6	**7.483333**
25	7.5	7.5	7.7	**7.566667**

Mean Treatment	**7.37**	**7.44**	**7.7**	**7.503333**

source of variance	SS	df	MS	F	p-value	f critical
Time	0.230667	4	0.057667	1.541203	0.27887	3.8379
Treatment	0.302333	2	0.151167	4.040089	0.06126	4.459
Error	0.299333	8	0.037417			
Total	0.832333	14				

Duncan multiple comparism test						
	a	b	c	aa	bb	cc
	7.2	7.4	7.4	51.84	54.76	54.76
	7.5	7.2	7.6	56.25	51.84	57.76
	7.4	7.5	8.2	54.76	56.25	67.24
	7.25	7.6	7.6	52.5625	57.76	57.76
	7.5	7.5	7.7	56.25	56.25	59.29
Sum	36.85	37.2	38.5	271.6625	276.86	296.81
Mean						
sum of squares	0.078					
	0.092					
	0.36					
Standard error	0.210159		df	12		
		no. of groups				
significance		2		3		
0.05		3.082		3.225		
0.01		4.32		4.604		
	a	b	c			
Mean	7.37	7.44	7.7			
mean difference		Rp at 0.05 SIG	INTER.			

AB	0.07	0.289664	NOT SIG			
BC	0.26	0.289664	NOT SIG			
AC	0.33	0.303104	SIG			

Analysis of variance for yield

	TREATMENT			
TIME	**1**	**2**	**3**	**Mean time**
5	116.65	94.32	114.26	**108.41**
10	137.23	120.7	171.1	**143.01**
15	149.46	166.7	188.5	**168.22**
20	157.49	182.9	212.1	**184.1633**
25	157.78	189.93	244.85	**197.52**
Mean Treatment	**143.722**	**150.91**	**186.162**	**160.2647**

ANOVA TABLE

Source of variance	**SS**	**df**	**MS**	**F**	**p-value**	**f critical**
Time	15027.07	4	3756.768	11.56959	0.002081	3.8379
Treatment	5159.207	2	2579.604	7.944317	0.012578	4.459
Error	2597.684	8	324.7106			
Total	22783.96	14				

Duncan multiple comparism test						
	a	b	c	aa	bb	cc
	116.65	94.32	114.26	13607.22	8896.262	13055.35
	137.23	120.7	171.1	18832.07	14568.49	29275.21
	149.46	166.7	188.5	22338.29	27788.89	35532.25
	157.49	182.9	212.1	24803.1	33452.41	44986.41
	157.78	189.93	244.85	24894.53	36073.4	59951.52
Sum	718.61	754.55	930.81	104475.2	120779.5	182800.7
Mean						
sum of squares	1195.149					
	6910.317					
	9519.289					

Standard error	38.32401		df	12		
		no. of groups				
significance		2		3		
0.05		3.082		3.225		
0.01		4.32		4.604		
	A	b	c			
Mean	143.722	150.91	186.162			
mean difference		Rp at 0.05 SIG	INTER.			
AB	7.188	52.82245	NOT SIG			
BC	35.252	52.82245	NOT SIG			
AC	42.44	55.27333	NOT SIG			

Appendix 4: Effect of temperature on extraction results

temperature	time								
	5 days			10 days			15 days		
	pH	T.S.S (°Brix)	Yield (g)	pH	T.S.S (°Brix)	Yield (g)	pH	T.S.S (°Brix)	Yield (g)
30	3.87	8.25	114.15	3.82	8.2	186.38	3.71	7.9	243.16
40	3.88	9.5	186.89	3.87	9.4	249.19	3.87	9.6	280.98
50	3.97	10.4	252.25	3.99	11	341.3	3.97	11.2	311.82

Appendix 5: Results for effect of water addition during drip extraction

Time (days)	Treatment											
	No water added			added 50ml of water			added 75ml of water			Added 100ml of water		
	pH	T.S.S (°Brix)	Yield	pH	T.S.S (°Brix)	Yield	pH	T.S.S (°Brix)	Yield	pH	T.S.S (°Brix)	Yield
9	3.33	7.7	103.69	3.48	6.2	118.46	3.16	6.6	119.52	3.21	6.6	142.05
18	3.09	8.8	123.45	3.81	6.5	144.5	3.43	6.45	136.54	3.15	5.9	147.84
27	3.14	7.7	134.73	3.08	7.3	139.7	3.54	6.2	148.07	2.89	7.4	147.67

Analysis of variance for pH

Time	Treatment				
	0	50	75	100	
					Mean
9	3.33	3.48	3.16	3.21	3.295
18	3.09	3.81	3.43	3.15	3.37
27	3.14	3.08	3.54	2.89	3.1625
Mean	3.186667	3.456667	3.376667	3.083333	3.275833

ANOVA Table for pH

Source of Variation	**SS**	**df**	**MS**	**F**	**p-value**	**F critical**
Time	0.088317	2	0.044158	0.767193	0.505022	5.1433
Treatment	0.263625	3	0.087875	1.526712	0.301133	4.7571
Error	0.34535	6	0.057558			
Total	0.697292	11				

Duncan multiple comparism test						
	a	b	c	aa	bb	cc
	0	0	0	0	0	0
	3.33	3.48	3.16	11.0889	12.1104	9.9856
	3.09	3.81	3.43	9.5481	14.5161	11.7649
	3.14	3.08	3.54	9.8596	9.4864	12.5316
	3.186667	3.456667	3.376667	10.15484	11.94854	11.40188
Sum	12.74667	13.82667	13.50667	40.65144	48.06144	45.68398
Mean						
sum of squares	8.155942					
	9.826102					
	9.197969					
Standard error	1.504992		df	12		
		no. of groups				
significance		2		3		
0.05		3.082		3.225		

0.01		4.32		4.604		
	a	b	c			
Mean	2.549333	2.765333	2.701333			
mean difference		Rp at 0.05 SIG	INTER.			
AC	0.152	2.074349	NOT SIG			
BC	0.064	2.074349	NOT SIG			
AB	0.216	2.170596	NOT SIG			

Analysis of variance for Total Soluble Solid (ºBrix)

Time	Treatment				
	0	50	75	100	
					Mean
9	7.7	6.2	6.6	6.6	6.775
18	8.8	6.5	6.45	5.9	6.9125
27	7.7	7.3	6.2	7.4	7.15
Mean	8.066667	6.666667	6.416667	6.633333	6.945833

ANOVA Table for Total Soluble Solid (ºBrix)

Source of Variation	**SS**	**df**	**MS**	**F**	**p-value**	**F critical**
Time	0.287917	2	0.143958	0.363876	0.709323	5.1433
Treatment	5.135625	3	1.711875	4.327014	0.060303	4.7571
Error	2.37375	6	0.395625			
Total	7.797292	11				

Duncan multiple comparism test						
	a	b	c	aa	bb	cc
	0	0	0	0	0	0
	7.7	6.2	6.6	59.29	38.44	43.56
	8.8	6.5	6.45	77.44	42.25	41.6025

	7.7	7.3	6.2	59.29	53.29	38.44
	8.066667	6.666667	6.416667	65.07111	44.44444	41.17361
Sum	32.26667	26.66667	25.66667	261.0911	178.4244	164.7761
Mean						
sum of squares	52.86356					
	36.20222					
	33.02056					
Standard error	3.189649		df	12		
		no. of groups				
significance		2		3		
0.05		3.082		3.225		
0.01		4.32		4.604		
	a	b	c			
Mean	6.453333	5.333333	5.133333			
mean difference		Rp at 0.05 SIG	INTER.			
AB	1.12	4.396333	NOT SIG			
BC	0.2	4.396333	NOT SIG			
AC	1.32	4.600316	NOT SIG			

Analysis of Variance for yield

Time	Treatment				
	0	50	75	100	
					Mean
9	103.69	118.46	119.52	142.05	120.93
18	123.45	144.5	136.54	147.84	138.0825
27	134.73	139.7	148.07	147.67	142.5425
Mean	120.6233	134.22	134.71	145.8533	133.8517

ANOVA Table Yield

Source of Variation	**SS**	**df**	**MS**	**F**	**p-value**	**F critical**
Time	1041.6	2	520.8	11.55197	0.008762	5.1433
Treatment	959.7036	3	319.9012	7.095793	0.021244	4.7571
Error	270.4993	6	45.08322			
Total	2271.803	11				

Duncan multiple comparism test						
	a	b	c	aa	bb	cc
	0	0	0	0	0	0
	103.69	118.46	119.52	10751.62	14032.77	14285.03
	123.45	144.5	136.54	15239.9	20880.25	18643.17
	134.73	139.7	148.07	18152.17	19516.09	21924.72
	120.6233	134.22	134.71	14549.99	18015.01	18146.78
Sum	482.4933	536.88	538.84	58693.68	72444.12	72999.71
Mean						
sum of squares	12133.72					
	14796.09					
	14930					
Standard error	59.06198		df	12		
		no. of groups				
significance		2		3		
0.05		3.082		3.225		
0.01		4.32		4.604		
	a	b	c			
Mean	96.49867	107.376	107.768			
mean difference		Rp at 0.05 SIG	INTER.			
AB	10.87733	81.40586	NOT SIG			
BC	0.392	81.40586	NOT SIG			
AC	11.26933	85.18296	NOT SIG			

Appendix 6: Validation of bioreactor results

Sample time (min)	**Tempt (oC)**	**Hum (%RM)**	**Dew Point (oC)**
20	28.96	82.81	25.74
40	42.48	80.49	38.39
60	44.80	83.49	41.34
80	46.48	84.57	43.22
100	47.32	86.57	44.5
120	48.00	88.02	45.49
140	48.64	89.27	46.39
160	49.24	90.39	47.23
180	49.52	90.78	47.59
200	49.92	91.47	48.14
220	49.76	92.08	48.11
240	49.92	92.45	48.35
260	50.08	92.59	48.54
280	50.20	92.67	48.67
300	50.32	92.97	48.86
320	50.36	92.52	48.8
340	50.36	92.74	48.84
360	50.32	92.65	48.79
380	50.36	92.6	48.82
400	50.40	92.83	48.91
420	50.44	92.73	48.92
440	50.40	92.61	48.86
460	50.36	92.87	48.87
480	50.36	92.79	48.86
500	50.32	92.75	48.81
520	50.32	92.7	48.8
540	50.28	92.74	48.77
560	50.24	92.63	48.71
580	50.24	92.68	48.72
600	50.20	92.62	48.66
620	50.16	92.82	48.67
640	50.20	92.83	48.71
660	50.28	92.69	48.76
680	50.36	92.93	48.88
700	50.40	92.72	48.88
720	50.44	92.65	48.91

740	50.24	92.47	48.67
760	50.20	92.56	48.65
780	50.24	92.74	48.73
800	50.28	92.58	48.73
820	50.36	92.76	48.85
840	50.40	92.83	48.91
860	50.48	92.74	48.97
880	50.60	92.76	49.09
900	50.64	92.61	49.09
920	50.72	92.79	49.21
940	50.72	92.71	49.19
960	50.76	92.69	49.23
980	50.76	92.8	49.26
1000	50.76	92.8	49.26
1020	50.80	92.51	49.23
1040	50.80	92.81	49.29
1060	50.80	92.62	49.26
1080	50.84	92.66	49.31
1100	50.84	92.66	49.31
1120	50.92	92.62	49.37
1140	50.88	92.42	49.29
1160	50.92	92.57	49.36
1180	50.80	92.57	49.24
1200	50.64	92.56	49.08
1220	50.56	92.59	49.01
1240	50.68	92.78	49.17
1260	50.84	92.63	49.3
1280	50.88	92.48	49.31
1300	51.00	92.48	49.42
1320	51.00	92.48	49.42
1340	51.00	92.53	49.43
1360	51.00	92.42	49.41
1380	51.00	92.45	49.42
1400	51.00	92.37	49.4
1420	51.00	92.59	49.44
1440	51.00	92.1	49.34
1460	50.96	92.23	49.33
1480	50.92	92.3	49.31
1500	50.84	92.22	49.21
1520	50.84	92.2	49.21
1540	50.84	91.95	49.15

1560	50.80	92.16	49.16
1580	50.76	92.02	49.08
1600	50.64	92.07	48.98
1620	50.60	92.28	48.98
1640	50.60	92.14	48.96
1660	50.60	92.14	48.96
1680	50.64	92.1	48.98
1700	50.72	92.09	49.06
1720	50.72	92.28	49.1
1740	50.76	92.37	49.16
1760	50.80	92.05	49.13
1780	50.84	92.28	49.22
1800	50.88	92.21	49.24
1820	50.88	92.26	49.26
1840	50.96	92.25	49.33
1860	50.96	92.17	49.32
1880	50.88	92.4	49.29
1900	50.88	92.34	49.27
1920	50.88	92.23	49.25
1940	50.88	92.18	49.24
1960	50.80	92.35	49.2
1980	50.80	92.16	49.16
2000	50.76	92.37	49.16
2020	50.76	92.48	49.18
2040	50.72	92.39	49.13
2060	50.80	92.43	49.22
2080	50.80	92.41	49.21
2100	50.84	92.22	49.21
2120	50.96	92.47	49.38
2140	50.96	92.47	49.38
2160	51.00	92.42	49.41
2180	51.08	92.36	49.48
2200	51.12	92.4	49.52
2220	51.12	92.34	49.51
2240	51.16	92.52	49.59
2260	51.24	92.43	49.65
2280	51.28	92.43	49.69
2300	51.36	92.67	49.82
2320	51.40	93	49.93
2340	51.48	92.59	49.92
2360	51.52	92.54	49.95

2380	51.56	92.58	50
2400	51.60	92.51	50.02
2420	51.72	92.54	50.14
2440	51.72	92.45	50.13
2460	51.76	92.87	50.26
2480	51.80	92.96	50.32
2500	51.84	93.32	50.44
2520	51.88	93.49	50.51
2540	51.96	93.57	50.61
2560	52.00	93.52	50.64
2580	52.00	93.47	50.63
2600	52.08	93.38	50.69
2620	52.08	93.11	50.63
2640	52.12	93.09	50.66
2660	52.12	93.17	50.68
2680	52.12	93.06	50.66
2700	52.20	93.05	50.73
2720	52.20	93.03	50.73
2740	52.20	93.08	50.74
2760	52.24	93.25	50.82
2780	52.24	93.25	50.82
2800	52.28	93.1	50.82
2820	52.20	93.14	50.75
2840	52.24	93.01	50.77
2860	52.12	92.93	50.63
2880	52.08	93	50.61
2900	52.00	92.93	50.51
2920	51.92	93.07	50.46
2940	51.92	92.83	50.41
2960	51.96	92.78	50.44
2980	52.08	92.62	50.52
3000	52.16	92.39	50.55
3020	52.28	92.42	50.68
3040	52.28	92.17	50.62
3060	52.20	92.24	50.56
3080	52.24	92.22	50.59
3100	52.20	92.21	50.55
3120	52.20	91.91	50.48
3140	52.16	92.09	50.48
3160	52.20	91.99	50.5
3180	52.24	91.67	50.47

3200	52.28	91.68	50.51
3220	52.36	91.42	50.53
3240	52.44	91.36	50.6
3260	52.44	91.22	50.57
3280	52.44	91.03	50.53
3300	52.52	91.16	50.63
3320	52.44	91.11	50.54
3340	52.40	91.19	50.52
3360	52.44	90.81	50.48
3380	52.40	90.94	50.47
3400	52.36	91.15	50.47
3420	52.28	91.13	50.39
3440	52.36	91.04	50.45
3460	52.28	91.19	50.41
3480	52.24	90.98	50.32
3500	52.36	91.12	50.47
3520	52.36	91.15	50.47
3540	52.52	91.27	50.66
3560	52.60	91.18	50.72
3580	52.68	91.06	50.77
3600	52.72	91.09	50.82
3620	52.84	91.04	50.92
3640	52.92	91.22	51.04
3660	52.76	90.66	50.76
3680	51.84	90.81	49.89
3700	45.72	96.38	45
3720	51.44	95.61	50.53
3740	51.96	96.08	51.14
3760	52.00	96.22	51.22
3780	52.44	96.33	51.68
3800	52.60	96.4	51.85
3820	52.64	96.56	51.92
3840	52.80	96.76	52.13
3860	53.00	97.1	52.39
3880	53.32	97.58	52.82
3900	52.80	97.68	52.32
3920	53.28	98.09	52.88
3940	53.20	98.44	52.88
3960	53.60	101.59	53.93
3980	52.52	100.6	52.64
4000	53.52	105.55	54.64

4020	54.12	106.04	55.34
4040	54.32	105.99	55.53
4060	50.44	96.58	49.74
4080	51.40	96.32	50.64
4100	51.56	96.41	50.82
4120	51.40	94.51	50.26
4140	47.72	95.11	46.73
4160	49.92	95.43	48.98
4180	50.72	95.1	49.71
4200	51.04	94.85	49.97
4220	51.40	94.4	50.23
4240	51.32	94.71	50.22
4260	51.60	94.77	50.51
4280	51.88	94.62	50.76
4300	52.04	94.56	50.9
4320	52.12	94.41	50.95
4340	52.24	94.44	51.07
4360	52.28	94.18	51.06
4380	52.24	94.12	51.01
4400	52.24	94.17	51.02
4420	52.28	94.18	51.06
4440	52.28	94.16	51.05
4460	52.24	93.98	50.98
4480	52.32	94	51.06
4500	52.32	93.92	51.04
4520	52.24	93.9	50.96
4540	52.24	93.9	50.96
4560	52.24	93.85	50.94
4580	52.24	93.88	50.95
4600	52.24	93.77	50.93
4620	52.24	93.77	50.93
4640	52.20	93.73	50.88
4660	52.16	93.8	50.86
4680	52.16	93.67	50.83
4700	52.16	93.7	50.83
4720	52.12	93.79	50.82
4740	52.08	93.76	50.77
4760	52.04	93.61	50.7
4780	52.08	93.6	50.73
4800	52.04	93.59	50.69
4820	51.92	93.83	50.63

4840	51.84	93.78	50.53
4860	51.84	93.84	50.55

Comparism of fruit atmosphere temperature and fruit temperature within bioreactor.

Actual fruit temperature measurement in bioreactor					
Fruit atmosphere temperature			**Measure fruit temperature**		
time	**atmosphere tempt.**	**Average atm. Tempt.**	**time measured**	**Fruit tempt.**	**Tempt. Variation**
12:41	53.32				
13:01	52.8	53.06	12:51	52.1	0.96
14:01	53.6				
14:21	52.52	53.06	14:10	52.1	0.96
15:01	54.12				
15:21	54.32	54.22	15:18	52.2	2.02
16:21	51.56				
16:41	51.4	51.48	16:36	52.1	(0.62)
17:21	49.92				
17:41	50.72	50.32	17:38	52.2	(1.88)
18:21	51.4				
18:41	51.32	51.36	18:37	52.1	(0.74)
19:21	51.88				
19:41	52.04	51.96	19:36	52.1	(0.14)

Appendix 7: Factorial experiment of mass, temperature and time results

Mass (kg)	Temperature (ºC)	time								
		5 days			10 days			15 days		
		pH	Total Solubl e Solid (ºBrix)	Yield (g)	pH	Total Solubl e Solid (ºBrix)	Yield (g)	pH	Total Solubl e Solid (ºBrix)	Yield (g)
0.5	30	3.62	9	9.22	3.73	8.4	31.18	3.76	8.2	45.26
	40									
	50	3.88	9.8	60.41	3.84	10.2	75.52			
1	30	3.77	8.6	56.03	3.77	9.6	107.03	3.78	8.2	146.49
	40									
	50	3.85	10.2	143.32	3.88	10.2	160.5			
1.5	30	3.87	8.25	114.15	3.82	8.2	186.38	3.71	7.9	243.16
	40	3.88	9.5	186.89	3.87	9.4	249.19	3.87	9.6	280.98
	50	3.97	10.4	252.25	3.99	11	341.3	3.97	11.2	311.82

Analysis of Variance 1.5 kg mass pH results

source of variance	SS	df	MS	F	p-value	f critical
Time	0.005267	2	0.002633	1.244094	0.380078	6.94
Treatment	0.047267	2	0.023633	11.16535	0.023078	6.94
Error	0.008467	4	0.002117			
Total	0.061	8				

Analysis of variance for 1.5 kg mass total soluble solid (°Brix) result

source of variance	SS	df	MS	F	p-value	f critical
Time	0.110556	2	0.055278	0.408624	0.68948	6.94
Treatment	10.80389	2	5.401944	39.93224	0.002275	6.94
Error	0.541111	4	0.135278			
Total	11.45556	8				

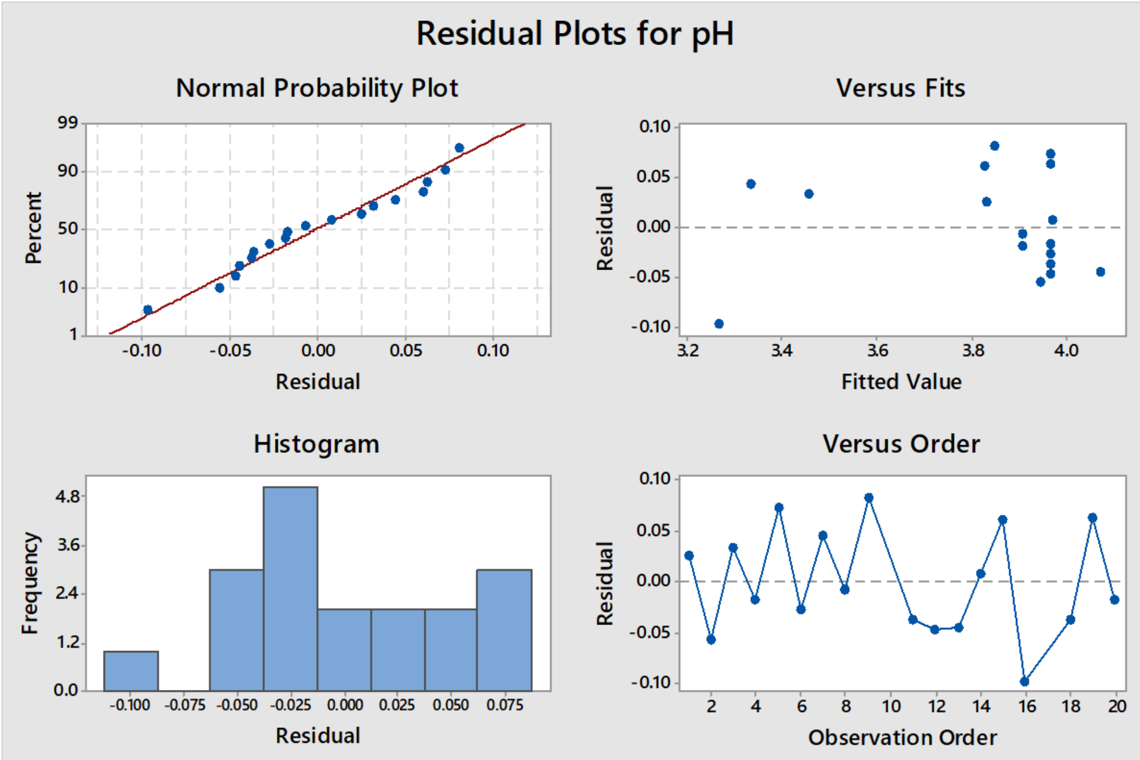
Analysis of variance for 1.5 kg mass yield results

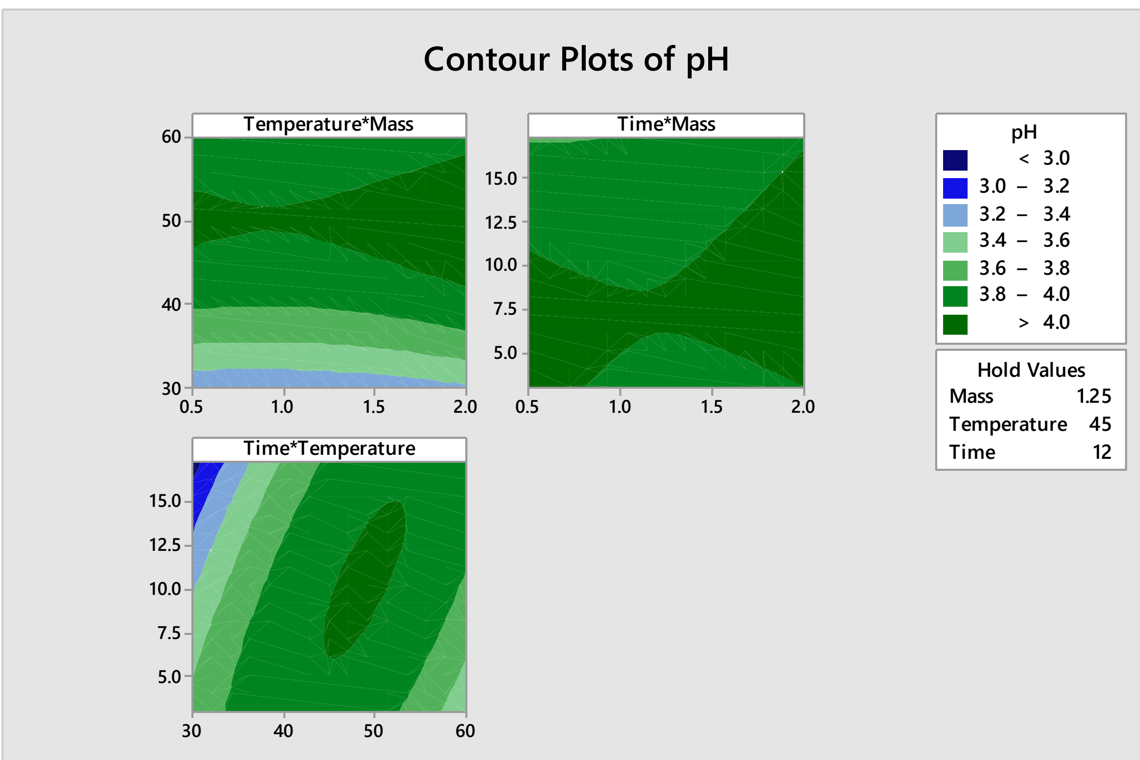
source of variance	SS	df	MS	F	p-value	f critical
Time	14823.59	2	7411.797	13.24382	0.017214	6.94
Treatment	21814.57	2	10907.29	19.48976	0.008662	6.94
Error	2238.568	4	559.6419			
Total	38876.73	8				

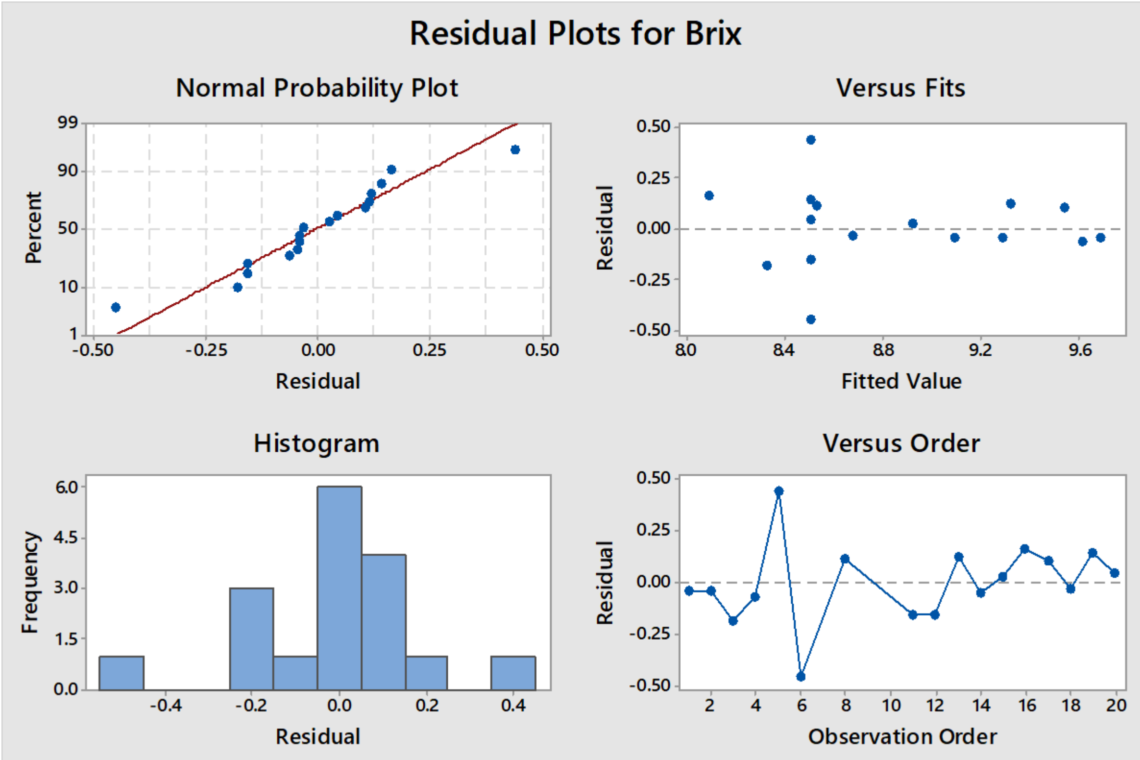
Appendix 8: CCRD Results

Run	Coded matrix		
	X_1	**X_2**	**X_3**
1	-1	-1	-1
1	-1	1	1
1	1	-1	1
1	1	1	-1
1	0	0	0
1	0	0	0
2	-1	-1	1
2	-1	1	-1
2	1	-1	-1
2	1	1	1
2	0	0	0
2	0	0	0
3	1.6817	0	0
3	-1.6817	0	0
3	0	1.6817	0
3	0	-1.6817	0
3	0	0	1.6817
3	0	0	-1.6817
3	0	0	0
3	0	0	0

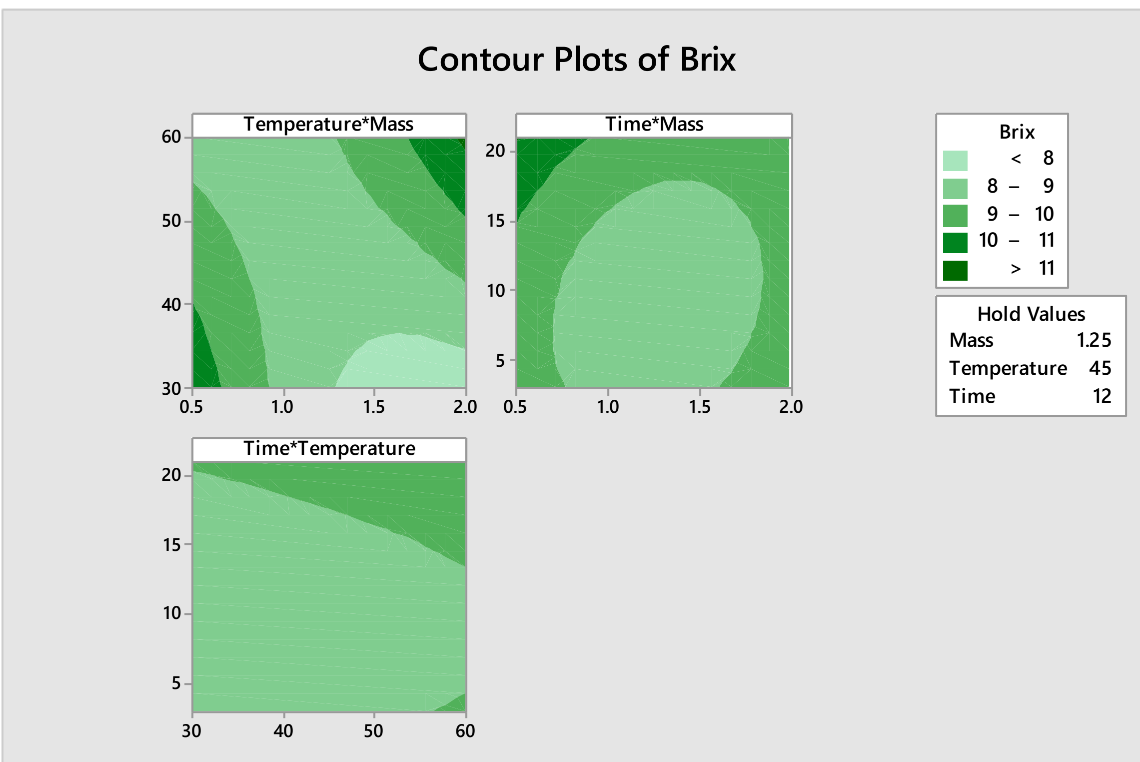
Uncoded Matrix			Results		
Mass	Temperature	Time	pH	Total Soluble Solids (ºBrix)	Yield (g)
0.8	36.08	6.65	3.86	9.052	116.88
0.8	53.92	17.35	3.89	9.25	114.16
1.7	36.08	17.35	3.49	8.149	295.3
1.7	53.92	6.65	3.89	9.552	281.42
1.25	45	12	4.04	8.949	205.13
1.25	45	12	3.94	8.052	108.77
0.8	36.08	17.35	3.38		136.85
0.8	53.92	6.65	3.9	8.649	121.17
1.7	36.08	6.65	3.93		220.86
1.7	53.92	17.35			301.15
1.25	45	12	3.93	8.35	113.59
1.25	45	12	3.92	8.349	138.36
2	45	12	4.03	9.45	342.23
0.5	45	12	3.98	9.649	82.56
1.25	60	12	3.89	8.949	243.41
1.25	30	12	3.17	8.252	133.1
1.25	45	21		9.649	134.01
1.25	45	3	3.93	8.649	99.22
1.25	45	12	4.03	8.65	134.18
1.25	45	12	3.95	8.55	132.14


Residual Plots for pH
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order

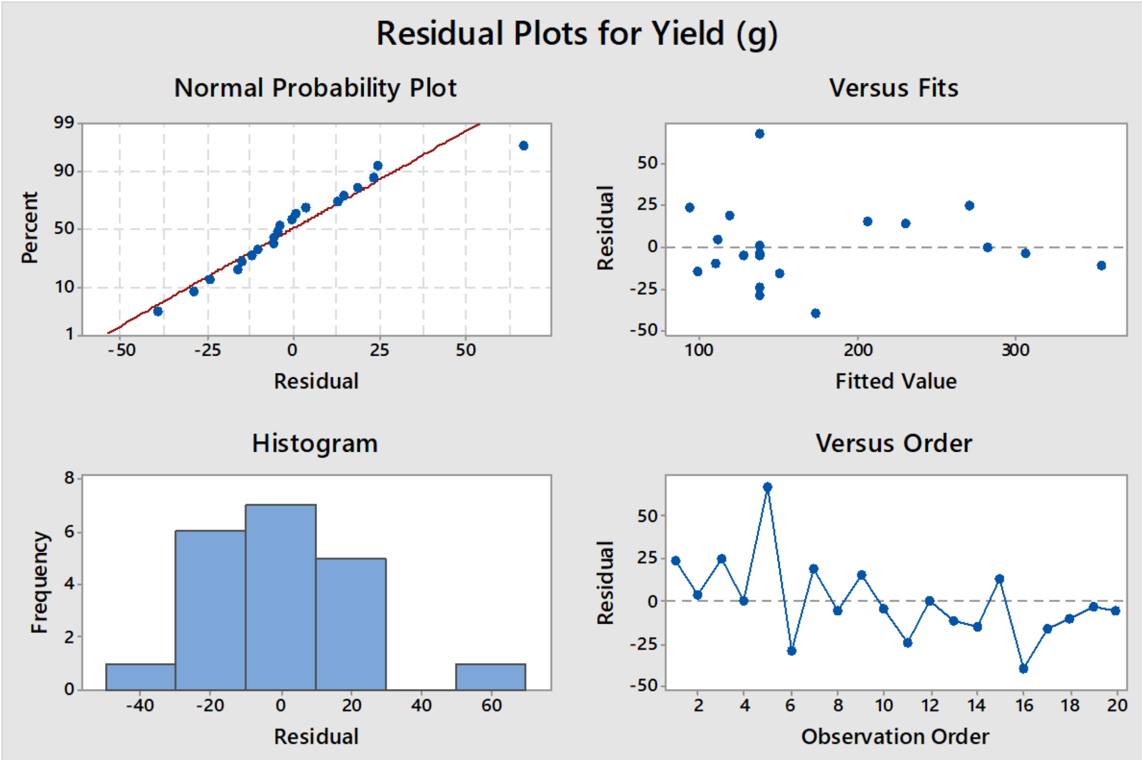

Contour Plots of pH
Temperature*Mass
Time*Mass
Time*Temperature
pH
< 3.0
3.0 – 3.2
3.2 – 3.4
3.4 – 3.6
3.6 – 3.8
3.8 – 4.0
> 4.0
Hold Values
Mass 1.25
Temperature 45
Time 12

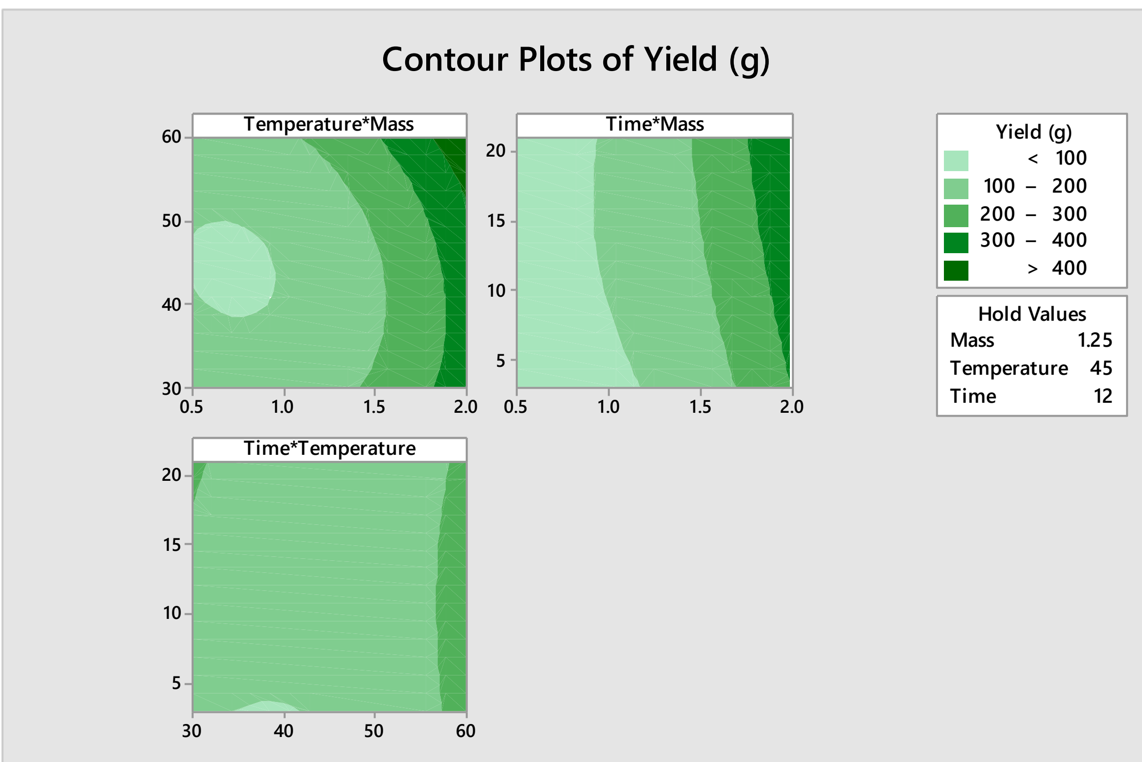


Residual Plots for Brix
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order



Contour Plots of Brix
Temperature*Mass
Time*Mass
Time*Temperature
Brix
< 8
8 – 9
9 – 10
10 – 11
> 11
Hold Values
Mass 1.25
Temperature 45
Time 12


Residual Plots for Yield (g)
Normal Probability Plot
Percent
Residual
Versus Fits
Residual
Fitted Value
Histogram
Frequency
Residual
Versus Order
Residual
Observation Order


Contour Plots of Yield (g)
Temperature*Mass
Time*Mass
Time*Temperature
Yield (g)
< 100
100 – 200
200 – 300
300 – 400
> 400
Hold Values
Mass 1.25
Temperature 45
Time 12