A Study of the Influence of the Parchment Hull in the Thin-Layer Drying of Parchment Coffee

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

________________________ Date 29/07/2005

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This thesis has been submitted for examination with my approval as a University supervisor for the award of degree of Master of Science in the Department of Environmental and Bio-systems Engineering in the Faculty of Engineering, University of Nairobi.

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Date: 29 July 2005

DEDICATION

To my loving mother, Anne Wangui Njoroge, for the innumerable things she has done for me, but most of all for dedicating all her life to the welfare of my dear sister Njeri, brother Ngari and I. May the Almighty God grant her peace always.

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Last but not least, my sincere gratitude goes to my family for the sacrifice, patience, understanding and moral support which kept me going.

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ABSTRACT

This research was conducted at the University of Nairobi with the broad objective being to determine the influence of the parchment hull on the thin-layer drying of parchment coffee.

Parchment coffee consists of a soft tissue bean enclosed in a woody husk (the parchment hull). Drying of parchment coffee is very important in maintaining the intrinsic high cup quality. The convectional drying process is sun drying, a process that consumes large ground space, is labour intensive, takes long and is vulnerable to bad weather. However, research has shown that the parchment coffee can be partly dried using mechanical dryers without significant loss of quality. In the development of mechanical dryers, the role of the thin-layer equation for accurate prediction of the drying process is pivotal, yet none existed for parchment coffee.

A laboratory dryer with air conditioning system was designed and fabricated for thin-layer drying studies. The dryer was tested and found to provide constant drying air conditions for temperature ranges between 31 and 66°C Data were collected for five thin-layer drying conditions for the parchment and the green coffee beans respectively. The drying conditions were composed of five dry bulb temperatures viz. 31°C, 38°C, 46°C, 50°C and 66°C and one dew point temperature viz. 14°C.

A mathematical model based on the Fick's second law of diffusion was developed to describe thin-layer drying of parchment coffee. Further two mathematical models were selected from literature. The models selected were the diffusion model and the Page equation. The proposed model and those selected from literature were evaluated to fit the data.

The results of the drying experiments indicated that the time taken to achieve any given moisture ratio was shorter for the green coffee beans than for the parchment coffee beans, hence the parchment hull retards the drying rate of parchment coffee beans.

The Page equation was found most suitable for describing thin-layer drying of parchment coffee beans for the drying air temperature range of 31 to 66°C, relative humidity of 3 to 31% and air velocity of 0.6 m/s.

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LIST OF SYMBOLS

C = moisture concentration gradient in kg/m^3

d = moisture diffusivity, m^2/hr

t = time in hours

x, y, z = dimensional coordinates

M = moisture content, dry basis(d. b.)

D = liquid diffusivity of water, m^2/hr

r = radial distance, m

R = radius of the bean, m

r = variable radius, m

C_e = equilibrium moisture concentration, kg/m^3

C_o = initial moisture concentration, kg/m^3

W_w = instantaneous mass of water, grammes.

W_c = instantaneous mass of wet coffee, grammes.

W_d = mass of dry matter (bone dry) of the coffee beans, grammes.

M_{wo} = initial moisture content, decimal, w.b.

M = average moisture content, d. b.

R = radius of sphere, m

MR_1 = moisture ratio of the bean

$M1_t$ = average moisture content of the bean at any time t, decimal, dry basis (d. b.)

M_o = initial moisture content, decimal, (d. b.)

M_e = equilibrium moisture content, decimal, (d. b.)

K = constant with respect to moisture content

LIST OF ABBREVIATIONS

d. b. - dry basis

w. b. - wet basis

m. c. - moisture content in percentage

m. r. - moisture ratio

ANOVA - Analysis of variance

^{o}C - temperature in degrees Centigrade

CHAPTER ONE

INTRODUCTION

1.1 Background

The design of mechanical drying systems and quality control of the final product requires accurate prediction of the drying curves of thin-layers of the product (Hall, 1980). Theoretical, semi-theoretical, and empirical equations have been developed to predict thin-layer drying for many agricultural crops using accepted theories of the mechanism of drying (Agrawal & Singh, 1977; Bruce, 1985; Byler, 1987; Chhinnan & Young, 1977; and Colson & Young, 1990).

One of the most widely accepted theories of the mechanism of drying is that moisture movement in a material is primarily a diffusion process due to moisture concentration difference. Mathematical models have been formulated for many agricultural crops based on Fick's second law of diffusion in which moisture diffusion is due to a concentration gradient within the material. Chhinnan and Young (1977) working with peanuts pods concluded that the liquid diffusion model was superior to the vapour diffusion model.

Other models have been designed taking considerations analogous to Newton's law of cooling in which moisture migration from a product is assumed to occur primarily due to the moisture concentration difference between the product and the drying air (Chhinnan, 1984; and Wang & Singh, 1977).

1.2 Statement of Problem

The basic problem is that there is no documented research on development of thin-layer drying equation for parchment coffee. Parchment coffee is a composite material that consists of a soft tissue bean enclosed in a woody husk (the parchment hull). This is quite unique yet most of the thin-layer models have been developed for homogeneous, porous, and hygroscopic bodies (Chhinnan & Young, 1977; and Steffe, 1980). Working with peanut pods, Whitaker and Young (1972) concluded that for composite materials models that considered the product as concentric spheres was more accurate in predicting the drying curves than those that considered the product as homogeneous.

Srivastava (1982) and Trim (1984) carried out research on the development of appropriate mechanical dryers for parchment coffee. Part of the research focussed on adopting existing mechanical grain dryers for parchment coffee, but the rate of success of these was varied. Design of mechanical dryers depends on accurate prediction of the drying process. Thin-layer drying equations provide the first building block in this process. Therefore developing or identifying an appropriate thin-layer drying equation would be a major contribution in this field. In 1978, the Kenya Coffee Quality Research Sub-Committee observed that, of the coffee dryers tested, none was suitable for drying wet parchment coffee without loss of quality. Lack of appropriate dryers for wet parchment coffee is attributed to lack of proper understanding of the mechanisms involved (Kulaba, 1979).

1.3 Justification

Research has shown that it is erroneous to consider a product such as parchment coffee, which is made of two non-homogeneous materials, that is the parchment hull and the bean, as homogeneous. Whitaker and Young (1972) working with peanut pods concluded that a model considering the pods as concentric spheres was more accurate in predicting the drying curve of peanut pods over the entire moisture curve. Further he found that as much as 88% improvement in describing the observed drying results was achieved with the composite model over the homogeneous model.

Drying of parchment coffee is very important in maintaining the intrinsic high cup quality of parchment coffee. In Kenya, both the large scale and the small-scale farmers produce parchment coffee through the wet processing method. According to Enden (2002), after wet processing, parchment coffee must be dried within the shortest acceptable period to stop microbiological activities (moulds, yeasts etc.) which can develop severe cup defects as well as toxins (such as aflatoxins) which pose health risks for consumers. According to Kulaba and Henderson (1980), parchment coffee must be dried to a moisture content of at least 11-12%, at which level coffee beans will preserve inherent quality characteristics, mould development is controlled and - provided good drying practices have been applied – beans are in a state where minimum breakages will occur during milling (secondary processing) In Kenya, the convectional drying process is sun drying, where parchment coffee is spread on coffee trays raised above the ground. The process consumes large areas and is labour intensive. The process also takes long and is vulnerable to bad weather. However, research has shown that the parchment coffee can be partly dried using mechanical dryers without significant loss of quality. Hence to reduce the large area and labour required, and to avoid losses during periods of bad weather, mechanical drying for part of the drying stages shall remain a viable alternative. In the development of these dryers, the role of the thin-layer equation for accurate prediction of the drying process is pivotal. Therefore, the importance of developing an appropriate thin-layer equation for parchment coffee is of significant importance.

Success of mechanical drying depends on the precision of control of the physical parameters, viz. airflow rate, temperature and relative humidity of the drying air. This has proved difficult with the existing machines (Kulaba, 1979). Research (Mwangi, 1983; Srivastava, 1982) has shown that the optimum drying air temperature is between 35 and 42°C for the mild arabica coffee grown in Kenya.

1.4 Objectives.

The broad objective of this research project is to study the influence of parchment hull on the drying of the parchment coffee. The study aims at developing a suitable mathematical model for the thin-layer drying of parchment coffee. The model developed will be compared to published thin-layer drying models using experimental drying data and hence determine the most suitable model for describing drying characteristics of parchment coffee. It is hoped that such findings will be of interest to researchers and designers of parchment coffee drying systems. The specific objectives of the study are to:

1. To design and fabricate a laboratory dryer.
2. To collect thin-layer drying data of parchment coffee beans, and 'green' coffee beans (beans without the parchment hull) under various drying conditions using the laboratory dryer fabricated.
3. To obtain drying profiles of single layer parchment coffee, and green coffee beans under various drying conditions.
4. To compare drying data from drying of parchment coffee and green coffee beans and determine whether, an appropriate thin-layer drying model for parchment coffee based on consideration of the parchment hull and the green coffee bean separately would be more appropriate.

CHAPTER TWO

LITERATURE REVIEW

2.1 Economic Importance of Coffee

Coffee, which originated from Ethiopia in Africa, is grown in over 60 countries of the world which are often heavily dependent on coffee export earnings. It generates income for more than 100 million people in the coffee growing areas worldwide according to DKV and GTZ (2004). It is the second-most widely traded commodity, second only to petroleum, according to Technoserve, a Connecticut-based charity that works with developing countries, as quoted by Scofield (2005).

Coffee is amongst the major cash crops for Brazil, Columbia, Ethiopia, Kenya and Uganda amongst others. According to ICO (2005), the average world green coffee production for coffee years 1998 to 2004 was 112 million bags (60 kg or 132.276 pounds bag) per annum, out of which 88 million bags (79%) was exported. The leading exporters were Brazil, Vietnam and Columbia whose combined annual average for 2000 to 2004 was 58% (see Table 1.1). Kenya accounted for 1 to 2% of the world coffee exports. According to ICO (2005) composite indicator price for 2000 to 2004 was 120.04 US cents per Kg (54.45 US cents per lb) and was on an upward trend. According to ICO (2005), the average for the decade 1990 to 1999 was 255.91 US cents per Kg (116.08 US cents per lb) and for the decade 1980 to 1989 was 308.51 US cents per Kg (139.94 US cents per lb), hence there is great potential for improved earnings.

Table 1.1 World's leading green coffee exporters

Country	Average coffee exports
Brazil	30%
Vietnam	16%
Columbia	12%
Indonesia	5%
Peru	5%
Guatemala	4%
India	4%
Ethiopia	3%
Honduras	3%
Uganda	3%
Cote d'Ive	3%
*** Average coffee exports based on year 2000 to 2004**	
Source : International Coffee Organization	

In December 2004, a draft of the 'Common Code for the Coffee Community' commonly referred to as the '4C' was finalised by over 70 representatives of coffee farmers, trade and industry, non-governmental organisations and trade unions (DKV and GTZ, 2004). The signatories include the world's largest coffee-roasters: Nestle, Kraft, Sara Lee and Tschibo according to Bosman (2004). The 'Common Code for the Coffee Community' is a voluntary code that lays down social and ecological criteria for the coffee trade. The Code has basic social, environmental and economic standards for achieving greater sustainability in the production, post-harvest processing and trade of green coffee. According to Bosman (2004), the code is now being pilot tested in countries such as Ethiopia, Uganda, Vietnam, and El Salvador. It should result in improvements in the living conditions of farmers, environmental protection and economic efficiency. The implementation of the Code is expected to result in more stringent standards for post harvest processing including drying.

In Kenya, where agriculture is the mainstay of the economy, coffee is amongst the three most important agricultural commodities both in terms of its contribution to the Gross Farm Revenue and foreign exchange earnings (Government of Kenya, 2004). . Therefore the importance of coffee need not be emphasised. For this reason research to further the knowledge in coffee is of great importance.

2.2 Classification of Coffee

Coffee belongs to *Rubiacea* family. In this family there are seventy species out of which only ten can be cultivated. Out of these only two species, *Coffea arabica, and Coffea canephora,* are commercially viable (Hilton et al., 2003).

According to ICO (2004), the coffee produced in the world is composed of about 64 % of *Coffea arabica* and 36 % of *Coffea robusta* (see Table 2.1). An update of world production by Marshall (2003) details depicts similar trends.

Although there are many different varieties of *Coffea canephora* the main one is *robusta*. In general, they thrive in hotter lowland areas i.e. below 900m above sea level and over 20°C. Robusta coffee is preferred for instant coffee production due to higher soluble solid extraction. However, although Robusta is more robust than Arabica plants, it produces an inferior tasting beverage with higher caffeine content according to Scofield (2005).

Table 2.1 Volume and Value of Green Coffee Exports* by Species

	2000		2001		2002		2003		Average	
	Volume	Value	Volume	Value	Volume	Value	Volume	Value	Volume	Value
Colombian Milds (arabica)	11.16	1.42	11.67	1.02	11.37	0.98	11.71	1.03	13%	18%
Other Milds (arabica)	27.06	3.2	22.09	1.83	21.31	1.71	20.45	1.7	26%	34%
Brazilian Naturals (arabica)	18.32	1.88	22.09	1.42	24.65	1.31	23.75	1.51	25%	26%
Robustas	32.62	1.68	33.5	1.12	30.23	1.12	29.31	1.32	36%	22%
TOTAL	**89.17**	**8.17**	**90.15**	**5.39**	**87.56**	**5.12**	**85.22**	**5.56**	**100%**	**100%**

* Volume in Million (60 kg or 132.276 pounds) bags

Value in Billion US$

Source : International Coffee Organization

Coffea arabica is a glossy leafed shrub or small tree with relatively small leaves and fragrant white flowers. Arabica coffee usually receives a premium price for its superior flavour and aroma. Arabica coffee is more suited for higher cooler climates i.e. 600-2000m above sea level and 15-20°C.

Coffea liberica is a larger tree with large leaves and berries. It can tolerate hot and wet conditions. The coffee produced is bitter. This is mainly grown in Malaysia and West Asia.

The coffee produced in Kenya consists of about 98% of mild arabica type, while robusta coffee makes up for the difference. *Coffea arabica* was therefore selected as the subject of this proposed study.

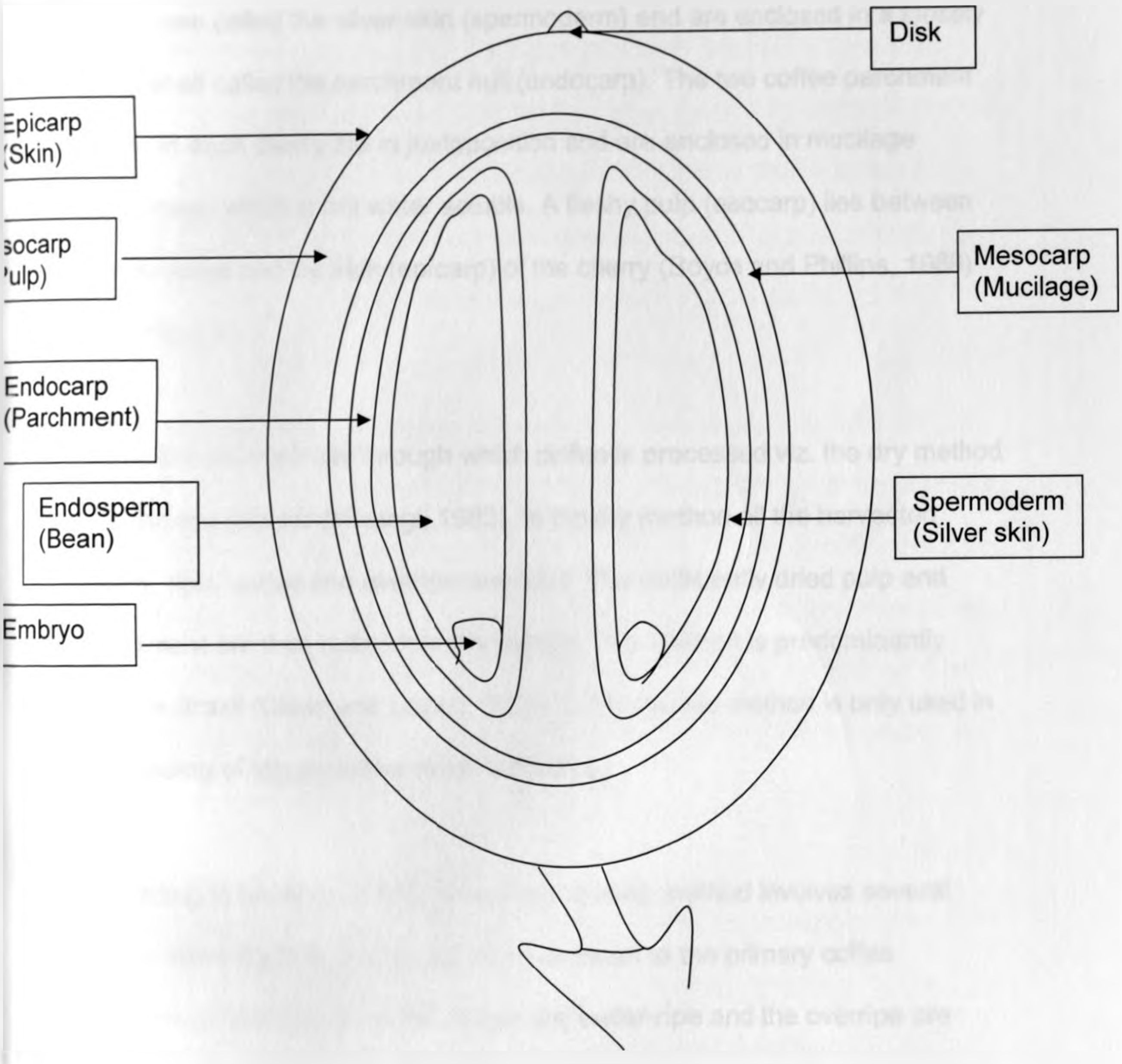

Fig 2.1 Longitudinal section of a coffee cherry.

2.3 Processing of Coffee

A normal coffee cherry contains two beans (endosperm) covered with a thin membrane called the silver-skin (spermoderm) and are enclosed in a loosely fitting shell called the parchment hull (endocarp). The two coffee parchment beans in each cherry are in juxtaposition and are enclosed in mucilage (mesocarp) which is not water soluble. A fleshy pulp (esocarp) lies between the mucilage and the skin (epicarp) of the cherry (Boyce and Phillips, 1969) (See Fig 2.1).

There are two methods through which coffee is processed viz. the dry method and the wet method (Mwangi, 1983). In the dry method all the harvested cherry, ripe, unripe and overripe are dried. The sufficiently dried pulp and parchment are then hulled from the beans. This method is predominantly used in Brazil (Clows and Logan, 1985). In Kenya this method is only used in processing of Mbuni (coffee dried with pulp).

According to Mwangi (1983), the wet processing method involves several stages (See Fig 2.2). Harvested cherry is taken to the primary coffee processing factories. Here the unripe, the under-ripe and the overripe are sorted manually because the overripe cherries are difficult to process since fermentation will have started while they are still on the tree, while the unripe and under-ripe are difficult to pulp since the mucilage is not fully formed and are slow to ferment. In this method, the coffee pulp and skin are removed soon after harvesting preferably the same day. This is followed by fermentation to remove the mucilage; and washing to remove the excess digested sugars on the parchment, the resulting coffee bean enclosed in a loosely fitting parchment hull is the parchment coffee bean. There are two fermentation methods namely the wet and dry fermentation (Mwangi, 1983). In the wet fermentation method, the parchment coffee is submerged under water to ferment after pulping. In dry fermentation the pulped coffee is drained of all water and left to ferment without water. After fermentation coffee is washed in washing channels to remove excess sugars. Parchment coffee beans from the washing channels are then placed in soak tanks to allow coffee on the drying table adequate time, and hence reduce the drying area required. Moreover it has also been observed that soaking improves the quality of final brew (Kulaba, 1979 and Mwangi, 1983). The parchment coffee is dried to reduce the moisture content from 50% to 11% moisture content (m. c.), wet basis (w. b) before conditioning and storage (Kulaba and Henderson, 1980). Research (CRF, 1968) has shown that each of these steps can have adverse effects on final quality of coffee of otherwise high intrinsic cup quality if not carried out correctly.

The parchment coffee produced from the primary coffee processing factories is transported to coffee milling factories for secondary processing. In the coffee mills, the parchment is removed by hulling, and the silver skin is also removed. The coffee beans without the parchment are referred to as 'green' coffee beans, owing to greenish-blue colour of the beans. The green coffee beans are then graded by size, sorted using density and colour and finally packed in 60 kg bags ready for sale. According to CRF (1968), ratio by weight of fresh coffee cherry to dry parchment coffee to dry coffee beans is

1000:200:166 for heavy coffees, 1000:166:125 for medium heavy coffees and 1000:150:100 for light coffees for coffee dried to 11% m.c. This implies that the weight of the parchment hull is between 17 to 33% of the parchment coffee beans.

After grading and colour sorting, liquoring of the green coffee beans is carried out to determine the cup quality of the beans. The grading and liquoring reports are prepared and used for marketing the green coffee.

The wet method of processing coffee is preferred for the mild Arabica coffee because it produces coffee of superior cup quality for this variety (Kulaba, 1979). The proposed study intends to look at thin layer drying of the parchment coffee processed through this method.

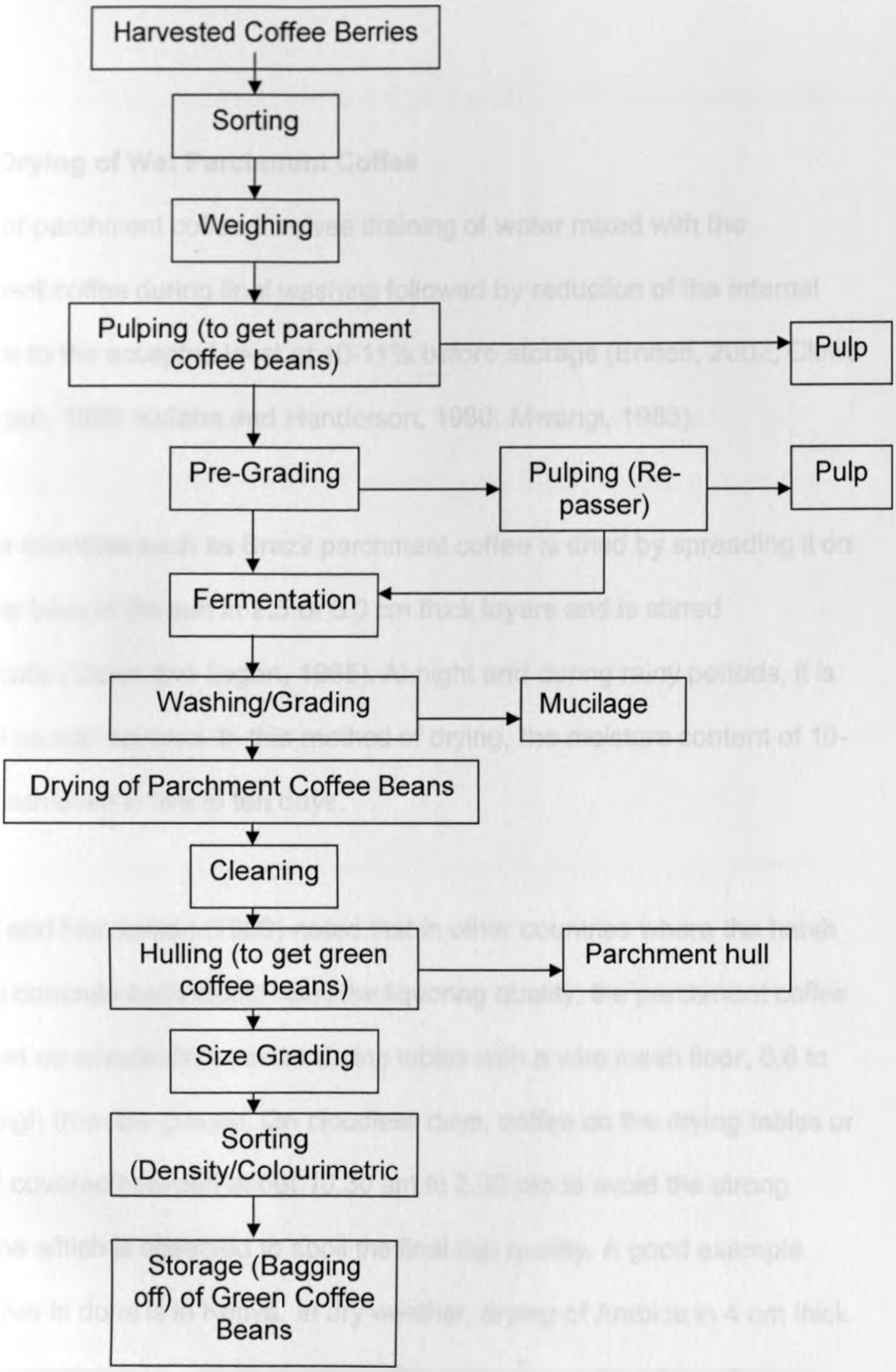

Fig 2.2 Flow Chart Illustrating the Stages of wet Coffee Processing

2.3.1 Drying of Wet Parchment Coffee

Drying of parchment coffee involves draining of water mixed with the parchment coffee during final washing followed by reduction of the internal moisture to the accepted level of 10-11% before storage (Enden, 2002; Clows and Logan, 1985; Kulaba and Henderson, 1980; Mwangi, 1983).

In some countries such as Brazil parchment coffee is dried by spreading it on concrete beds in the sun in 2.5 or 5.0 cm thick layers and is stirred periodically (Clows and Logan, 1985). At night and during rainy periods, it is heaped up and covered. In this method of drying, the moisture content of 10-11% is achieved in five to ten days.

Kulaba and Henderson (1980) noted that in other countries where the harsh heat on concrete beds would spoil the liquoring quality, the parchment coffee is spread on wooden trays or on drying tables with a wire mesh floor, 0.6 to 0.9 m high from the ground. On cloudless days, coffee on the drying tables or trays is covered between about 10.30 am to 2.30 pm to avoid the strong sunshine which is observed to spoil the final cup quality. A good example where this is done is in Kenya. In dry weather, drying of Arabica in 4 cm thick layers (containing 15 - 16 kg of dried coffee per m^2) can take 10 - 15 days.

According to Mwangi (1983), sun dried beans require a curing period of not less than two months. The high labour and area of drying tables required in this method leads to congestion in the drying tables and hence loss of quality during peak periods.

After drying, parchment coffee is placed in the conditioning bins to homogenise the moisture content. The conditioned coffee which is at 10-11% m. c.(w.b.) is transported in 50 kg bags to milling depots by lorries. The parchment and the silver skin are removed by milling. To make a brew, the green coffee beans are roasted then ground. According to the Coffee Board of Kenya (CBK), Kenya coffee is largely sold as green coffee beans. The green coffee beans from Kenya are mainly used for blending with coffee from other parts of the world because of the intrinsic high cup quality.

Increased demand for land for human settlement in coffee growing areas of the country has caused shortage of land for coffee drying. This shortage of land in the vicinity of coffee processing factories has led to loss of quality during drying due to congestion, particularly during the peak harvesting periods. .

2.4 Theory of drying.

2.4.1 Introduction

Mechanical dryers use heated air as the drying medium. The primary factor influencing the rate of drying is temperature (Yunfei and Morey, 1987). Pathak et al., (1991) working with rapeseed concluded that drying air temperature had the highest influence on thin-layer drying, followed by initial moisture content and air velocity. Relative humidity had the least effect and therefore warranted its exclusion from considerations in the evaluation of drying rate of the rapeseed. Sun and Woods (1994) quoting Simmonds et al., 1953) reported that drying was independent of air velocity in the range of 0.15 to 0.81 m/s, but depends sharply on the drying air temperature of the air from 21 to 79°C. ASAE Standards, 1999-581, states that in thin-layer drying of grains and crops, the air velocity approaching the product should be at least 0.3 m/s, but care should be exercised to prevent displacement of particles in the thin-layer holder during a test.

Considerable research has dealt with the drying theory of agricultural crops. Several researchers (Henderson et al. 1997; Brooker et al., 1992; Hall, 1980; and Parker, 1991) have explained drying of agricultural products using the diffusion theory in which moisture migration is due to moisture concentration difference. According to this theory moisture moves from areas of high to low concentration by diffusion. One of the assumptions is that the diffusion was due to liquid concentration difference, while another assumption is that the diffusion process was due to vapour concentration gradient (Chhinnan and Young, 1977; Steffe, 1980; Sun and Wood, 1994; Young and Whitaker, 1971a and 1971b). In both cases, the material such as grain is assumed as homogeneous and isotropic experiencing negligible volume changes and keeping a constant mass diffusivity constant during drying (Gaston et al., 2003).

Researchers (Chhinnan and Young,1977 and Steffe, 1980) designed mathematical models to quantify drying process using the Fick's second law of diffusion. Chhinnan and Young (1977) working with peanut pods concluded that the liquid diffusion model was superior to the vapour diffusion model. Steffe (1980) used the liquid diffusion model to develop drying models for white, brown, and rough rice. Another widely used theory is that resistance to moisture migration during drying is concentrated at the surface of individual kernels of the product (Syarief, 1984; Chhinnan, 1984; Agrawal and Singh, 1977). Mathematical models such as the Page equation have been developed using analogies to Newton's law of cooling (Chhinnan, 1984; Agrawal and Singh, 1977; Hall 1980; Pathak et al, 1991).

2.4.2 Rate Periods of Drying.

The two major periods of drying are (a) the constant rate period and (b) the falling rate period (Hall, 1980; Brooker et al., 1992). In the constant rate period drying takes place from surface of the product and is similar to the evaporation of moisture from a free water surface. The rate depends largely on area of product rather than the material from which the moisture is being evaporated. The end of constant rate period occurs when the rate of moisture diffusion within the product decreases below that necessary to replenish the moisture at the surface.

Next to occur is the falling rate period. The critical moisture content occurs between the constant and the falling rate period. The falling rate period of drying is controlled by the product and involves (a) the movement of moisture within the material to the surface by liquid diffusion and (b) the removal of moisture from the surface. The falling rate period can be divided into two stages (a) unsaturated surface drying and (2) drying where the rate of water diffusion within the product is slow and is the controlling factor. These intervals are sometimes called the first falling rate period and the second falling rate period respectively (Hall, 1980). Research indicates that there are generally more than two falling rate periods. Many theories have been proposed for predicting the drying behaviour of agricultural crops in the falling rate period, but only semi-theoretical and empirical expressions have proved useful to the dryer designers (Brooker et al., 1992). The rate periods of drying are determined from plots of moisture against time and rate of drying against time and moisture content determined from drying data obtained from thin-layer of product fully exposed to the air stream.

2.4.3 Thin Layer Drying

A considerable amount of work has been reported in the literature on thin-layer models for many agricultural crops. The author is unaware of similar research in the drying of parchment coffee. Whitaker and Young (1972) working with peanut pods concluded that a model considering the pods as concentric spheres was more accurate in predicting the drying curve of the peanut pods over the entire moisture curve than models for homogeneous bodies. Comparing the exponential model, the diffusion model, and the Page equation in the drying of in-shell pecans, Chhinnan (1984) found that the Page equation, a modification of the Lewis equation was adequate

Some of the most common assumptions made in developing these models are; simple geometric shape, homogeneity of the material, and that shrinkage is negligible during drying. Without these assumptions solution to these models would be very tedious, without increasing the accuracy of the solution significantly.

2.5 Selected Mathematical Models.

Several mathematical models describing moisture migration during drying in various agricultural crops have been proposed (Henderson et al., 1997; Hall, 1980). Chhinnan and Young (1977) working with peanut pods and Steffe (1980) working with rough rice used the diffusion model to develop thin-layer drying models for these crops. As mentioned above, parchment coffee is a composite material just like peanut pods or rough rice, hence the diffusion model was selected as a possibility for describing thin-layer drying for parchment coffee.

The second model was selected by considering the resistance to moisture migration as concentrated in the parchment hull. This is the basic assumption of the Page equation. Chhinnan (1984) and Wang and Singh (1977) used this equation to describe thin-layer drying of in-shell pecans and rough rice respectively. Therefore, the Page equation was also selected as possible alternative in describing the thin-layer drying for parchment coffee. These models, the diffusion and the Page equation are reviewed below.

The basic difference between these models is that the diffusion model assumes that resistance to moisture migration is spread throughout the product, while resistance at the surface is assumed negligible. On the other hand, the Page equation assumes that resistance to moisture migration is concentrated in a thin shell surrounding the product while internal resistance is negligible.

2.5.1 Diffusion Model

The diffusion model assumes that drying is a diffusion process. Crank (1989), has shown how to set-up and solve diffusion equations for certain geometry. If resistance to diffusion lies on the surface of the particle then one term would suffice otherwise several terms are required. Mathematically, the diffusion model, based on Fick's second law of diffusion, can be expressed in spherical co-ordinates as shown in equation 2.1;

$$\frac{\partial M}{\partial t} = D(\frac{\partial^2 C}{\partial r^2} + \frac{2}{r} * \frac{\partial C}{\partial r}) \tag{2.1}$$

Researchers have used Fick's second law of diffusion in which the predominant driving force is the moisture concentration gradient and also the vapour concentration gradient. Chhinnan and Young (1977) and Steffe (1980) working on peanut pods and rice respectively used this approach successfully. Many other researchers have also used this law in modelling the drying process in solids during the falling rate period.

According to Crank (1989), the solution to equation 2.1 could be used to describe moisture migration for hygroscopic, porous, and approximately spherical bodies. Expressed for the whole parchment coffee, equation 2.1 can be written as:-

$$MR = K_1 \sum_{1}^{\infty} \frac{1}{n^2} \mathrm{EXP}(-K_2 n^2 t) \tag{2.2}$$

2.5.2 The Page Equation

The Page equation a modification of the exponential equation is expressed as;

$$MR = \mathrm{EXP}(-K_3 t^{K_4}) \tag{2.3}$$

This equation was employed by Chhinnan (1984), and by Wang and Singh (1978) to describe thin-layer drying for in-shell pecans, and for rough rice respectively. Agrawal and Singh (1977) working with short grain rice and Syarief et al (1984) working on sunflower seeds also used this model to describe thin layer drying rates.

CHAPTER THREE

PROPOSED MODEL FOR PARCHMENT

Parchment coffee is a composite body which consists of a soft tissue bean, (referred to as green coffee bean) enclosed in the parchment hull (woody husk). This was the basis of the development of the proposed model.

3.1 Model for the Green Coffee Beans

Assumptions

1. The bean is approximately spherical;
2. The bean is approximately homogeneous;
3. The predominant mechanism of drying is liquid diffusion of moisture and that the diffusion constant does not vary with moisture concentration;
4. Shrinkage is negligible;
5. There is no temperature gradient within the individual beans;
6. The bean achieves the temperature of the drying air almost instantly

Fick's second law of diffusion can be expressed as;

$$\frac{\partial C}{\partial t} = \nabla.(D.\nabla C) \tag{3.1}$$

where

$$\nabla = \frac{\partial}{\partial x^2} + \frac{\partial}{\partial y^2} + \frac{\partial}{\partial z^2}$$

3.2

In spherical co-ordinates, equation 3.1 can be expressed as;

$$\frac{\partial M}{\partial t} = D(\frac{\partial^2 C}{\partial r^2} + \frac{2}{r} * \frac{\partial C}{\partial r})$$

3.3

This is the partial differential equation that describes change of moisture concentration with time for a spherical body, based on Fick's second law of diffusion;

For the drying of the beans the boundary conditions are;

$$\frac{\partial M}{\partial t} = 0$$

r = 0 t >= 0 3.4

$C = C_e$, r = R t > 0 3.5

$C = C_o$ 0 =< r =< R t = 0 3.6

A solution of equation 3.3 by the method of separation of variables, (Crank, 1989) is expressed as;

$$\frac{C - C_e}{C_o - C_e} = \frac{2R}{\Pi r}\sum_{1}^{\infty}\frac{(-1)^n}{n}\mathrm{SIN}(\frac{n\Pi r}{R})\mathrm{EXP}(\frac{-Dn^2\Pi^2 t}{R^2})$$

3.7

Integrating equation 3.7 over the radius, the solution obtained (Crank, 1989) is;

$$\frac{M_o - M_{1t}}{M_o - M_e} = 1 - \frac{6}{\Pi^2}\sum_{1}^{\infty}\frac{1}{n^2}\mathrm{EXP}(\frac{-Dn^2\Pi^2 t}{R^2})$$

3.8

Simplifying,

$$MR_1 = \frac{6}{\Pi^2}\sum_{1}^{\infty}\frac{1}{n^2}\exp(-\frac{n^2\Pi^2 Dt}{R^2})$$

3.9

Since the assumptions listed above are not necessarily true, equation 3.9 can be reduced to;

$$MR_1 = K_5\sum_{1}^{\infty}\frac{1}{n^2}\mathrm{EXP}(-K_6 n^2 t)$$

3.10

.Crank (1989) observed that if the resistance to diffusion lies at the surface, one term would suffice, otherwise several terms are required. However, Noomhorm and Verma (1986) working with rice found that the two-term model was superior. Green coffee bean is a homogeneous material just like the rice, hence a two terms model was proposed for the bean. Hence equation 3.10 can be reduced to:

$$MR_t = K_5\{\mathrm{EXP}(-K_6t) + 0.25 * \mathrm{EXP}(-4K_6t)\}$$

3.11

Further the moisture content of the bean at any time t, t> 0 can be expressed as;

$$M\,1_t = (M_o - M_e)K_5\{\mathrm{EXP}(-K_6t) + 0.25 * \mathrm{EXP}(-4K_6t)\} + M_e$$

3.12

This model was proposed for thin layer drying of the green coffee beans.

3.2 Model for the Parchment Hull

Assumptions;

1. The drying rate of the parchment hull can be quantified by considerations analogous to Newton's law of cooling;
2. The parchment hull is a porous homogeneous material;
3. The parchment hull offers negligible resistance to moisture migrating from the bean;
4. The parchment has negligible internal resistance to loss of moisture present in the parchment hull;

Loss of parchment moisture can therefore be expressed as ;

$$\frac{\partial M}{\partial t} \propto (M\,2_t - M_e)$$

3.13

Solving the above equation yields the theoretical model known as the exponential of Newtonian model (Sun and Woods, 1994). The model could be described as (Nellist, 1976; and Colson and Young, 1990):

$$\frac{dM}{dt} = K_7(M2_t - M_e)$$

$$t > 0 \tag{3.14}$$

Boundary conditions are;

$$M2_t = M_o \qquad t = 0 \qquad M2_t = M_e \qquad t = \infty \tag{3.15}$$

Differentiating equation 3.14 and applying the boundary conditions gives (Nellist, 1976; and Sun and Woods, 1994);

$$MR_2 = \mathrm{EXP}(-K_7 t) \tag{3.16}$$

Further the moisture content at any time t, t > 0, can be expressed as;

$$M2_2 = (M_o - M_e)\,\mathrm{EXP}(-K_7 t) + M_e \tag{3.17}$$

Colson and Young, (1990) noted that the equation above assumes that the resistance to moisture movement within the material is negligible. Sharp, (1982) and Bruce (1985) used this model successfully for barley. Kachru et al., (1980) also used it successfully for paddy. Yunfei and Morey (1987) concluded that the drying constants in thin-layer drying for the above equation varied with temperature.

3.3 Proposed Model for the Parchment Coffee Beans

Assumptions

1. The overall moisture content of the parchment coffee is a function of the moisture content of the bean and the parchment hull.
2. The initial and equilibrium moisture contents of the two components are the same.

The average moisture content for the parchment coffee at any time t during drying is a combination of the contribution from the bean and the parchment, this can be expressed as;

$$M_t = K_8 M1_t + K_9 M2_t \qquad 3.18$$

Where K_8 and K_9 are constants.

Combining equation 3.12, 3.17 and 3.18, we get;

$$M_t = K_8((M_o - M_e) K_5 \{\mathrm{EXP}(-K_6 t) + 0.25 * \mathrm{EXP}(-4K_6 t)\} + M_e) + K_9((M_o - M_e)\mathrm{EXP}(-K_7 t) + M_e) \qquad 3.19$$

Or,

$$MR = K_8 K_5 \{\mathrm{EXP}(-K_6 t) + 0.25 * \mathrm{EXP}(-4 K_6 t)\} + K_9 \mathrm{EXP}(-K_7 t) \qquad 3.20$$

Constants K_8 can be combined to K_5 to produce a new K_8 and old K_8 can be combined with 0.25 to produce K_{10} without loss of generality. Equation 3.20 then becomes;

$$MR = K_8\,\mathrm{EXP}(-K_6 t) + K_{10}\,\mathrm{EXP}(-4K_6 t) + K_9\,\mathrm{EXP}(-K_7 t) \tag{3.21}$$

Equation 3.21 was proposed for the prediction of thin-layer drying curve of parchment coffee. Constants K_6, K_8 and K_{10} can be determined from the drying curve of the green coffee beans, while constants K_7 and K_9 can be determined from the curve of the parchment coffee once K_6, K_8 and K_{10} are determined. Steffe (1980) successively used this concept in determining the constants for mathematical models he developed for thin-layer drying of rough rice components.

CHAPTER FOUR

MATERIALS AND METHODS

4.1 Development of a Laboratory Dryer with air conditioning

4.1.1 Design of the dryer

The dryer designed and constructed consisted of the following components drying chamber with a plenum, sample tray, air heater battery, an air cooling tower, relay switches, a water chillers, water pump, water-pipes, motor-driven backwards curved centrifugal fan, air ducts and instrumentation. (See Fig 4.1 for a schematic drawing of the dryer). The design was made as per ASAE Standards 448 (ASAE S448), 1999 for grains and crops.

The drying chamber was constructed from 20 mm thick batten board and measured 1220 mm high, 550 mm wide and 550 mm long. The plenum chamber was made inside the drying chamber. The drying chamber was painted white to enhance insulation. A recess for the sample tray was made above the plenum. The sample tray was made of metal, with a wire mesh to hold the sample and had a cross-section of 210 mm x 210 mm, with a floor area of 0.0441 square metres, and average mass of 956.24 grammes.

The air heater battery casing was constructed with sheet metal of gauge 16. Heater elements were fitted to provide 7.2 kW. The heater battery was equipped with mercury thermostat switches and sensors to regulate temperature. The heater battery casing was enclosed in a casing made of 20 mm thick batten board for insulation.

The air cooler, which was air-tight, was made of galvanised steel sheet. It was 1220 mm high and 305 mm in diameter, and was insulated with 50 mm thick of polystyrene. The cooling tower was filled with hard granite ballast size 12 to 20 mm up to 760 mm deep. The gravel fill rested on a perforated floor, while an eliminator bank was provided at the top of the gravel fill. Below the perforated floor of the air-cooling tower, a water pod 200 mm in diameter and 500 mm in depth was provided.

The water chillers tank was designed with a capacity of 64 litres. The chilled water was pumped to the cooling tower from the top of the fill by a pump at the rate of 0.78 litres per second. The water flowed through the air cooler by gravity, passed through the water chillers tank, was chilled and then re-circulated to the air cooling tower. The air cooling tower also acted as a humidifier for the air passing through.

Air was forced into the drying system through the bottom of the cooling tower by a backward curved centrifugal fan with a 0.75 kW motor as the prime-mover. After passing through the gravel fill in the cooling tower, the air passed through an eliminator bank to remove any water droplets. The air from the cooling tower was then heated to the required temperature using the heater battery, then passed though the dryer plenum to harmonise the conditions before passing through the drying sample.

4.1.2 Fabrication of the Dryer

All the parts of the dryer were fabricated at the workshops for the Department of Environmental and Bio-Systems Engineering of the University of Nairobi by the author in conjunction with the workshop technicians, except the water chillers tank. The water chillers tank was fabricated in the Industrial Area of Nairobi by a commercial firm specialising in refrigeration and air conditioning. The fabrication was based on the design provided and was supervised by the author.

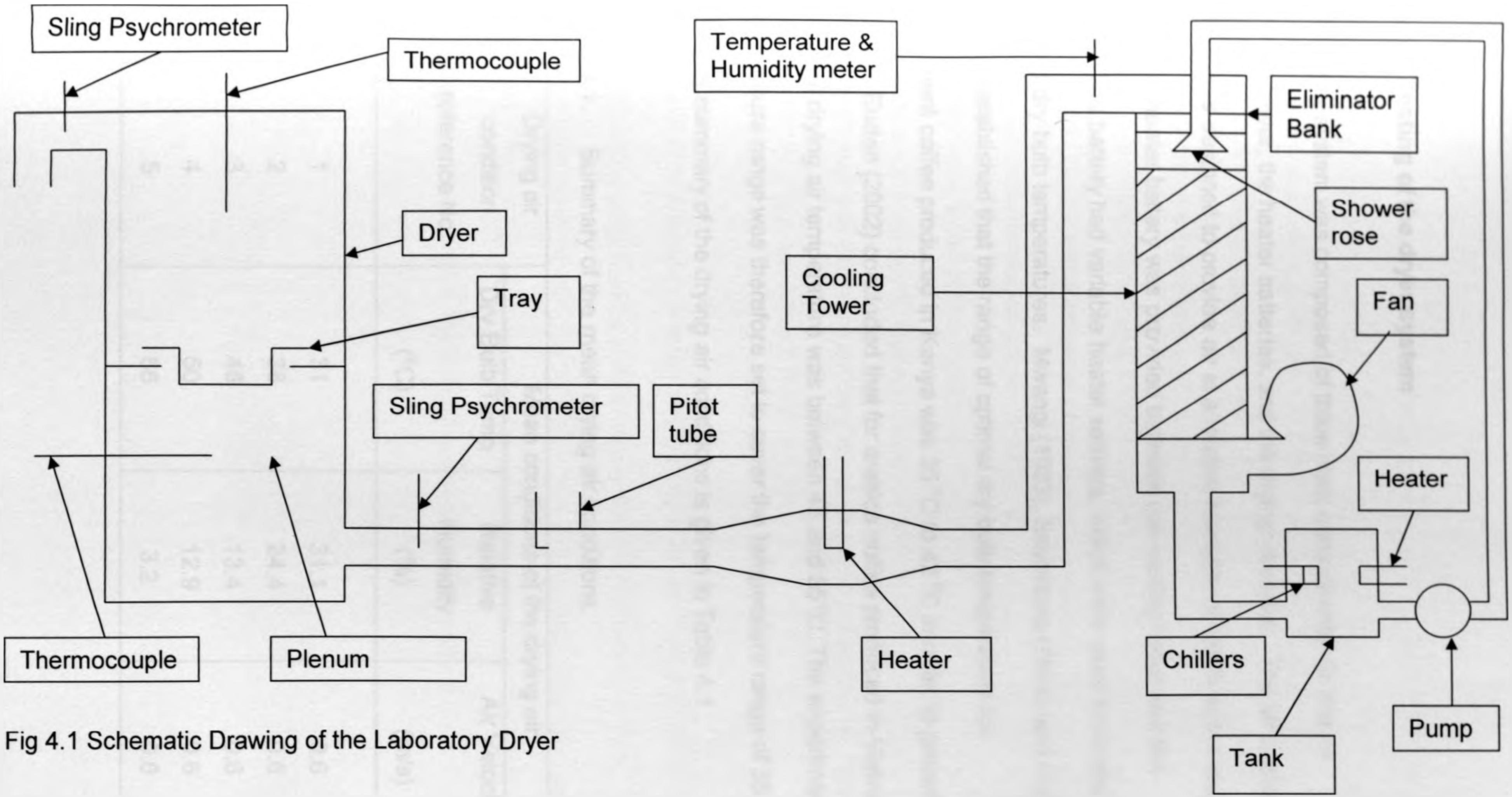

Fig 4.1 Schematic Drawing of the Laboratory Dryer

4.1.3 Testing of the dryer system

The dryer system was composed of three main components viz. the air cooling tower, the heater batteries, and the drying chamber. The air cooling tower was designed to provide air at a relative humidity of 100% at the tower outlet. A heater battery was provided between the cooling tower and the dryer. The battery had variable heater settings, which were used to control the desired dry bulb temperatures. Mwangi (1983), Srivastava (1982) and Kulaba (1979) established that the range of optimal dry bulb temperature for parchment coffee produced in Kenya was 35 °C to 42 °C in order to preserve quality. Enden (2002) concluded that for arabica coffee produced in Vietnam, the ideal drying air temperature was between 45 and 55 °C. The experimental temperature range was therefore set to cover the temperature range of 35 to 55 °C. A summary of the drying air conditions is given in Table 4.1 .

Table 4.1. Summary of the mean drying air conditions.

Drying air condition reference No.	Mean conditions of the drying air		
	Dry Bulb Temp (°C)	Relative Humidity (%)	Air Velocity (m/s)
1	31	31.1	0.6
2	38	24.4	0.6
3	46	13.4	0.6
4	50	12.9	0.6
5	66	3.2	0.6

The fabricated dryer was first tested before being used for the parchment coffee drying experiments. Initially, the dryer was run for 36 hours with the heater battery at a setting of a mean air temperature of 80°C during which, all the elements were checked and those that required minor adjustments made. Then fifteen experiments were performed to test the dryer at the conditions which were to be used for the parchment coffee drying experiments. The experiments were composed of three replicates for each of the five dryer settings detailed above. Initially, the dryer temperature was set 66°C and allowed to run till the conditions of the leaving air had minimum variation about the set point. During this period the conditions of air leaving the cooling tower and entering and leaving the dryer were monitored. The system was also tested to ensure it was air-tight.

The drier was then tested for each of the dryer settings. For each group the conditions were determined by the settings of the heater battery, which provided different temperature and relative humidity for the drying air. For each setting, the air conditions viz. air-flow rate, temperature and relative humidity in the plenum were measured, and the results recorded (see Appendix 1).

4.2 Parchment Coffee Drying Experiments

4.2.1 Materials

Evenly ripe coffee was picked from the University of Nairobi's coffee farm and pulped at the University's primary coffee processing factory situated in the field station at Kabete Campus. The pulped coffee was fermented through the dry fermentation method for 48 hours and then washed. Twelve (12) kilogrammes of washed parchment coffee was placed in a bucket and submerged in water and stored in a cold room at $4^{o}C$.

It was ensured that the sample was clean and representative in particle size. It was free from broken, cracked, weathered, and immature coffee beans and other materials that were not inherently part of the product. The sample had its natural moisture content of between 46.07 and 52.64% w.b. Before the start of each experiment, about 450 grammes of parchment coffee was obtained from the cold room and spread on a wire mesh in a thin-layer to dry the skin water and to bring the sample to room temperature of between19 and $23^{o}C$. This was done at about 5.00 pm of the day before the experiment. Before the start of the experiment the sample was divided into four sub-samples, one of about 150 grammes and the rest of about 100 grammes each. For each experiment, the sub-sample of about 150 grammes was spread in a one kernel thick layer on the tray and placed in the dryer. The other three sub-samples were all placed in an air oven at $130^{o}C$ for 24 hours to determine the initial moisture content of the sample. The duration of oven-drying of the sample was determined experimentally. A weighted average of the initial moisture content (%w. b.) was computed from the results of the three samples. The mass of the sample tray was recorded before and after each experiment, and the average used.

a) Drying Experiments.

As detailed in section 4.1.1 to 4.1.3, a laboratory dryer was developed, fabricated and tested. Parchment and green coffee beans were dried using this dryer. The drying air conditions were one dew point temperature of 14°C and five dry bulb temperatures of 31°C, 38°C, 46°C, 50°C and 66°C. Table 4.1 gave a summary of drying air conditions. In total, thirty experiments were performed, fifteen each for the parchment and the green coffee beans respectively. For each set of drying air conditions, the drying experiment was replicated three times for both the parchment and the green coffee beans.

Tests were conducted only after drying equipment reached steady-state conditions. Steady state was achieved when the approaching air-stream temperature and approaching air-stream relative humidity variation about the set point was minimal.

Coffee beans in a thin layer were exposed fully to the air-stream. The air-stream approaching the sample was as uniform as possible in temperature and humidity at a given cross section parallel to the thin layer so that the air contact to the sample particles was uniform. Passing the air through a plenum before contacting the sample did this. Care was exercised to prevent displacement of coffee beans in the thin-layer holder during all the tests. To achieve this, the air velocity approaching the coffee beans was set at 0.6 m/s which was above the recommended minimum velocity of 0.3 m/s by ASAE Standards 1999-448 for grains and crops such as maize which has physical characteristics close to coffee beans.

b) Measurements

The dryer was pre-tested with the parchment coffee sample at the five selected drying air temperatures. The results of the pre-testing were used to determine the intervals of data collection and total drying duration required to achieve a moisture ratio of about 0.05. The time interval between recordings depended on the mean dry bulb air temperature. Higher temperatures required shorter time intervals between readings. Initially, data were recorded at intervals of ten minutes, but as time progressed, the intervals were increased. The interval was increased because the rate of moisture change decreased with time. Other parameters such as mean dry bulb air temperature, relative humidity, and air velocity were monitored.

c) Accuracy of measurements

Temperature sensors were accurate to 1 °C. Mass was measured with an accuracy of 0.2% of sample mass to ensure that the calculated moisture content was within 0.002 of the coffee bean's actual moisture content. Relative humidity was measured directly or computed from measurements of dry bulb and wet bulb temperature and was accurate to within 3 percentage points. The air velocity measurement was accurate within 5%.

d) Duration of experiment

For each sample, the experiment continued until the change in the weight of the sample over a period of 2 hours was about 0.5g, at which time the moisture ratio, MR was about 0.05. The equilibrium moisture content was determined from plots of moisture content against time for each replicate, and a weighted average determined. The actual moisture content of the sample was computed using equation 4.1

$$MR_t = \frac{Mt - Me}{Mo - Me} \qquad 4.1$$

e) Reporting

Sample identification consisted of; type and variety; year; location of harvest; initial moisture content; storage conditions and history; sample purity; sample preparation. Drying conditions used were specified. These conditions included: initial and final moisture contents; drying time (min); air velocity (m/s); mean dry bulb temperature (°C); and relative humidity (%). All air-condition data included mean and standard deviations computed for the duration of the drying test. Drying rate data reported consisted of the following; the numerical values of moisture content versus time; the estimated values of the constants determined including standard errors of estimates in equations under consideration. The units for parameter k were consistent with the unit of time (min) and included the standard deviation of each. The ranges of temperature, relative humidity, and moisture content were also clearly stated.

f) Data Analysis

The laboratory dryer designed was tested for consistency in maintaining the drying conditions. The null hypothesis being tested was that for each dryer setting, the data obtained was from the same parent population. Statistical comparison of data was based on the analysis of variance. The F statistic was compared with the tabular F statistic from the tables to decide whether to accept the null hypothesis of no difference between the population means or the alternative hypothesis of a difference. In general, where the calculated F statistic exceeded the 1% tabular F, it was concluded that the experiment provided real differences among the means. The F statistic was used because it was an appropriate criterion of testing the hypothesis of homogeneity.

Constants for the thin-layer drying models described in sections 2.5.1, 2.5.2, 3.1, 3.2 and 3.3 were determined from the experimental data by regression techniques for the natural logarithm of the moisture ratio and time. Comparison of the models was based on the sum of squared deviations of the observed and predicted moisture ratios.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Dryer System

During the initial dryer testing which was conducted for 36 hours with the heater battery at a setting of a mean air temperature of 80°C, the steady state conditions were achieved after 200 minutes, but this reduced to 60 minutes after running the dryer for a week. Five drying air conditions were used for testing the dryer (see Table 4.1).These were similar to the air conditions (dry bulb temperature, relative humidity and velocity) that were to be used for the parchment coffee beans drying experiments. For each of the five different dryer settings, the experiments were repeated three times.

The results of these experiments and the corresponding statistical computations including the analysis of variance (ANOVA) are as shown in Tables A1.1 to A1.5 of Appendix 1. The corresponding tabular F statistics (Steel and Torrie 1981), are also shown along the calculated F statistics. The null hypothesis being tested was that the means of the drying conditions came from the same parent population for each setting of the drying air conditions.

Tables A1.1 to A1.5 shows the drying air conditions at various dryer settings and the corresponding ANOVA. From Tables A1.1 to A1.4 the calculated F statistics for temperature ranges between 0.46 and 2.74 while the F tabular ranges between 3.12 and 3.19. In Table A1.5, representing data from experiment performed at an average plenum temperature of 66°C , the calculated F statistic for temperature is 8.48, while F tabular is 3.19.

The results for relative humidity from Tables A1.1 to A1.4, indicate that the experimental F statistic ranges between 0.51 and 3.03, while F tabular lies between 3.12 and 3.19. In Table A1.5, representing data from experiment performed at an average plenum temperature of 66°C , the calculated F statistic for relative humidity is 5.37, while F tabular is 3.19.

Therefore for the experiments whose ANOVA is represented in Tables A.1 to A1.4, there is no significant variation of temperatures and relative humidity in each setting, but for the experiment whose ANOVA is represented in Table A1.5, there is significant variation of temperature and relative humidity within the same air heater settings. These variations could be attributed to inadequate insulation, since the loss of heat to the surrounding depend on the temperature difference.

From above, it can be deduced that temperatures and relative humidity for all the experiments except for the one conducted at drying air temperature of 66°C came from the same parent population. From the evidence available therefore, it was concluded that the drying air conditions were kept fairly constant, except in the experiment performed at an average temperature of 66°C.

Air flow rate through the dryer was also analysed. For the experiment performed at a drying air temperature of 31°C and 46°C, the F statistic is 1.13 and 0.77 while the tabular F statistic is 3.16 and 3.12 at 0.01 respectively. Hence the variation in flow rate was not significant at these two drying air temperatures. But for rest of the experiment, the calculated F statistics lies between 7.60 and 16.56 while the corresponding tabular F statistic at 0.01 lies between 3.14 and 3.19. Therefore, there was a significant difference among the means of the flow rates. The flow rates therefore varied significantly during the experimentation. This could be attributed to inadequate flow rate control for the air forced into the drying system by the fan. Table A1.1 to A1.5 in Appendix 1 shows that typical drying air flow rate were between 0.54 and 0.68 m/s, which is above the minimum velocity of 0.3 m/s recommended by ASAE Standards, 1999-581. The drying air velocity was also within the range of 0.15 to 0.81 m/s and therefore did not have a significant affect on thin-layer drying rate (see section 2.4.1).

In summary therefore the dryer system, except for the flow rate was able to maintain constant mean drying air conditions, except for conditions set at 66°C where there were some variations.

5.2 Influence of the Parchment Hull

The time taken to reach any given moisture ratio for the parchment coffee beans was found to be higher than that of the green coffee beans. Table 5.1 shows the mean time taken to achieve a moisture ratio of 0.09 at various drying air temperatures for both the parchment and green coffee beans. Figure 5.1 shows typical moisture ratio curves for parchment and green coffee beans.

Table 5.1: Time taken to achieve a moisture content of 0.09 for parchment and green coffee beans.

Drying Air Temperature (°C)	Time Taken to Achieve a MR of 0.09 (in Minutes)	
	Parchment Coffee Beans	Green Coffee Beans
31	2430	1560
38	1595	1360
46	698	540
50	360	330
66	210	201

Analysis of variance for the time taken by both the parchment and green coffee beans to achieve any moisture ratio yielded calculated F values of between 54 and 398, the higher values being for low drying air temperatures. These values were higher compared to 1% tabular F value of 2.89. This was a clear indication that the means were not from the same population mean.

Analysis of the data above therefore implies that the parchment hull retards drying however, at higher drying air temperatures, the influence of the parchment on the drying rate is reduced.

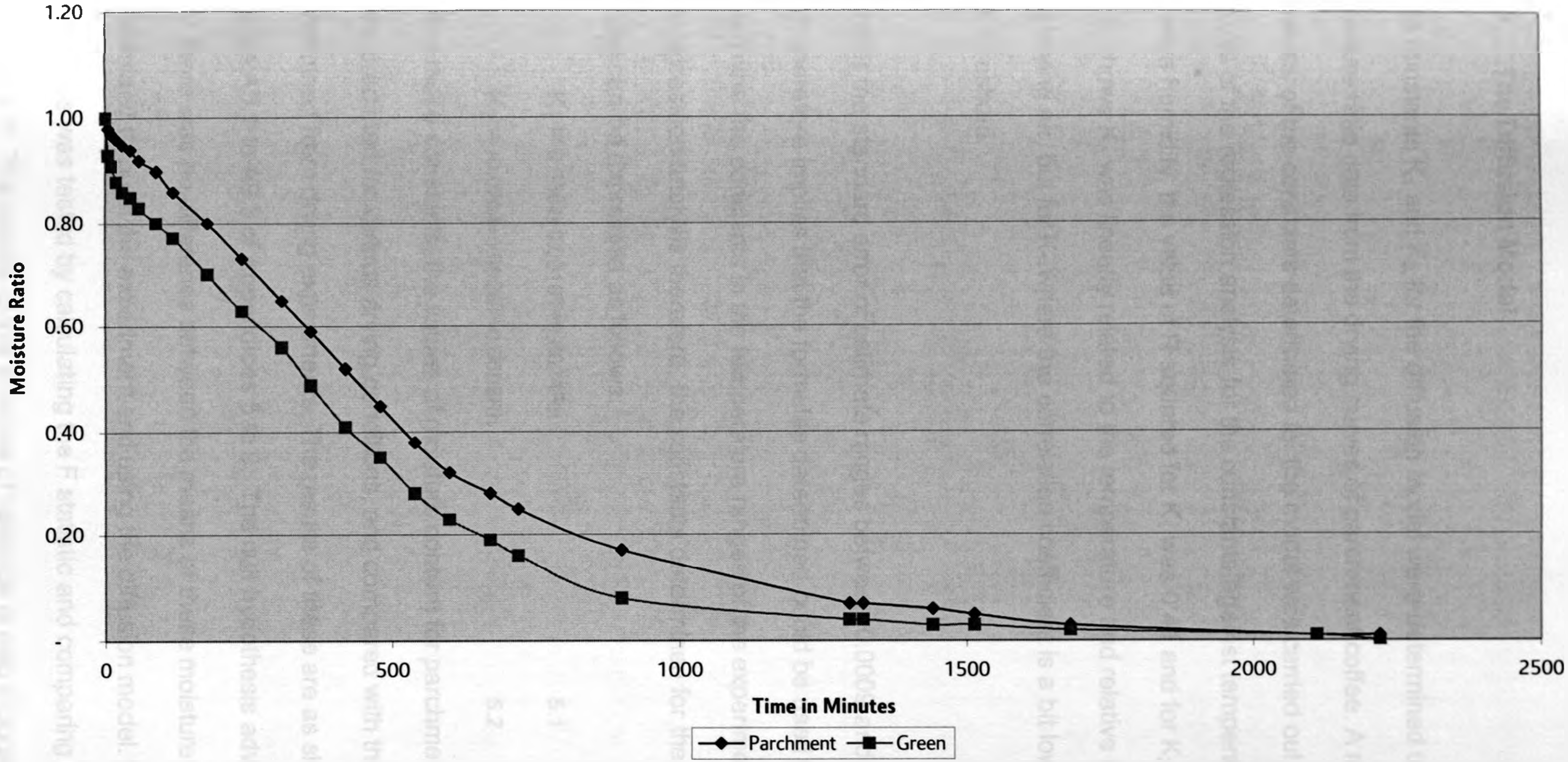

Fig 5.1 Moisture ratio curves for parchment and green coffee at 38 oC

5.3 The Diffusion Model

The constants K_1 and K_2, for the diffusion model were determined using the moisture ratio data from the drying curves of parchment coffee. A regression analysis of the constants determined for the model was carried out. From the results of the regression analysis for the constants against temperature and relative humidity, the value of R squared for K_1 was 0.41 and for K_2 was 0.98. This shows K_8 was linearly related to the temperature and relative humidity of the drying air, but for K_1 where the correlation coefficient is a bit low was on the threshold.

Further the standard error of estimate ranges between 0.0009 and 0.011. This therefore implies that the formulae determined could be used reliably to determine the constants in the temperature ranges of the experiments. From the regression analysis therefore, the constants determined for the diffusion model can be expressed as follows:

$$K_1 = 0.6594+0.0018T+0.0024Rh \qquad 5.1$$

$$K_2 = -0.0264+0.0006T+0.0003Rh \qquad 5.2$$

Using these constants, the values of moisture content for parchment coffee were predicted for various drying conditions, and compared with the actual determined from drying experiments. The results of these are as shown in Tables A5.1 to A9.3 of Appendices 5 to 9. The null hypothesis advanced was that there was no difference between the means of these moisture ratios determined through the experiment and using the diffusion model. The hypothesis was tested by calculating the F statistic and comparing this with the tabular F. The results of this analysis of variance is also included in the

Tables A5.1 to A9.3 of Appendices 5 to 9. Table 5.2 shows a summary of the F statistics for the diffusion model.

Table 5.2 Summary of F statistic for the diffusion model

Dry bulb temperature of the drying air (^oC)	Calculated F statistic (for the diffusion model)	Tabular F statistic at 0.01
31	0.87	4.10
38	2.29	4.07
46	0.05	4.08
50	0.43	4.05
66	0.13	4.15

From the Table 5.2, all the calculated F statistics range from 0.05 to 2.29. All these values are lower than the tabular F at 0.01, which ranges between 4.05 and 4.15. Hence it can be deduced that there is no significant difference between the actual and predicted moisture ratio using the diffusion model. Therefore the diffusion model can be used for predicting the drying of parchment coffee in thin-layer drying. Figure 5.2 shows typical drying curves for the experimental and predicted moisture ratios.

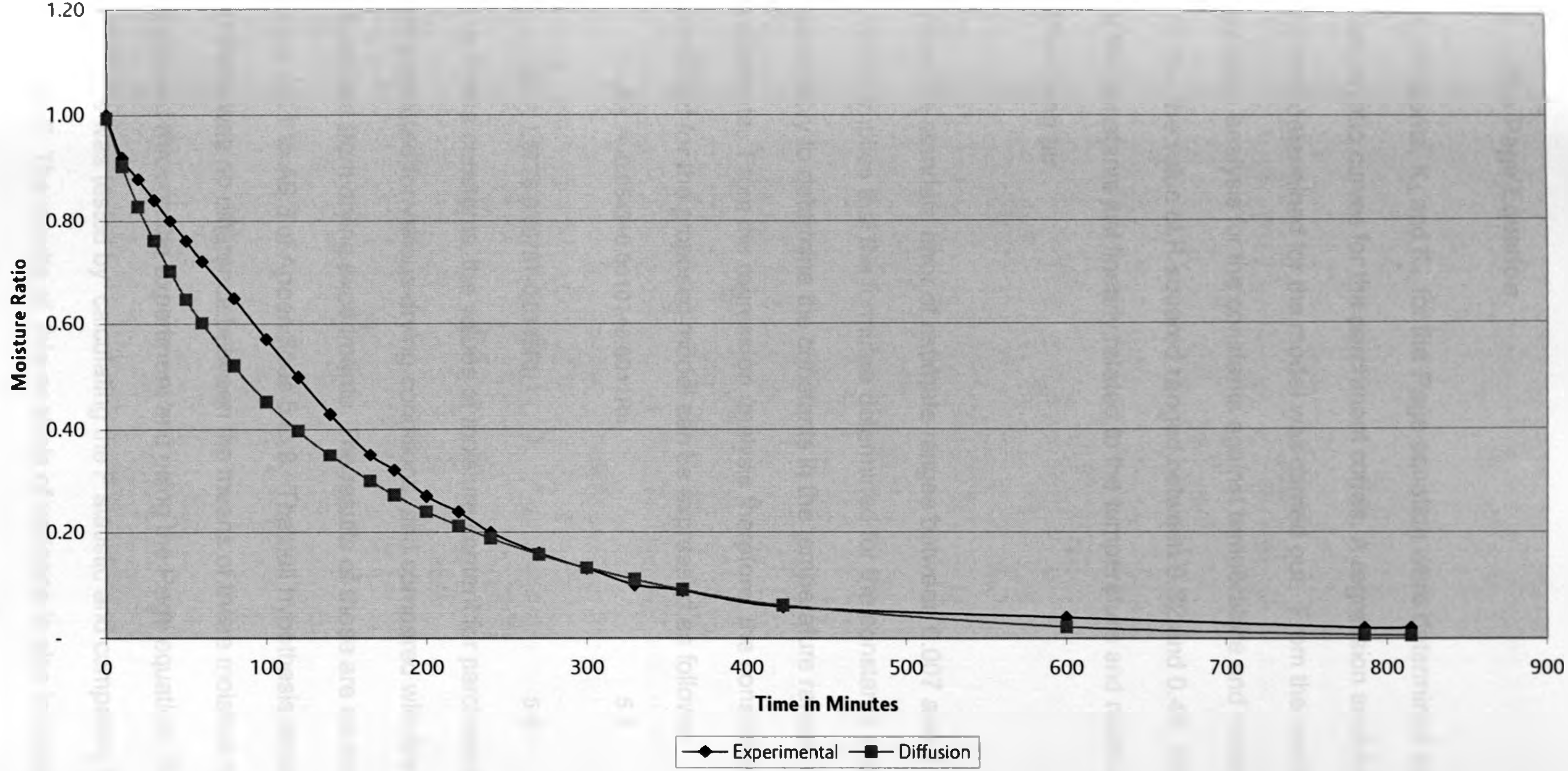

Fig 5.2 Moisture ratio curves for the diffusion model and the experiment at 50 oC

5.4 The Page Equation

The constants, K_3 and K_4, for the Page equation were determined from the moisture ratio curves for the parchment coffee. A regression analysis of the constants determined for the model was carried out. From the results of the regression analysis for the constants against temperature and relative humidity, the value of R squared ranged between 0.32 and 0.46. This shows that the constants just linearly related to the temperature and relative humidity of the drying air.

Further the standard error of estimate ranges between 0.007 and 0.156. This therefore implies that the formulae determined for the constants could be used reliably to determine the constants in the temperature ranges of the experiments. From the regression analysis therefore, the constants determined for the proposed model can be expressed as follows:

$$K_3 = -0.0543+0.0010T+0.0011Rh \qquad 5.3$$

$$K_4 = 1.5776-0.0078T-0.0185Rh \qquad 5.4$$

Using these constants, the values of moisture content for parchment coffee were predicted for various drying conditions, and compared with the actual determined from drying experiments. The results of these are as shown in Tables A5.1 to A9.3 of Appendices 5 to 9. The null hypothesis advanced was that there was no difference between the means of these moisture ratios determined through the experiment and using the Page equation. The hypothesis was tested by calculating the F statistic and comparing this with the tabular F. The results of this analysis of variance is also included in the

Tables A5.1 to A9.3 of Appendices 5 to 9. Table 5.3 shows a summary of the F statistics for the Page equation.

Table 5.3 Summary of F statistic for the Page equation

Dry bulb temperature of the drying air (°C)	Calculated F statistic (for the Page equation)	Tabular F statistic at 0.01
31	0.38	4.10
38	2.41	4.07
46	0.09	4.08
50	0.78	4.05
66	0.59	4.15

From the Table 5.3, all the calculated F statistics range from 0.09 to 2.41. All these values are lower than the tabular F at 0.01, which ranges between 4.05 and 4.15. Hence it can be deduced there is no significant difference between the actual and the moisture ratio predicted using the proposed model. Therefore the model can be used for predicting the drying of parchment coffee in thin-layer drying. Figure 5.3 shows typical drying curves for the experimental and predicted moisture ratios.

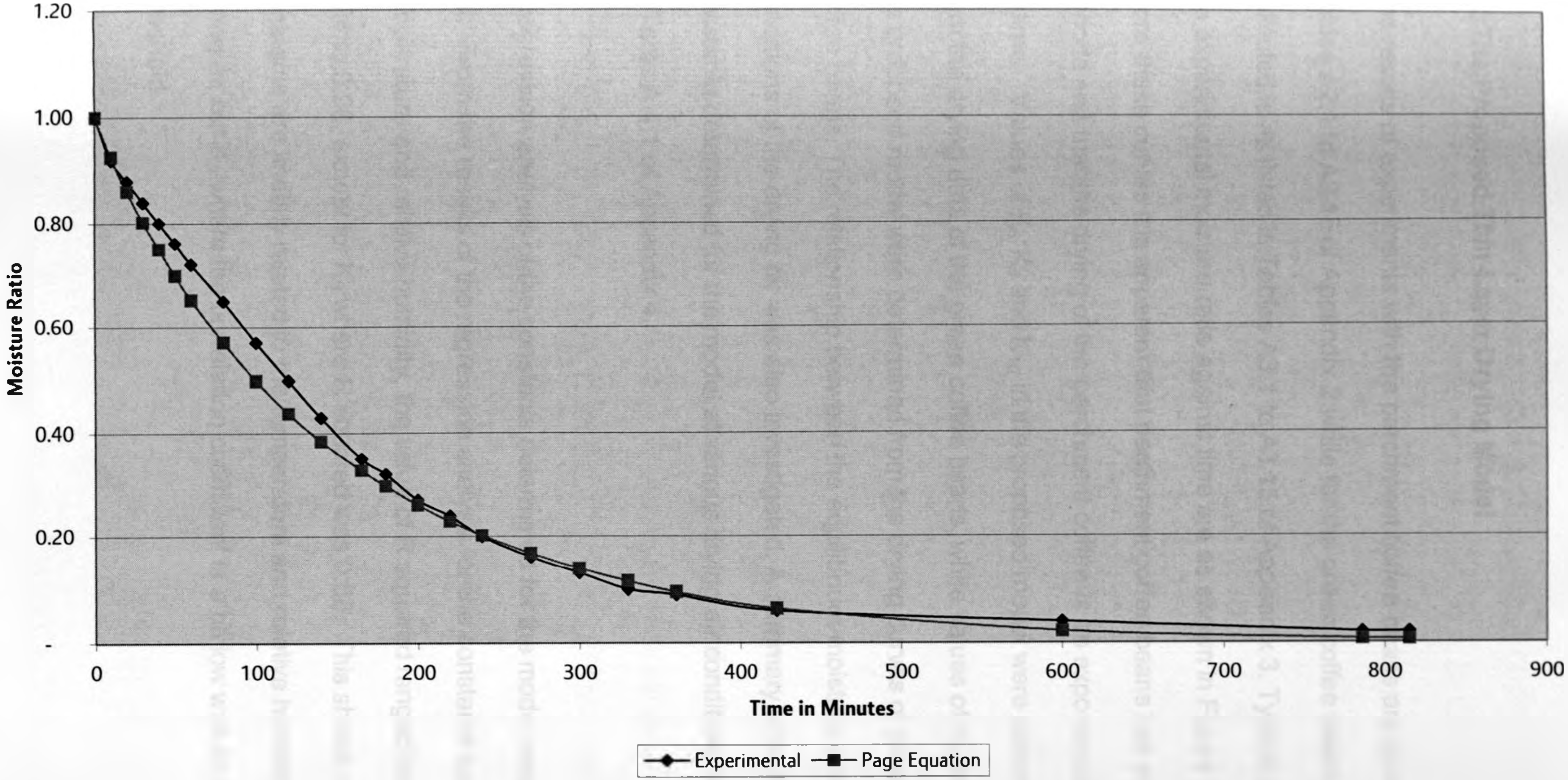

Fig 5.3 Moisture ratio curves for the Page equation and the experiment at 50 oC

5.5 The Proposed Thin-Layer Drying Model

The results of experiments with the parchment coffee beans are as listed in Tables A2.1 to A2.15 of Appendix 2 while for the green coffee beans the data collected is as listed in Tables A3.1 to A3.15 of Appendix 3. Typical plots of the experimental moisture ratio against time are as shown in Figure 5.2. From these curves it is apparent that parchment coffee beans has many rate periods and that the drying of the parchment coffee is an exponential function of time. Values of K_6, K_8 and K_{10} in the proposed model were determined from the drying data of the green coffee beans, while values of K_7, and K_9 in the proposed model were determined from the drying curves of parchment coffee beans. The relationship between the equilibrium moisture content and conditions of the drying air was also investigated. A summary of all the constants determined for the model at various drying air conditions is detailed in Table A.4.1 of Appendix 4.

A regression analysis of the constants determined for the model was carried out. From the results of the regression analysis for the constants against temperature and relative humidity, the value of R squared ranged between 0.94 to 0.98, except for K_9 where R squared was 0.53. This shows that the constants are linearly related to the temperature and relative humidity of the drying air but K_9 where the correlation coefficient is a bit low was on the threshold.

Further the standard error of estimate ranges between 0.0007 and 0.055. This therefore implies that the formulae determined could be used reliably to determine the constants in the temperature ranges of the experiments. From the regression analysis therefore, the constants determined for the proposed model can be expressed as follows:

$$K_6=-0.0060+0.0002T \quad 5.5$$

$$K_7=-0.0263+0.0006T+0.0003Rh \quad 5.6$$

$$K_8=1.5740-0.0168T-0.0038Rh \quad 5.7$$

$$K_9=-0.2609+0.0039T+0.0066Rh \quad 5.8$$

$$K_{10}=-0.3131+0.0129T-0.0028Rh \quad 5.9$$

$$M_e=0.02744-0.0002T-0.00122Rh \quad 5.10$$

Using these constants, the values of moisture ratio for parchment coffee were predicted for various drying conditions, and compared with the actual determined from drying experiments. The results of these are as shown in Tables A5.1 to A9.3 of Appendices 5 to 9. The null hypothesis advanced was that there was no difference between the means of these moisture ratios determined through the experiment and using the proposed model. The hypothesis was tested by calculating the F statistic and comparing this with the tabular F. The results of this analysis of variance are also included in the Tables A5.1 to A9.3 of Appendices 5 to 9. Table 5.4 shows a summary of the F statistics for the proposed model.

Table 5.4 Summary of F statistic for the proposed model

Dry bulb temperature of the drying air (^{o}C)	Calculated F statistic (for the proposed model)	Tabular F statistic at 0.01
31	0.30	4.10
38	2.13	4.07
46	0.58	4.08
50	0.78	4.05
66	0.59	4.15

From the Table 5.4 all the calculated F statistics range from 0.30 to 2.13. All these values are lower than the tabular F at 0.01, which ranges between 4.05 and 4.15. Hence it can be deduced there is no significant difference between the actual and predicted moisture ratio using the proposed model. Therefore the model can be used for predicting the drying of parchment coffee in thin-layer drying. Figure 5.4 shows typical drying curves for the experimental and predicted moisture ratios.

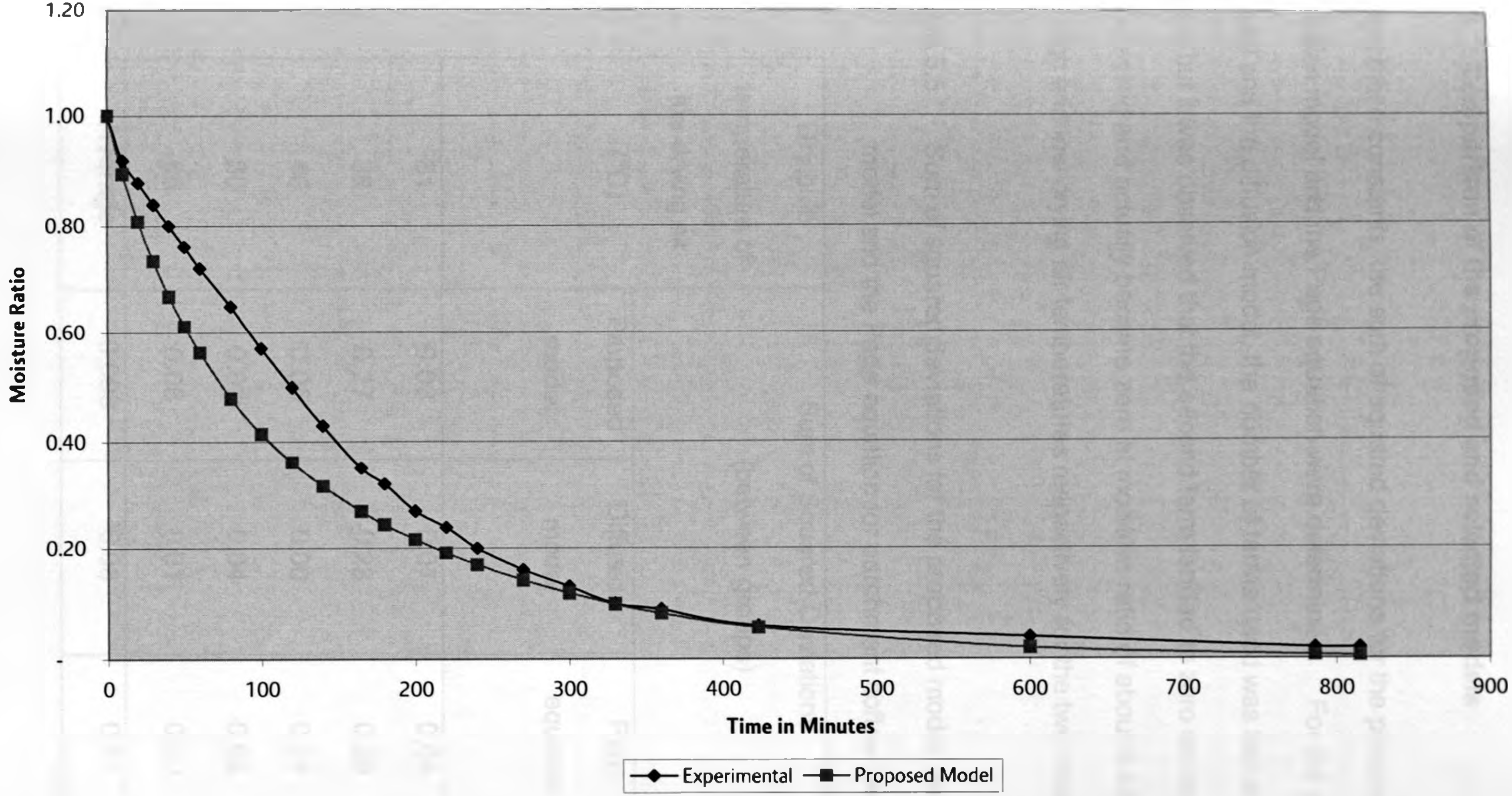

Fig 5.4 Moisture ratio curves for the proposed model and the experiment at 50 oC

5.6 Comparison of the proposed and selected models

Using these constants, the sum of squared deviations for the proposed model, diffusion model and the Page equation were determined. For the proposed model and the diffusion model, the number of terms used was two in each case, but it was observed that the second term tended to zero as the drying progressed and actually became zero at moisture ratio of about 0.42 to 0.73 for high and low drying air temperatures respectively for the two models.

Table 5.5 Sum of squared deviations for the proposed model, the diffusion model and the Page equation for parchment coffee beans.

Dry bulb temperature of the drying air (^oC)	Sum of Squared Deviations (between groups)		
	Proposed model	Diffusion model	Page equation
31	0.03	0.07	0.04
38	0.27	0.28	0.29
46	0.05	0.00	0.01
50	0.08	0.04	0.02
66	0.06	0.01	0.00
Average	0.098	0.08	0.07

The results of the sum of squared deviations from the proposed model, the diffusion model and the Page equation are tabulated in Table 5.5. From these results, the sum of squared deviations for the Page equation are the lowest in two out of the five drying air temperatures i.e. at dry bulb temperatures of 50°C and 66°C. The diffusion model had the lowest value at 46 °C, and the proposed model had the lowest value at 31 and 38°C. The sums of squared deviations for the proposed model are higher than for the diffusion model for temperatures of 46°C, 50°C and 66°C.

The average of the sum of the squared deviations for the proposed model is higher than for the diffusion model. Therefore the accuracy of the proposed model is similar to that of the diffusion model. The average sum of the squared deviations for the Page equation is lower than for the proposed model and the diffusion model, therefore the Page equation is superior in predicting thin-layer drying of parchment coffee. Using the conventional notation, K_3 is the k and K_4 is the n in the Page equation. Therefore, for the temperature range of 31 to 66 °C, relative humidity of 3 to 31% and air velocity of 0.6 m/s, the constants for the Page equation for thin-layer drying of parchment coffee beans could be expressed as follows:

$$k = -0.0543+0.0010T+0.0011Rh \qquad 5.11$$

$$n = 1.5776-0.0078T-0.0185Rh \qquad 5.12$$

The finding that the Page equation is superior to the proposed model and the diffusion model confirms that resistance to moisture migration is concentrated in the parchment hull. This is also a confirmation that it is true that the parchment hull retards drying for the parchment coffee.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions can be drawn from the study:

1. The time taken to attain any given moisture ratio for the parchment coffee was higher than for the green coffee beans for all the drying air conditions used. Analysis of variance of the time taken to achieve any given moisture ratio for the parchment coffee and the green coffee beans respectively for the same drying air conditions indicated that there was real difference between the means, hence they were from different populations. Therefore, the conclusion drawn from this study was that parchment hull retards the rate of drying of parchment coffee beans.

2. The moisture ratios predicted using the model developed, and two others, the diffusion and the Page equation, selected from literature were compared with the actual from the experiments using the sum of squared deviations. The average sum of squared deviations was 0.098 for the proposed model, 0.08 for the diffusion model and 0.07 for the Page equation. From these results it can be concluded that although all these models could be used to predict thin-layer drying of parchment coffee, the diffusion model is almost similar to the model developed, but the Page equation is superior.

6.2 Recommendations

6.2.1 Laboratory Dryer System

One of the weaknesses of the dryer system was lack of proper instrumentation and control mechanisms. In particular provision for weighing of the sample with minimum disturbance should be incorporated.
Incorporating a computer with appropriate interfacing card to record data continuously would greatly enhance the accuracy and timeliness of data capturing.

Finally enhancing the insulation of the dryer system would ensure its reliability for drying air temperatures higher than 66°C.

6.2.2 Parchment Coffee Beans

The percentage reduction of quality of parchment coffee when dried with and without the parchment should be looked into. The economic viability of drying coffee beans with the parchment, which forms about 33% of the weight, and transporting the same to the milling depots whereas the parchment does not form part of the final brew should be investigated.

REFERENCES

Agrawal, Y. C. and R. P. Singh, 1977. Thin-layer drying studies for short grain rice. ASAE Paper No. 77 - 3531, ASAE. St. Joseph, MI 49085

ASAE Standards 448 (ASAE S448), 1999. Thin-Layer Drying of Grain and Crops Standards. Grain & Feed Processing and Storage Committee. ASAE. St. Joseph, MI 49085

Bosman, E., 2004. Coffee giants sign Common Code for Coffee Community. Novib Network, No. 6 of December 2004.

Brooker D. B., F. W. Bakker - Arkema, and C. W. Hall, 1992. Drying and Storage of Grains and Oilseeds. New York, NY: Van Nostrand Reinhold Pub. Inc.

Bruce, D. M. 1985. Exposed layer barley drying: three models fitted to new data up to 150 °C. J. Agric. Eng. Res. 32:337–347.

Byler, R. K., C. R. Anderson, and R. C. Brook. 1987. Statistical methods in thin-layer parboiled rice drying models. TRANS ASAE 30(2): 533 - 538.

Byler, R. K., and R. C. Brook. 1984. Thin layer model, temperature and relative humidity variable. **ASAE** Paper No. 84-2535.

Chhinnan M. S., 1984. Evaluation of selected mathematical models for describing thin-layer drying of in-shell pecans. TRANS ASAE 27(2): 610 - 615.

Chhinnan M. S. and J. H. Young, 1977. A study of diffusion equations describing moisture movement in peanut pods - I: Comparison of the vapour and liquid diffusion equations. TRANS. ASAE 20(3): 539 - 546.

Chu S. T. and Hustrilid, A., 1968. Numerical solutions of diffusion equations. Trans. ASAE 11, 705 - 709.

Clows, M. St. and Logan, W. S. C., 1985. Coffee Drying. Advances in Coffee Management and Technology in Zimbabwe. Cannon Press (1976) (PVT) Ltd. Harare, Zimbabwe.

Coffee Research Foundation (CRF), 1968. Sun drying of arabica coffee. Technical circular No. 11. Coffee Board of Kenya, Nairobi, Kenya.

Colson K. H. and J. H. Young, 1990. Two-Component Thin-Layer Drying Model for Unshelled Peanuts. TRANS. ASAE, 33(1): 241-246

Crank, J., 1989. The Mathematics of Diffusion. Clarendon Press, Oxford, Great Britain.

Crisp J. and J. L. Woods, 1994. The Drying Properties of Rape Seed. J. Agric. Eng. Res. 57, 89-97

Enden Jan von, 2002. Improvement of coffee quality and sustainability of coffee production in Vietnam. Post Harvest Processing - Arabica Coffee GTZ-PPP Project

Food and Agricultural Organisation of the United Nations (FAO), 1985. Production Yearbook. Rome, Italy.

Gaston A. L., Abalone R. M., Giver S. A., and Bruce D. M., 2003. Geometry effect on water diffusivity estimation in proita-isla verde and broom wheat cultivators. Latin American Applied Research 33:327-331(2003).

German Coffee Association (DKV) and German Technical Cooperation (GTZ), 2004. Common Code for the Coffee Community. German Ministry of Economic Co-operation and Development (BMZ), Germany.

Government of Kenya, 2004. 2004 Economic Survey. Prepared by the Ministry of Planning and National Development.

Hall, C. W., 1980. Drying and Storage of Agricultural Crops. The AVI Publishing co. Inc. Westport Connecticut.

Hilton, Hein Jan van, 2003. Coffee: An exporter's guide. Published by International Trade Centre UNCTAD/GATT, Geneva, Switzerland.

Henderson, S. M., R.L. Perry, and J. H. Young, 1997. Principles of Process Engineering. 4th Edition ASAE, 1997.

Hutchinson, D. and L. Otten, 1982. Thin layer drying of soybeans and white beans. **ASAE**/CSAE Paper No. 82-104.

International Coffee Organization (ICO), 2003. Production of ICO's exporting member countries (1996-2002). International Coffee Organisation. London, England

International Coffee Organisation (ICO), 2004. Exports by ICO member countries. International Coffee organisation. London, England

International Coffee Organisation (ICO), 2005. ICO's composite indicator prices (1982 – 2004). International Coffee Organization. London, United, England

Kajuma S. T. A R., Silayo V. C. K., Mkenda A., and Makungu . J. J., 2001. Thin-layer drying of diced cassava roots. African Journal of Science and Technology (AJST), Vol. 2. No. 2, pp 94-100

Kashru R., T. . Ojha and G. T. Kurp, 1980. Drying Characteristics of Indian Paddy Varieties. J. Agric. Eng. Res. 7:16-23

Kulaba G. W. and Henderson S., 1980. Moisture content/equilibrium relative humidity relationship of Parchment Coffee. Kenya Coffee Vol. 45, No. 534.

Kulaba G. W., 1979. Coffee Processing Research: A Review. Kenya Industrial Research Development Institute (KIRDI), Nairobi, Kenya.

Kulasiri, D. G., D. H. Vaughan, J. S. Cundiff and W. F. Wilcke. 1989. Thin layer drying rates of Virginia type peanuts. **ASAE** Paper No. 89-6600.

Marshall C. F., 2003. The World Coffee Trade: A guide to production, trading and consumption of Coffee. Published by Woodhead-Faulker Ltd. Cambridge, England.

Misra, M. K. and D. B. Brooker. 1980. Thin layer drying and re-wetting equations for shelled yellow corn. Transactions of the **ASAE** 23(5):1254–1260.

Mwangi, C. N., 1983. Coffee growers' handbook. Coffee Research Foundation. Ruiru, Kenya.

Nellist M. E., 1976. Exposed Layer Drying of Ryegrass seeds. J. Agric. Eng. Res. 21, 49-66

Noomhorm A. and L. R. Verma, 1986. Generalised single layer rice drying models. TRANS. ASAE 29(2): 587 - 591

O'Callaghan, J. R., D. J. Menzies and P. H. Bailey. 1971. Digital simulation of agricultural drier performance. J. Agric. Eng. Res. 16:223–244.

Pathak P. K., Agrawal Y. C. and Singh B. P. N., 1991. Thin-layer drying models for rapeseed. TRANS. ASAE, 34(6): 2505-2508.

Paulsen, M. R. and T. L. Thompson. 1973. Drying analysis of grain sorghum. Transactions of the **ASAE** 16(3):537–540.

Patil, B. G. and G. T. Ward. 1989. Heated air drying of rapeseed. Agricultural Mechanization in Asia, Africa, and Latin America. 20(4):52– 58.

Scofield A., 2005. Vietnam: silent global coffee power. INeedCoffee.com, a project of Digital Colony.

Sharp J. R., 1982. A review of low-temperature drying simulation models. J. Agric. Eng. Res. 27:169-190

Sivetz, M. S. M. and Desrosier, N. W., 1979. Coffee Technology. The AVI Publishing co. Inc. Westport Connecticut.

Smallholder Coffee Improvement Project, 1988. Project Preparation Report (Project Phase II). Kenya Government, Nairobi.

Srivastava, R. K., 1982. Report on Testing Mechanical Dryers for Coffee. Report submitted to Coffee Research Station, Ruiru, Kenya.

Steel, R. G. D. and J. H. Torrie. 1981. Principles and Procedures of Statistics. A Biometrical Approach. Mc Graw-Hill International Editions. 2nd Edition. London, Lisbon.

Steffe, J. F. and R. P. Singh, 1980. Liquid diffusivity of rough rice components. TRANS. of the ASAE. 23(3): 767 - 774,782

Sun D. W. and J. L. Woods, 1994. Low temperature moisture transfer characteristics of wheat in thin-layers. TRANS. ASAE. 37(6):1919-1926

Syarief A. M., Morey R. V., and Gustafson R. J., 1984. Thin-layer Drying Rates of Sunflower Seed. TRANS. Of ASAE. 27(1): 195-200

Tang, J., S. Sokhansanj and F. W. Sosulski. 1989. Thin-layer drying of lentil. **ASAE** Paper No. 89-6540. **ASAE STANDARDS 1999 583**

Trim, D. S., Brenndorfer, B. and Kamau, I. N., 1984. A new parchment drying system for co-operative factories: I System design and operating principles. Kenya coffee. 128 - 136.

Trim, D. S., and Kamau, I. N., 1984. A new parchment drying system for co-operative factories: II System commissioning. Kenya coffee. 137 - 142.

Wang, C. Y. and R. P. Singh., 1978. A single layer drying equation for rough rice. ASAE Paper No. 78 - 3001, ASAE St. Joseph, MI 49085

Whitaker T. B. and J. H. Young, 1972. Application of the vapour diffusion equation in a porous composite sphere with concentric shells. TRANS. of the ASAE 15(1): 167 – 174

Wilbaux R. 1963. Coffee Processing. Agricultural Processing Branch, Land and Water Division, Food and Agricultural Organisation (FAO) of the United Nations. Rome Italy.

Young J. H. and T. B. Whitaker, 1971(a). Evaluation of the diffusion equation for describing thin-layer drying of peanuts in the hull. TRANS of the ASAE 14(2): 309 - 312.

Young J. H. and T. B. Whitaker, 1971(b). Numerical analysis of the vapour diffusion in a porous composite sphere with concentric shells. TRANS of the ASAE 14(6): 1051 - 1057

Yunfei Li. R., Morey V., and Afinrud., 1987. Thin-layer drying rates of oilseed sunflower. TRANS. ASAE, 30(4): 1172-1175

Verma L. R., Bucklin R. A., Endan J. B. and Wratten F. T., 1985. Effect of drying air parameters on rice drying models. TRANS. ASAE, 28: 296-301

Westerman P. W., White G. M., and Ross J. J., 1973. Relative humidity effect on the high temperature drying of shelled corn. TRANS. ASAE., 16:1136-1139

APPENDICES

APPENDIX 1

TableA1.1

Drying air conditions during three drying experiments performed at similar dryer system settings on different days at an average drying air temperature of 31 °C and relative humidity of 31%. This includes the analysis of variance.

Time	AIR CONDITIONS								
	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
(min)	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	TEMP oC	TEMP oC	TEMP oC	RH %	RH %	RH %
0	0.57	0.55	0.59	32.57	31.51	31.58	29.50	31.00	30.00
10	0.57	0.55	0.59	33.18	30.52	31.71	28.00	30.50	31.00
20	0.57	0.57	0.61	32.31	31.23	31.94	30.00	30.50	30.50
30	0.59	0.57	0.61	31.34	31.25	30.16	31.00	30.50	31.40
40	0.59	0.59	0.61	31.15	31.30	29.97	31.00	30.50	29.90
50	0.59	0.61	0.62	31.11	32.91	31.10	31.50	30.20	29.00
60	0.61	0.61	0.62	30.17	31.55	29.39	32.00	30.00	29.20
80	0.61	0.62	0.62	30.45	30.10	30.91	32.00	30.50	31.00
100	0.62	0.64	0.62	30.93	31.03	30.10	31.00	30.00	29.50
120	0.64	0.66	0.64	31.37	27.41	30.31	30.50	32.00	29.50
150	0.64	0.67	0.64	30.88	27.64	29.87	31.00	31.00	28.50
180	0.62	0.67	0.64	31.97	28.55	29.39	30.00	33.00	28.90
240	0.62	0.67	0.66	30.45	30.68	29.24	32.00	32.00	28.50
300	0.62	0.67	0.66	28.32	31.99	30.09	37.00	33.50	29.20
360	0.62	0.67	0.67	29.01	32.31	30.28	38.00	31.00	32.00
1,080	0.64	0.64	0.66	27.41	31.24	31.25	38.00	32.00	33.20
1,440	0.62	0.59	0.61	31.03	31.05	32.10	31.00	31.00	35.20
1,800	0.62	0.57	0.61	34.09	30.24	32.20	25.00	29.10	28.90
2,160	0.64	0.59	0.64	31.22	31.12	32.40	30.50	33.00	29.90
2,430	0.64	0.61	0.64	32.69	30.47	31.00	29.00	32.00	28.30

TableA1.1 - Contd

ANOVA for drying air temperatures

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	20.00	621.65	31.08	2.52
Column 2	20.00	614.10	30.71	1.98
Column 3	20.00	614.99	30.75	1.01

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.70	2.00	0.85	0.46	0.63	3.16
Within Groups	104.57	57.00	1.83			
Total	106.27	59.00				

ANOVA for relative humidities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	20.00	628.00	31.40	9.88
Column 2	20.00	623.30	31.17	1.33
Column 3	20.00	603.60	30.18	3.02

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	16.76	2.00	8.38	1.77	0.18	3.16
Within Groups	270.46	57.00	4.74			
Total	287.22	59.00				

ANOVA for air velocities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	20.00	12.26	0.61	0.00
Column 2	20.00	12.31	0.62	0.00
Column 3	20.00	12.53	0.63	0.00

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00	2.00	0.00	1.13	0.33	3.16
Within Groups	0.05	57.00	0.00			
Total	0.06	59.00				

Table A1.2

Drying air conditions during three drying experiments performed at similar dryer system settings on different days at an average drying air temperature of 38 °C and relative humidity of 24%. This includes the analysis of variance.

Time (min)	AIR CONDITIONS								
	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	TEMP oC	TEMP oC	TEMP oC	RH %	RH %	RH %
0	0.54	0.57	0.62	35.43	36.88	35.78	27.50	25.5	28.00
10	0.54	0.57	0.64	36.59	37.10	36.88	26.50	25.00	26.50
20	0.54	0.59	0.66	37.53	38.08	37.24	25.00	23.00	25.00
30	0.54	0.59	0.67	36.89	38.44	37.67	25.50	22.00	25.00
45	0.54	0.59	0.67	36.05	37.95	37.82	27.00	23.20	24.90
60	0.55	0.61	0.67	36.89	37.24	36.99	25.00	25.50	25.50
120	0.57	0.62	0.67	35.55	37.02	37.49	28.00	25.00	24.90
180	0.62	0.64	0.68	37.20	36.78	38.03	25.50	25.10	23.00
240	0.62	0.66	0.68	37.08	36.60	38.74	25.00	25.60	22.00
310	0.66	0.67	0.68	38.70	36.38	36.49	22.00	26.00	26.50
360	0.66	0.68	0.68	37.49	37.43	37.88	25.00	25.50	22.00
420	0.66	0.68	0.68	38.90	37.80	38.65	22.50	25.10	22.00
480	0.66	0.68	0.67	38.30	40.77	37.88	25.00	21.00	23.00
540	0.66	0.67	0.67	37.55	40.70	37.24	26.00	21.00	25.00
600	0.64	0.66	0.67	36.15	41.01	36.41	22.50	20.00	25.50
720	0.57	0.64	0.64	38.39	40.11	37.24	25.00	21.00	25.00
900	0.55	0.62	0.62	37.68	38.42	35.9	25.00	24.90	26.00
1,296	0.51	0.57	0.59	37.13	37.00	37.55	25.50	25.00	24.90
1,320	0.55	0.61	0.61	36.65	36.38	37.43	25.60	26.00	24.00
1,510	0.55	0.62	0.67	37.47	37.84	39.05	25.40	25.10	22.00
1,680	0.64	0.67	0.68	37.32	37.01	37.82	25.70	25.00	23.50
2,110	0.61	0.66	0.66	36.89	38.15	39.25	25.00	22.50	22.00

Table A1.2 - Contd

ANOVA for drying air temperatures

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	22.00	817.83	37.17	0.84
Column 2	22.00	835.09	37.96	2.07
Column 3	22.00	825.43	37.52	0.84

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	6.80	2.00	3.40	2.72	0.07	3.14
Within Groups	78.86	63.00	1.25			
Total	85.66	65.00				

ANOVA for relative humidities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	22.00	555.20	25.24	2.12
Column 2	22.00	528.00	24.00	3.65
Column 3	22.00	536.20	24.37	2.98

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	17.70	2.00	8.85	3.03	0.06	3.14
Within Groups	183.79	63.00	2.92			
Total	201.49	65.00				

ANOVA for air velocities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	22.00	12.95	0.59	0.00
Column 2	22.00	13.87	0.63	0.00
Column 3	22.00	14.49	0.66	0.00

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.05	2.00	0.03	16.56	0.00	3.14
Within Groups	0.10	63.00	0.00			
Total	0.16	65.00				

Table A1.3

Drying air conditions during three drying experiments performed at similar dryer system settings on different days at an average drying air temperature of 46 °C and relative humidity of 13.4%. This includes the analysis of variance.

Time	AIR CONDITIONS								
	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
(min)	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	TEMP oC	TEMP oC	TEMP oC	RH %	RH %	RH %
0	0.59	0.62	0.62	47.08	47.54	45.27	12.50	12.00	12.50
20	0.59	0.64	0.62	47.79	48.48	45.60	12.50	14.00	13.50
30	0.59	0.66	0.62	47.84	47.58	45.67	12.60	11.00	11.00
40	0.61	0.66	0.62	47.51	47.01	44.72	12.60	14.50	14.00
50	0.61	0.64	0.64	47.32	47.79	44.25	12.70	11.00	13.00
60	0.61	0.62	0.64	47.08	45.04	44.49	12.08	12.00	13.50
70	0.61	0.62	0.64	47.32	45.44	45.44	12.50	13.00	13.70
80	0.61	0.62	0.64	46.80	44.49	45.58	12.40	12.50	12.00
90	0.62	0.62	0.66	47.28	47.02	45.05	13.00	13.00	13.50
100	0.62	0.64	0.67	47.08	46.21	44.79	13.20	14.00	14.50
110	0.62	0.66	0.67	47.67	46.14	47.70	12.80	14.50	14.00
120	0.64	0.66	0.67	46.14	46.28	46.16	13.00	14.50	14.30
140	0.64	0.67	0.67	47.01	45.91	46.50	12.90	15.00	14.50
160	0.64	0.66	0.67	46.91	46.15	46.50	13.50	12.00	11.50
180	0.64	0.66	0.67	47.74	45.24	46.21	14.00	13.00	12.50
210	0.62	0.66	0.67	44.78	46.83	47.17	14.20	13.50	14.00
240	0.62	0.66	0.67	45.04	45.99	46.67	15.10	14.00	13.50
300	0.62	0.66	0.66	45.58	46.01	47.21	14.90	14.00	14.00
400	0.62	0.66	0.66	45.44	46.44	47.03	14.00	15.00	14.50
500	0.62	0.67	0.66	44.49	47.15	45.47	16.00	13.00	12.50
600	0.63	0.68	0.64	46.91	46.19	46.35	14.00	13.00	13.00
700	0.62	0.66	0.64	47.74	46.5	47.77	14.20	12.00	12.00
840	0.62	0.64	0.62	47.32	46.49	47.78	12.80	12.50	12.50
960	0.62	0.62	0.61	46.80	46.12	47.24	13.00	13.00	13.00
1,080	0.62	0.61	0.59	44.02	46.14	47.80	18.00	12.50	12.50

Table A1.3 - Contd

ANOVA for drying air temperatures

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	25.00	1,166.69	46.67	1.25
Column 2	25.00	1,160.18	46.41	0.80
Column 3	25.00	1,154.42	46.18	1.21

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.01	2.00	1.51	1.39	0.26	3.12
Within Groups	78.32	72.00	1.09			
Total	81.34	74.00				

ANOVA for relative humidities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	25.00	338.48	13.54	1.81
Column 2	25.00	328.50	13.14	1.30
Column 3	25.00	329.50	13.18	0.94

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.42	2.00	1.21	0.89	0.41	3.12
Within Groups	97.26	72.00	1.35			
Total	99.67	74.00				

ANOVA for air velocities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	25.00	20.90	0.84	1.18
Column 2	25.00	16.14	0.65	0.00
Column 3	25.00	16.12	0.64	0.00

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.61	2.00	0.30	0.77	0.47	3.12
Within Groups	28.39	72.00	0.39			
Total	29.00	74.00				

Table A1.4

Drying air conditions during three drying experiments performed at similar dryer system settings on different days at an average drying air temperature of 50 °C and relative humidity of 12.8%. This includes the analysis of variance.

Time	AIR CONDITIONS								
	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
(min)	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	TEMP oC	TEMP oC	TEMP oC	RH %	RH %	RH %
0	0.57	0.59	0.62	50.01	50.1	48.92	13.00	12.5	11
10	0.57	0.59	0.62	50.48	50.50	48.89	12.90	13.00	13
20	0.57	0.59	0.62	50.14	51.30	48.92	12.50	11.00	12.5
30	0.57	0.61	0.62	50.82	49.90	49.96	12.00	11.50	13.5
40	0.59	0.61	0.64	50.69	49.50	49.18	12.20	12.00	12.5
50	0.59	0.62	0.64	51.16	50.10	49.59	12.50	14.00	12
60	0.59	0.62	0.64	51.52	49.57	49.77	12.50	13.50	14
80	0.61	0.62	0.64	51.46	49.73	49.97	12.00	12.50	12
100	0.61	0.64	0.66	51.29	49.78	49.87	11.00	15.00	13
120	0.62	0.64	0.66	51.18	49.65	49.68	11.20	11.20	14
140	0.64	0.64	0.66	51.29	49.61	49.81	11.20	11.40	13.5
165	0.64	0.64	0.66	50.93	49.60	50.01	11.40	11.40	12
180	0.64	0.66	0.66	52.57	49.81	49.97	11.40	11.50	13.5
200	0.64	0.66	0.66	50.61	49.76	50.43	11.50	12.50	12.5
220	0.64	0.66	0.66	50.69	49.84	50.77	12.00	14.00	14
240	0.64	0.66	0.66	51.06	50.20	50.95	12.20	12.00	12.5
270	0.64	0.67	0.66	50.69	50.54	51.09	12.20	13.00	13
300	0.62	0.67	0.67	51.06	50.73	52.16	12.70	12.50	14
330	0.62	0.67	0.67	50.59	50.84	52.93	12.20	12.00	14.5
360	0.62	0.67	0.67	50.71	51.95	52.96	12.60	14.00	12
423	0.61	0.67	0.66	50.87	50.10	52.46	15.00	11.00	14
600	0.59	0.66	0.64	49.29	50.20	50.4	16.50	14.00	12
780	0.59	0.66	0.62	49.14	49.84	49.32	16.00	13.00	11.5
815	0.59	0.64	0.61	48.94	49.52	48.74	15.50	12.00	12.5

Table A1.4 - Contd

ANOVA for drying air temperatures

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	24.00	1,217.19	50.72	0.64
Column 2	24.00	1,202.67	50.11	0.37
Column 3	24.00	1,206.75	50.28	1.56

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.67	2.00	2.34	2.74	0.07	3.13
Within Groups	58.93	69.00	0.85			
Total	63.61	71.00				

ANOVA for relative humidity

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	24.00	304.20	12.68	2.32
Column 2	24.00	300.50	12.52	1.24
Column 3	24.00	309.00	12.88	0.88

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.51	2.00	0.76	0.51	0.60	3.13
Within Groups	102.11	69.00	1.48			
Total	103.62	71.00				

ANOVA for air velocities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	24.00	14.61	0.61	0.00
Column 2	24.00	15.32	0.64	0.00
Column 3	24.00	15.48	0.65	0.00

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.02	2.00	0.01	16.11	0.00	3.13
Within Groups	0.04	69.00	0.00			
Total	0.06	71.00				

Table A1.5

Drying air conditions during three drying experiments performed at similar dryer system settings on different days at an average drying air temperature of 66 °C and relative humidity of 3%. This includes the analysis of variance.

Time	AIR CONDITIONS								
	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
(min)	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	DRYING AIR FLOW RATE m/s	TEMP oC	TEMP oC	TEMP oC	RH %	RH %	RH %
0	0.57	0.59	0.62	62.24	65.55	64.25	4.00	3.50	3.80
5	0.57	0.59	0.62	65.35	66.45	65.54	5.00	3.00	3.50
10	0.57	0.61	0.64	64.21	66.83	66.41	3.00	3.10	3.20
15	0.57	0.61	0.64	65.08	66.42	66.45	4.50	3.20	3.10
20	0.57	0.61	0.62	65.12	66.45	66.55	3.50	3.00	3.20
25	0.57	0.61	0.64	65.50	66.68	67.07	3.00	3.00	2.60
30	0.59	0.62	0.64	65.73	66.24	67.16	2.50	3.00	2.70
40	0.59	0.64	0.64	66.21	66.24	67.22	3.00	2.90	2.80
50	0.61	0.66	0.64	66.68	66.64	67.26	2.80	2.60	2.90
60	0.61	0.66	0.64	66.75	67.16	69.68	2.50	2.60	2.10
75	0.62	0.66	0.66	66.90	67.25	67.45	3.50	2.50	2.80
90	0.62	0.67	0.66	65.11	67.31	67.22	3.00	2.90	2.70
105	0.64	0.67	0.67	64.16	66.5	66.87	2.90	2.60	3.20
120	0.64	0.67	0.67	66.19	67.35	66.01	3.00	2.30	3.30
150	0.66	0.67	0.62	64.18	69.77	65.22	3.50	2.50	3.50
180	0.66	0.67	0.64	65.89	67.54	64.74	5.00	2.60	3.80
300	0.67	0.67	0.66	65.50	67.31	64.51	4.00	2.50	4.00

Table A1.5 - Contd

ANOVA for Drying air temperatures

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	17.00	1,110.80	65.34	1.37
Column 2	17.00	1,137.69	66.92	0.81
Column 3	17.00	1,129.61	66.45	1.78

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	22.40	2.00	11.20	8.48	0.00	3.19
Within Groups	63.39	48.00	1.32			
Total	85.78	50.00				

ANOVA for relative humidities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	17.00	58.70	3.45	0.63
Column 2	17.00	47.80	2.81	0.10
Column 3	17.00	53.20	3.13	0.25

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.49	2.00	1.75	5.37	0.01	3.19
Within Groups	15.62	48.00	0.33			
Total	19.11	50.00				

Anova for Air velocities

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	17.00	10.32	0.61	0.00
Column 2	17.00	10.84	0.64	0.00
Column 3	17.00	10.91	0.64	0.00

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.01	2.00	0.01	7.60	0.00	3.19
Within Groups	0.04	48.00	0.00			
Total	0.05	50.00				

APPENDIX 2

Table A2.1

Drying data of parchment coffee beans dried at an average plenum temperature of 31 °C and relative humidity of 31%. Replicate 1

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	49.61%
EQUILIBRIUM MOISTURE CONTENT % d.b	5.90%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
min	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	147.89	0.57	26.00	36.00	14.50	98	33.57	27.70	33.52	98.45%	1.00
10	141.30	0.57	26.00	36.00	14.50	98	33.18	28.00	32.77	89.61%	0.90
20	139.55	0.57	26.00	36.00	14.60	97	32.31	30.00	32.17	87.26%	0.88
30	138.64	0.59	26.00	36.00	14.60	98	31.34	31.00	31.12	86.04%	0.87
40	137.72	0.59	26.00	36.00	14.60	98	31.15	31.00	31.00	84.81%	0.85
50	137.14	0.59	26.00	36.00	14.60	99	31.11	31.50	31.00	84.03%	0.84
60	136.52	0.61	26.00	36.00	14.70	98	30.17	32.00	30.20	83.19%	0.84
80	135.37	0.61	25.50	38.50	14.70	100	30.45	32.00	30.32	81.65%	0.82
100	134.22	0.62	25.50	38.50	14.80	100	30.93	31.00	30.81	80.11%	0.80
120	133.16	0.64	25.50	38.50	14.90	100	31.37	30.50	31.22	78.69%	0.79
150	131.60	0.64	25.00	44.00	14.90	99	30.88	31.00	30.66	76.59%	0.76
180	129.82	0.62	24.00	46.00	15.00	99	31.97	30.00	31.69	74.20%	0.74
240	127.01	0.62	22.00	51.00	13.60	99	30.45	32.00	30.12	70.43%	0.70
300	124.82	0.62	20.50	52.50	13.90	99	28.32	37.00	28.01	67.49%	0.67
360	122.75	0.62	20.00	56.00	13.80	100	27.39	38.00	27.12	64.72%	0.64
1,080	97.69	0.64	18.00	58.00	15.70	99	27.41	38.00	26.90	31.09%	0.27
1,440	92.81	0.62	24.50	40.00	15.60	99	31.03	31.00	30.74	24.54%	0.20
1,800	87.82	0.62	26.00	39.00	15.40	98	35.09	25.00	35.05	17.84%	0.13
2,160	87.82	0.64	23.00	45.00	15.30	100	31.22	30.50	31.00	17.84%	0.13
2,430	83.63	0.64	18.00	58.00	14.90	100	32.69	29.00	32.00	12.22%	0.07

Table A2.2

Drying data of parchment coffee beans dried at an average plenum temperature of 31 °C and relative humidity of 31%. Replicate 2

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	49.51%
EQUILIBRIUM MOISTURE CONTENT % d.b	5.89%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	151.10	0.55	17.00	66.00	13.50	100	31.51	31.00	31.46	98.06%	1.00
10	144.16	0.55	18.00	69.00	14.50	100	31.32	30.50	31.15	88.96%	0.90
20	142.08	0.57	18.00	69.00	13.70	99	31.23	30.50	31.07	86.24%	0.87
30	141.38	0.57	18.00	68.00	13.80	100	31.25	30.50	31.21	85.32%	0.86
40	140.69	0.59	18.00	67.00	13.80	99	31.30	30.50	31.10	84.41%	0.85
50	139.99	0.61	19.00	62.00	13.90	99	32.91	30.20	32.59	83.50%	0.84
60	139.30	0.61	19.00	61.00	14.00	99	31.55	30.00	31.46	82.59%	0.83
80	137.91	0.62	19.00	60.00	14.20	98	35.32	29.00	35.20	80.77%	0.81
100	136.52	0.64	18.00	79.00	14.30	98	31.03	30.00	30.74	78.95%	0.79
120	135.83	0.66	18.00	78.00	14.40	98	27.41	34.00	26.91	78.04%	0.78
150	134.44	0.67	18.50	79.00	14.50	99	27.64	37.00	27.02	76.22%	0.76
180	132.36	0.67	18.50	80.00	14.60	99	28.55	36.00	28.24	73.49%	0.73
240	129.58	0.67	19.50	81.00	14.60	99	30.68	35.00	30.12	69.85%	0.69
300	127.50	0.67	22.00	75.00	14.60	100	31.99	34.00	31.60	67.12%	0.66
360	125.42	0.67	24.50	58.00	14.60	99	32.31	35.00	31.17	64.40%	0.63
800	108.75	0.64	19.50	75.00	14.60	98	33.41	32.00	32.92	42.55%	0.40
1,080	99.73	0.59	19.50	56.00	14.60	98	31.05	31.00	30.95	30.72%	0.27
1,440	94.87	0.57	14.00	85.00	14.20	100	32.19	28.00	31.80	24.35%	0.20
1,800	89.32	0.59	25.00	62.00	14.60	99	32.22	36.00	31.91	17.08%	0.12
2,160	86.54	0.61	19.00	75.00	14.60	100	30.47	32.00	29.72	13.43%	0.08
2,430	85.15	0.64	17.00	80.00	14.00	99	27.41	31.00	26.91	11.61%	0.06

Table A2.3

Drying data of parchment coffee beans dried at an average plenum temperature of 31 °C and relative humidity of 31%. Replicate 3

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	51.32%
EQUILIBRIUM MOISTURE CONTENT % d.b	5.91%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
min	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	149.31	0.59	16.00	80.00	14.00	100	31.58	27.50	31.47	105.42%	1.00
10	142.90	0.59	16.00	79.00	14.10	99	31.71	27.00	31.60	96.60%	0.91
20	140.76	0.61	16.50	78.00	14.10	99	31.94	28.00	31.71	93.66%	0.88
30	140.04	0.61	16.50	78.00	14.10	99	30.16	28.50	29.94	92.67%	0.87
40	139.33	0.61	17.00	80.00	14.20	99	29.97	28.60	29.69	91.69%	0.86
50	138.62	0.62	17.00	79.00	14.20	98	27.26	29.00	26.95	90.72%	0.85
60	137.91	0.62	18.00	81.00	14.20	98	29.39	29.20	29.06	89.74%	0.84
80	136.48	0.62	18.00	80.00	14.30	99	30.91	31.00	30.63	87.77%	0.82
100	135.06	0.62	18.50	78.00	14.40	98	29.82	29.50	29.60	85.82%	0.80
120	134.34	0.64	18.50	81.00	14.50	99	30.31	28.90	30.16	84.83%	0.79
150	132.92	0.64	18.50	83.00	14.50	99	29.87	28.50	29.65	82.87%	0.77
180	130.78	0.64	19.00	81.00	14.50	98	29.39	28.90	29.26	79.93%	0.74
240	127.93	0.66	21.50	75.00	14.60	100	29.24	28.50	29.07	76.01%	0.70
300	125.79	0.66	23.00	68.00	14.70	97	30.09	29.20	29.94	73.06%	0.67
360	123.65	0.67	24.50	62.00	14.80	100	30.28	32.00	30.06	70.12%	0.65
800	106.55	0.66	19.00	76.00	14.70	100	31.25	35.20	30.98	46.59%	0.41
1,080	97.28	0.61	19.50	58.00	14.00	100	27.56	35.20	27.38	33.84%	0.28
1,440	92.29	0.61	17.00	65.00	13.50	100	28.93	28.90	28.90	26.97%	0.21
1,800	86.59	0.64	26.00	54.00	14.60	100	27.50	27.50	32.07	19.13%	0.13
2,160	83.74	0.64	22.00	59.00	14.70	100	28.30	28.30	30.95	15.21%	0.09
2,430	82.31	0.62	20.00	58.00	14.00	100	30.00	30.00	29.25	13.24%	0.07

Table A2.4

Drying data of parchment coffee beans dried at an average plenum temperature of 38 °C and relative humidity of 24%. Replicate 1

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	46.07%
EQUILIBRIUM MOISTURE CONTENT % d.b	5.02%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
min	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	133.34	0.54	19.50	67.50	13.90	100	35.43	27.50	35.28	85.43%	1.00
10	131.64	0.54	19.50	67.00	13.90	100	36.59	26.50	36.48	83.06%	0.97
20	131.06	0.54	19.50	67.50	13.90	99	37.53	25.00	37.47	82.25%	0.96
30	130.58	0.54	20.00	68.00	13.90	100	36.89	25.50	36.65	81.59%	0.95
45	129.80	0.54	20.00	68.00	14.00	99	36.05	27.00	35.81	80.50%	0.94
60	128.98	0.55	21.00	69.00	14.40	98	36.89	25.00	36.64	79.36%	0.92
120	125.62	0.57	24.00	60.00	15.10	99	35.55	28.00	35.11	74.69%	0.87
180	122.20	0.62	26.00	52.00	15.30	97	37.20	25.50	36.60	69.93%	0.81
240	118.42	0.62	27.00	50.00	15.30	98	37.08	25.00	36.72	64.68%	0.74
310	113.92	0.66	29.00	46.00	15.20	99	38.70	22.00	38.34	58.42%	0.66
360	110.72	0.66	29.00	40.00	15.40	100	37.49	25.00	37.28	53.97%	0.61
420	106.84	0.66	29.00	41.00	15.40	99	38.90	22.50	38.87	48.57%	0.54
480	102.94	0.66	28.50	45.50	15.50	100	38.30	25.00	37.09	43.15%	0.47
540	99.40	0.66	27.00	44.00	15.20	99	37.55	26.00	37.32	38.23%	0.41
600	96.16	0.64	25.00	47.00	14.80	100	36.15	22.50	35.79	33.72%	0.36
720	92.16	0.57	22.00	47.00	14.00	100	38.39	25.00	37.93	28.16%	0.29
900	87.80	0.55	19.50	59.50	14.00	100	37.68	25.00	37.32	22.10%	0.21
1,298	82.06	0.51	17.00	65.00	13.50	100	37.13	25.50	36.72	14.11%	0.11
1,320	81.86	0.55	18.00	65.00	15.00	99	36.65	25.60	35.79	13.84%	0.11
1,513	80.96	0.55	21.50	65.00	15.30	99	37.47	25.40	37.15	12.58%	0.09
1,680	79.90	0.64	26.50	49.50	14.50	97	37.32	25.70	36.96	11.11%	0.08
2,110	78.86	0.61	22.50	51.50	15.00	99	36.89	25.00	36.72	9.66%	0.06

Table A2.5

Drying data of parchment coffee beans dried at an average plenum temperature of 38 °C and relative humidity of 24%. Replicate 2

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	50.08%
EQUILIBRIUM MOISTURE CONTENT % d.b	4.98%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	149.11	0.57	16	70	13.9	100	36.88	25.5	36.66	100.32%	1.00
10	146.41	0.57	16.50	71.00	14.00	100	37.10	25.00	37.00	96.69%	0.96
20	145.73	0.59	18.50	65.00	14.20	100	38.08	23.00	37.73	95.78%	0.95
30	145.05	0.59	18.50	69.00	14.40	99	38.44	22.00	38.30	94.87%	0.94
45	144.38	0.59	20.00	71.00	14.50	100	37.95	23.20	36.60	93.97%	0.93
60	143.70	0.61	20.50	69.00	14.40	99	37.24	25.50	36.69	93.05%	0.92
120	138.97	0.62	22.50	59.00	14.50	99	37.02	25.00	36.39	86.70%	0.86
180	134.91	0.64	24.00	52.00	14.60	100	36.78	25.10	36.64	81.24%	0.80
240	130.18	0.66	24.50	49.00	14.50	99	36.60	25.60	36.17	74.89%	0.73
310	124.77	0.67	25.00	49.00	14.50	98	36.38	26.00	36.23	67.62%	0.66
360	120.72	0.68	25.50	48.00	14.60	99	37.43	25.50	37.37	62.18%	0.60
420	115.98	0.68	26.00	45.00	14.70	100	37.80	25.10	37.60	55.81%	0.53
480	111.25	0.68	26.50	42.00	14.60	98	40.77	21.00	40.68	49.46%	0.47
540	107.20	0.67	25.00	46.00	14.50	99	40.70	21.00	4.40	44.02%	0.41
600	103.14	0.66	24.50	48.00	14.40	99	41.01	20.00	40.80	38.56%	0.35
720	98.41	0.64	20.50	54.00	14.60	99	40.11	21.00	39.82	32.21%	0.29
900	93.00	0.62	19.00	72.00	14.70	98	38.42	24.90	37.38	24.94%	0.21
1,296	85.59	0.57	17.00	79.00	14.30	99	37.00	25.00	36.76	14.99%	0.10
1,320	85.56	0.61	17.50	76.00	14.30	100	36.38	26.00	36.23	14.94%	0.10
1,510	84.23	0.62	18.00	75.00	14.50	98	37.84	25.10	37.60	13.16%	0.09
1,680	82.86	0.67	24.50	42.00	14.70	98	37.01	25.00	36.76	11.32%	0.07
2,110	82.25	0.66	23.00	48.00	14.30	98	38.15	22.50	37.55	10.50%	0.06

Table A2.6

Drying data of parchment coffee beans dried at an average plenum temperature of 38 °C and relative humidity of 24%. Replicate 3

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	51.21%
EQUILIBRIUM MOISTURE CONTENT % d.b	5.01%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	143.57	0.62	18.00	58.00	14.00	100	35.78	28.00	35.59	104.96%	1.00
10	143.57	0.64	18.00	57.00	14.20	100	36.88	26.50	36.82	104.96%	1.00
20	140.90	0.66	19.00	57.00	14.40	100	37.24	25.00	37.06	101.15%	0.96
30	140.24	0.67	19.00	57.00	14.50	100	37.67	25.00	37.29	100.21%	0.95
45	139.57	0.67	20.00	58.00	14.50	99	37.82	24.90	37.50	99.25%	0.94
60	138.90	0.67	20.50	61.00	14.60	99	36.99	25.50	36.10	98.29%	0.93
120	134.23	0.67	22.00	55.00	14.60	100	37.49	24.90	37.07	91.63%	0.87
180	130.23	0.68	24.40	42.00	14.60	99	38.03	23.00	37.68	85.92%	0.81
240	125.56	0.68	25.00	41.00	14.60	98	38.74	22.00	38.27	79.25%	0.74
310	120.23	0.68	25.50	40.00	14.70	99	36.49	26.50	36.14	71.64%	0.67
360	116.23	0.68	26.00	43.00	14.70	98	37.88	22.00	37.67	65.93%	0.61
420	111.56	0.68	25.00	38.00	14.60	99	38.65	22.00	37.41	59.26%	0.54
480	106.89	0.67	24.50	40.00	14.60	100	37.88	23.00	37.82	52.60%	0.48
540	102.90	0.67	23.00	48.00	14.60	100	37.24	25.00	37.01	46.90%	0.42
600	98.89	0.67	21.00	52.00	14.50	99	36.41	25.50	36.16	41.18%	0.36
720	94.22	0.64	19.00	58.00	14.50	100	37.24	25.00	37.03	34.51%	0.30
900	88.88	0.62	18.00	60.00	14.50	99	35.9	26.00	35.46	26.88%	0.22
1,296	81.56	0.59	15.50	75.00	14.50	99	37.55	24.90	36.95	16.43%	0.11
1,320	81.48	0.61	16.50	69.00	14.30	100	37.43	24.00	31.07	16.32%	0.11
1,510	80.22	0.67	20.00	63.00	14.50	99	39.05	22.00	38.70	14.52%	0.10
1,680	78.88	0.68	25.00	50.00	14.60	100	37.82	23.50	37.60	12.61%	0.08
2,110	78.28	0.66	20.50	55.00	14.30	100	39.25	22.00	39.22	11.75%	0.07

Table A2.7

Drying data of parchment coffee beans dried at an average plenum temperature of 46 °C and relative humidity of 13.4%. Replicate 1

1. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	46.40%
EQUILIBRIUM MOISTURE CONTENT % d.b	3.48%

2. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	150.09	0.59	26.50	46.50	14.90	99	47.08	12.50	46.07	86.57%	1.00
20	141.62	0.59	26.50	46.50	14.90	100	47.79	12.50	46.76	76.04%	0.87
30	139.48	0.59	26.50	46.50	15.00	100	47.84	12.60	46.83	73.38%	0.84
40	137.66	6.05	26.50	43.00	15.10	100	47.51	12.60	46.45	71.12%	0.81
50	134.83	0.61	26.50	43.00	14.90	100	47.32	12.70	46.16	67.60%	0.77
60	132.15	0.61	26.50	43.00	15.00	99	47.08	12.08	46.06	64.27%	0.73
70	129.77	0.61	26.00	42.00	15.00	99	47.32	12.50	46.26	61.31%	0.70
80	127.42	0.61	26.00	42.00	14.90	100	46.80	12.40	45.91	58.39%	0.66
90	125.62	0.62	25.50	45.00	14.80	99	47.28	13.00	46.26	56.15%	0.63
100	122.82	0.62	25.50	42.00	14.50	98	47.08	13.20	46.05	52.67%	0.59
110	120.51	0.62	25.00	44.00	14.50	98	47.67	12.80	46.63	49.80%	0.56
120	118.29	0.64	24.50	43.00	14.50	99	46.14	13.00	45.18	47.04%	0.52
140	114.12	0.64	24.50	43.50	14.50	98	47.01	12.90	47.57	41.86%	0.46
160	111.35	0.64	42.00	44.00	14.50	99	46.91	13.50	45.89	38.41%	0.42
180	108.14	0.64	23.00	45.00	14.00	99	47.74	14.00	46.66	34.42%	0.37
210	104.14	0.62	22.00	47.00	13.90	98	44.78	14.20	43.74	29.45%	0.31
240	104.14	0.62	21.00	49.00	13.60	98	45.04	15.10	43.77	29.45%	0.31
300	98.24	0.62	19.50	55.50	13.60	99	45.58	14.90	44.56	22.12%	0.22
840	85.27	0.62	16.00	71.00	13.70	97	45.44	14.00	44.37	5.99%	0.03
960	85.26	0.62	16.50	69.50	14.00	98	44.49	16.00	43.46	5.98%	0.03
1,080	84.88	0.62	20.00	73.00	14.00	97	44.02	18.00	42.94	5.51%	0.02

Table A2.8

Drying data of parchment coffee beans dried at an average plenum temperature of 46 °C and relative humidity of 13.4%. Replicate 2

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	51.33%
EQUILIBRIUM MOISTURE CONTENT % d.b	3.49%

B. DRYING OF THE COFFEE BEANS SAMPLE

		AIR CONDITIONS									
TIME OF DRYING	MASS OF SAMPLE	DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET	MOISTURE CONTENT	MOISTURE RATIO
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	145.79	0.62	19.00	63.00	13.50	100	47.54	12.00	46.20	105.47%	1.00
20	136.57	0.64	19.00	63.00	13.50	100	48.48	14.00	47.22	92.47%	0.87
30	133.73	0.66	18.50	80.50	14.00	100	47.58	11.00	47.29	88.47%	0.83
40	132.31	0.66	18.50	80.50	14.00	99	47.01	14.50	47.57	86.47%	0.81
50	128.76	0.64	18.50	80.50	14.20	98	47.79	11.00	46.66	81.46%	0.76
60	125.92	0.62	19.00	81.00	14.20	99	45.04	12.00	43.77	77.46%	0.73
70	123.79	0.62	19.00	81.00	14.30	99	45.44	13.00	44.37	74.46%	0.70
80	120.95	0.62	20.00	77.00	14.30	100	44.49	12.50	43.46	70.46%	0.66
90	118.12	0.62	20.00	77.00	14.30	100	47.02	13.00	46.39	66.47%	0.62
100	115.99	0.64	20.50	73.00	14.30	99	46.21	14.00	45.68	63.47%	0.59
110	113.15	0.66	20.50	73.00	14.30	100	46.14	14.50	45.52	59.47%	0.55
120	111.15	0.66	21.50	73.50	14.20	100	46.28	14.50	45.49	56.65%	0.52
140	106.76	0.67	21.50	73.50	14.30	100	45.91	15.00	45.44	50.46%	0.46
160	103.92	0.66	22.00	74.00	14.30	100	46.15	12.00	45.56	46.46%	0.42
180	100.38	0.66	22.00	74.00	14.20	100	45.24	13.00	44.64	41.47%	0.37
210	96.12	0.66	21.00	78.00	14.10	100	46.83	13.50	44.97	35.46%	0.31
240	92.57	0.66	20.00	81.00	14.40	100	45.99	14.00	45.32	30.46%	0.26
300	89.73	0.66	22.00	58.00	14.50	100	46.01	14.00	45.38	26.46%	0.23
400	85.47	0.66	22.00	58.00	14.60	99	46.44	15.00	45.59	20.45%	0.17
500	82.64	0.67	21.00	65.00	14.80	98	47.15	13.00	46.52	16.47%	0.13
500	79.80	0.68	21.00	54.00	14.90	99	46.19	13.00	45.20	12.46%	0.09
700	78.38	0.66	21.00	51.00	14.00	99	46.5	12.00	45.89	10.46%	0.07
840	75.82	0.64	20.50	52.00	14.14	99	46.49	12.50	45.26	6.85%	0.03
960	75.54	0.62	20.50	54.00	14.00	100	46.12	13.00	45.44	6.46%	0.03
1,080	75.11	0.61	19.50	56.00	13.60	100	46.14	12.50	45.51	5.85%	0.02

Table A2.9

Drying data of parchment coffee beans dried at an average plenum temperature of 46 °C and relative humidity of 13.4%. Replicate 3

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

AVERAGE INITIAL MOISTURE CONTENT % w.b	52.64%
EQUILIBRIUM MOISTURE CONTENT % d.b	3.47%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING (min)	MASS OF SAMPLE (g)	DRYING AIR FLOW RATE m/s	AIR CONDITIONS: AMBIENT TEMP oC	AMBIENT RH %	TOWER OUTLET TEMP oC	TOWER OUTLET RH %	DRYING AIR (Plenum) TEMP oC	DRYING AIR (Plenum) RH %	DRYER OUTLET TEMP oC	MOISTURE CONTENT % d.b	MOISTURE RATIO
0	147.89	0.62	17.00	80.00	12.00	100	45.27	12.00	44.00	111.15%	1.00
20	139.02	0.62	17.00	76.00	11.00	100	45.60	14.00	44.58	98.48%	0.88
30	136.06	0.62	17.00	71.00	14.00	100	45.67	11.00	44.40	94.26%	0.84
40	134.58	0.62	17.50	70.00	15.00	100	44.72	14.50	43.50	92.15%	0.82
50	130.88	0.64	17.50	69.50	14.00	99	44.25	11.00	42.95	86.86%	0.77
60	127.93	0.64	17.50	69.00	12.00	99	44.49	12.00	43.46	82.65%	0.74
70	125.71	0.64	17.50	69.00	13.00	98	45.44	13.00	44.37	79.48%	0.71
80	122.75	0.64	19.00	68.50	16.00	97	45.58	12.50	44.57	75.26%	0.67
90	119.79	0.66	18.50	68.00	15.00	98	45.05	13.00	43.78	71.03%	0.63
100	117.57	0.67	19.00	67.50	14.50	99	44.79	14.00	43.75	67.86%	0.60
110	114.62	0.67	20.00	66.00	14.00	99	47.70	14.50	46.60	63.65%	0.56
120	112.40	0.67	20.50	69.00	13.00	98	46.16	14.50	45.50	60.48%	0.53
140	107.96	0.67	19.50	75.00	13.50	98	46.50	15.00	45.27	54.14%	0.47
160	105.00	0.67	20.50	74.00	12.00	97	46.50	12.00	45.89	49.91%	0.43
180	101.31	0.67	21.00	70.00	11.50	97	46.21	13.00	45.22	44.64%	0.38
210	96.87	0.67	21.50	69.00	11.00	98	47.17	13.50	46.54	38.31%	0.32
240	93.17	0.67	21.50	67.00	12.00	99	46.67	14.00	45.60	33.02%	0.27
300	90.22	0.66	22.00	65.00	12.50	98	47.21	14.00	46.53	28.81%	0.24
400	87.26	0.66	23.50	62.00	12.00	100	47.03	15.00	45.20	24.58%	0.20
500	82.76	0.66	24.00	60.00	13.00	98	45.47	13.00	45.02	18.16%	0.14
600	80.60	0.64	24.00	62.00	15.00	98	46.35	13.00	45.90	15.08%	0.11
700	78.39	0.64	26.00	50.00	14.00	99	47.77	12.00	46.43	11.92%	0.08
840	75.72	0.62	28.00	47.50	12.50	100	47.78	12.50	47.50	8.11%	0.04
960	75.43	0.61	23.50	59.50	10.00	99	47.24	13.00	47.59	7.69%	0.04
1,080	74.69	0.59	20.00	65.00	11.00	100	47.80	12.50	46.66	6.64%	0.03

…e A2.10

…ng data of parchment coffee beans dried at an average plenum temperature of 50 °C

…ative humidity of 12.8%. Replicate 1

…TERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

…TED AVERAGE INITIAL MOISTURE CONTENT % w.b	47.54%
…LIBRIUM MOISTURE CONTENT % d.b	3.26%

…DRYING OF THE COFFEE BEANS SAMPLE

…E OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
…	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	110.66	0.57	24.50	53.50	14.90	100	50.01	13.00	49.06	90.62%	1.00
10	106.86	0.57	24.50	53.50	15.00	100	50.48	12.90	49.08	84.08%	0.93
20	104.66	0.57	24.50	53.50	15.00	100	50.14	12.50	49.19	80.29%	0.88
30	102.68	0.57	25.00	47.00	15.10	99	50.82	12.00	50.10	76.88%	0.84
40	100.68	0.59	25.00	47.00	15.10	100	50.69	12.20	49.91	73.43%	0.80
50	98.74	0.59	25.00	47.00	15.10	100	51.16	12.50	50.24	70.09%	0.76
60	96.84	0.59	26.50	46.50	15.10	99	51.52	12.50	50.82	66.82%	0.73
80	93.06	0.61	26.50	46.50	15.00	99	51.46	12.00	50.65	60.30%	0.65
100	89.34	0.61	27.50	44.50	14.80	98	51.29	11.00	50.36	53.90%	0.58
120	85.72	0.62	27.50	44.50	14.00	100	51.18	11.20	50.00	47.66%	0.51
140	82.44	0.64	27.50	44.50	14.00	99	51.29	11.20	50.82	42.01%	0.44
165	78.60	0.64	27.50	44.50	14.00	98	50.93	11.40	50.24	35.40%	0.37
180	76.66	0.64	29.00	40.00	14.10	99	52.57	11.40	51.78	32.05%	0.33
200	74.36	0.64	29.00	40.00	14.10	98	50.61	11.50	49.91	28.09%	0.28
220	72.68	0.64	29.00	40.00	14.30	100	50.69	12.00	50.24	25.20%	0.25
240	71.04	0.64	29.00	38.00	14.70	99	51.06	12.20	50.36	22.37%	0.22
270	69.00	0.64	29.00	38.00	14.60	99	50.69	12.20	50.22	18.86%	0.18
300	67.42	0.62	28.50	39.00	14.60	99	51.06	12.70	50.48	16.14%	0.15
330	66.20	0.62	28.00	39.00	14.60	99	50.59	12.20	49.99	14.04%	0.12
360	65.30	0.62	28.50	37.00	14.80	98	50.71	12.60	50.22	12.48%	0.11
423	64.12	0.61	28.50	37.00	14.50	99	50.87	15.00	49.99	10.45%	0.08
600	63.54	0.59	21.00	45.00	14.30	99	49.29	16.50	49.00	9.45%	0.07
780	62.22	0.59	19.50	55.50	13.80	100	49.14	16.00	48.49	7.18%	0.04
815	62.22	0.59	19.50	55.60	13.30	100	48.94	15.50	47.69	7.18%	0.04

Table A2.11

Drying data of parchment coffee beans dried at an average plenum temperature of 50 °C and relative humidity of 12.8%. Replicate 2

DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

ESTIMATED AVERAGE INITIAL MOISTURE CONTENT % w.b	51.09%
EQUILIBRIUM MOISTURE CONTENT % d.b	3.27%

DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
min	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	152.02	0.59	17.5	80	13.9	100	48.7	12.5	47.95	104.46%	1.00
10	146.13	0.59	17.5	79	14	100	48.44	13.00	47.69	96.54%	0.92
20	142.45	0.59	17.50	85.00	14.00	100	48.20	11.00	47.49	91.59%	0.87
30	139.50	0.61	17.50	84.00	14.00	100	48.24	11.50	47.50	87.62%	0.83
40	136.56	0.61	18.00	79.00	14.10	99	48.27	12.00	47.68	83.66%	0.79
50	133.61	0.62	18.00	78.00	14.30	98	48.95	14.00	48.22	79.70%	0.76
60	131.40	0.62	18.50	76.00	14.40	99	49.57	13.50	48.42	76.72%	0.73
80	125.51	0.62	18.50	74.00	14.50	99	49.73	12.50	48.74	68.80%	0.65
100	120.36	0.64	18.50	79.00	14.60	98	49.78	15.00	49.09	61.88%	0.58
120	114.47	0.64	19.00	78.00	14.60	99	49.65	11.20	48.48	53.95%	0.50
140	110.05	0.64	19.50	81.00	14.60	99	49.61	11.40	48.72	48.01%	0.44
165	104.16	0.64	19.50	78.00	14.70	99	49.60	11.40	49.14	40.09%	0.36
180	101.21	0.66	30.50	77.00	14.60	98	49.81	11.50	49.04	36.12%	0.32
200	97.53	0.66	21.50	74.00	14.70	100	49.76	12.50	48.95	31.17%	0.28
220	95.32	0.66	21.50	73.00	14.60	100	49.84	14.00	49.07	28.20%	0.25
240	93.11	0.66	21.50	72.00	14.60	99	50.20	12.00	49.44	25.23%	0.22
270	90.17	0.67	22.00	71.00	14.70	99	50.54	13.00	49.94	21.27%	0.18
300	87.22	0.67	22.50	72.00	14.00	98	50.73	12.50	50.14	17.31%	0.14
330	85.75	0.67	23.00	70.00	14.70	99	50.84	12.00	50.29	15.33%	0.12
360	84.27	0.67	24.50	62.00	14.70	98	51.95	14.00	51.62	13.34%	0.10
420	82.81	0.67	25.00	58.00	14.70	99	52.71	11.00	52.10	11.37%	0.08
600	80.59	0.66	25.00	51.00	14.60	100	52.73	14.00	51.98	8.39%	0.05
780	80.09	0.66	20.50	58.00	14.60	100	49.84	13.00	49.63	7.72%	0.04
815	79.79	0.64	20.00	62.00	14.50	99	49.52	12.00	49.21	7.31%	0.04

Table A2.12

Drying data of parchment coffee beans dried at an average plenum temperature of 50 °C and relative humidity of 12.8%. Replicate 3

…NATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

…ERAGE INITIAL MOISTURE CONTENT % w.b	49.14%
…M MOISTURE CONTENT % d.b	3.28%

… OF THE COFFEE BEANS SAMPLE

…E OF …ING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
…	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	145.49	0.62	17.00	62.00	13.50	100.00	48.92	11.00	48.17	96.62%	1.00
10	140.76	0.62	17.00	62.00	13.50	100.00	48.89	13.00	48.17	90.23%	0.93
20	137.58	0.62	17.00	62.00	13.50	100.00	48.92	12.50	48.91	85.93%	0.89
30	134.68	0.62	17.50	58.00	13.60	99.00	49.96	13.50	48.27	82.01%	0.84
40	131.97	0.64	18.00	59.00	13.70	99.00	49.18	12.50	48.45	78.35%	0.80
50	129.27	0.64	18.00	59.00	13.80	99.00	49.59	12.00	48.67	74.70%	0.77
60	127.24	0.64	18.00	59.00	13.90	98.00	49.77	14.00	48.98	71.95%	0.74
80	121.84	0.64	18.50	55.00	14.00	100.00	49.97	12.00	49.29	64.66%	0.66
100	117.11	0.66	18.50	55.00	14.10	98.00	49.87	13.00	48.72	58.26%	0.59
120	111.70	0.66	19.00	56.00	14.10	100.00	49.68	14.00	48.97	50.95%	0.51
140	107.65	0.66	19.00	61.00	14.20	100.00	49.81	13.50	49.38	45.48%	0.45
165	102.24	0.66	19.00	61.00	14.30	100.00	50.01	12.00	49.24	38.17%	0.37
180	99.54	0.66	20.00	58.00	14.50	99.00	49.97	13.50	49.18	34.52%	0.33
200	96.16	0.66	21.00	54.00	14.50	100.00	50.43	12.50	49.67	29.95%	0.29
220	94.13	0.66	22.00	53.00	14.50	99.00	50.77	14.00	50.16	27.21%	0.26
240	92.11	0.66	24.50	46.00	14.60	99.00	50.95	12.50	50.37	24.48%	0.23
270	89.40	0.66	24.50	46.00	14.60	98.00	51.09	13.00	50.52	20.82%	0.19
300	86.70	0.67	25.00	43.00	14.60	99.00	52.16	14.00	51.86	17.17%	0.15
330	85.35	0.67	25.50	42.00	14.60	100.00	52.93	14.50	52.32	15.34%	0.13
360	84.00	0.67	25.50	42.00	14.60	100.00	52.96	12.00	52.21	13.52%	0.11
420	82.64	0.66	26.00	41.00	14.70	99.00	52.46	14.00	51.67	11.68%	0.09
600	80.62	0.64	23.00	48.00	14.50	100.00	50.40	12.00	50.20	8.95%	0.06
780	79.53	0.62	20.00	52.00	14.40	99.00	49.32	11.50	48.61	7.48%	0.04
815	79.06	0.61	18.00	58.00	14.30	100.00	48.74	12.50	47.96	6.84%	0.04

42.13

of parchment coffee beans dried at an average plenum temperature of 66 °C humidity of 3.2%. Replicate 1

ATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

ERAGE INITIAL MOISTURE CONTENT % w.b	47.53%
M MOISTURE CONTENT % d.b	1.82%

OF THE COFFEE BEANS SAMPLE

OF DRYING	MASS OF SAMPLE	DRYING AIR FLOW RATE	AIR CONDITIONS							MOISTURE CONTENT	MOISTURE RATIO
			AMBIENT		TOWER OUTLET		DRYING AIR (Plenu		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	152.07	0.57	23.50	63.50	14.10	99	62.24	4.00	61.36	90.59%	1.00
5	146.13	0.57	23.50	63.50	14.20	99	65.35	5.00	62.25	83.14%	0.92
10	142.63	0.57	23.50	63.00	14.20	100	64.21	3.00	65.01	78.75%	0.87
15	139.15	0.57	24.00	64.00	14.20	99	65.08	4.50	64.23	74.39%	0.82
20	135.77	0.57	24.00	65.00	14.20	98	65.12	3.50	64.12	70.16%	0.77
25	132.33	0.57	24.50	64.50	14.20	98	65.50	3.00	63.21	65.85%	0.72
30	129.07	0.59	24.50	64.00	14.30	99	65.73	2.50	63.48	61.76%	0.68
40	123.17	0.59	24.50	64.50	14.30	97	66.21	3.00	65.53	54.37%	0.59
50	117.35	0.61	24.50	64.50	14.40	99	66.68	2.80	65.77	47.07%	0.51
60	111.73	0.61	25.00	61.00	14.40	100	66.75	2.50	65.05	40.03%	0.43
75	104.67	0.62	25.00	61.00	14.50	98	66.90	3.50	65.81	31.18%	0.33
90	99.47	0.62	26.00	62.00	14.80	99	65.11	3.00	63.99	24.66%	0.26
105	95.57	0.64	26.00	62.00	14.80	100	64.16	2.90	62.01	19.78%	0.20
120	93.01	0.64	26.50	59.50	14.80	99	66.19	3.00	65.73	16.57%	0.17
150	89.77	0.66	26.50	53.50	14.70	100	64.18	3.50	62.89	12.51%	0.12
180	88.03	0.66	27.50	53.50	14.60	100	65.89	5.00	62.26	10.33%	0.10
300	85.41	0.67	28.50	48.50	14.50	100	65.50	4.00	63.48	7.04%	0.06

ble 4.2.14

...ing data of parchment coffee beans dried at an average plenum temperature of 66 °C
...relative humidity of 3.2%. Replicate 2

...MINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

...ERAGE INITIAL MOISTURE CONTENT % w.b	51.94%
...BRIUM MOISTURE CONTENT % d.b	1.82%

...ING OF THE COFFEE BEANS SAMPLE

		AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
[illegible]	MASS OF SAMPLE	DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	150.32	0.59	20.00	72.00	14.00	100	65.55	3.50	63.35	108.07%	1.00
5	143.54	0.59	20.50	69.00	14.10	98	66.45	3.00	65.44	98.69%	0.91
10	139.77	0.61	20.50	69.00	14.20	99	66.83	3.10	64.81	93.47%	0.86
15	136.01	0.61	20.50	69.00	14.30	99	66.42	3.20	65.53	88.27%	0.81
20	132.24	0.61	21.00	70.00	14.30	100	66.45	3.00	64.55	83.05%	0.76
25	128.48	0.61	21.50	68.00	14.40	100	66.68	3.00	64.22	77.84%	0.72
30	124.71	0.62	21.50	68.00	14.50	100	66.24	3.00	64.52	72.62%	0.67
40	118.68	0.64	22.00	63.00	14.60	100	66.24	2.90	65.54	64.28%	0.59
50	111.91	0.66	22.50	59.00	14.50	100	66.64	2.60	65.32	54.91%	0.50
60	105.88	0.66	22.50	59.00	14.50	100	67.16	2.60	64.9	46.56%	0.42
75	98.35	0.66	22.50	58.00	14.60	100	67.25	2.50	66.18	36.14%	0.32
90	93.07	0.67	23.00	57.00	14.70	100	67.31	2.90	65.84	28.83%	0.25
105	88.55	0.67	23.50	51.00	14.70	100	66.5	2.60	66.98	22.57%	0.20
120	85.54	0.67	24.00	53.00	14.70	99	67.35	2.30	69.05	18.40%	0.16
150	82.53	0.67	24.50	52.00	14.70	99	69.77	2.50	66.4	14.24%	0.12
180	80.27	0.67	55.00	55.00	14.80	99	67.54	2.60	64.84	11.11%	0.09
300	77.26	0.67	51.00	51.00	14.70	100	67.31	2.50	67.88	6.94%	0.05

Table A2.15

Drying data of parchment coffee beans dried at an average plenum temperature of 66 °C and relative humidity of 3.2%. Replicate 3

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	47.32%
EQUILIBRIUM MOISTURE CONTENT % d.b	1.80%

B. DRYING OF THE COFFEE BEANS SAMPLE

		AIR CONDITIONS									
TIME OF DRYING	MASS OF SAMPLE	DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET	MOISTURE CONTENT	MOISTURE RATIO
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
-	147.95	0.62	22.00	17.50	14.20	100	64.25	3.80	63.48	89.83%	1.00
5	142.55	0.62	22.00	17.50	14.20	100	65.54	3.50	63.22	82.90%	0.92
10	139.18	0.64	22.00	61.00	14.10	98	66.41	3.20	65.75	78.57%	0.87
15	135.80	0.64	22.50	63.00	14.00	100	66.45	3.10	64.43	74.24%	0.82
20	132.43	0.62	22.50	63.00	14.10	99	66.55	3.20	65.46	69.91%	0.77
25	129.05	0.64	23.00	66.00	14.20	99	67.07	2.60	65.23	65.58%	0.72
30	125.68	0.64	23.50	62.00	14.30	99	67.16	2.70	64.81	61.25%	0.68
40	120.28	0.64	23.50	62.00	14.20	100	67.22	2.80	66.09	54.32%	0.60
50	114.20	0.64	24.00	65.00	14.20	100	67.26	2.90	66.59	46.52%	0.51
60	108.81	0.64	24.00	65.00	14.10	100	69.68	2.10	68.96	39.61%	0.43
75	102.06	0.66	24.50	62.00	14.30	98	67.45	2.80	66.31	30.95%	0.33
90	97.34	0.66	25.00	61.00	14.50	100	67.22	2.70	64.75	24.89%	0.26
105	93.28	0.67	25.00	61.00	14.60	99	66.87	3.20	66.54	19.68%	0.20
120	90.58	0.67	25.50	63.00	14.70	98	66.01	3.30	65.37	16.22%	0.16
150	87.21	0.62	26.00	60.00	14.80	99	65.22	3.50	64.54	11.89%	0.11
180	85.18	0.64	27.00	58.00	14.80	99	64.74	3.80	62.49	9.29%	0.09
300	82.48	0.66	26.50	55.00	14.80	99	64.51	4.00	62.22	5.82%	0.05

APPENDIX 3

… 4.2.1

… of green coffee beans dried at an average drying air temperature of 31°C and … humidity of 31%. Replicate 1

…ATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

…ERAGE INITIAL MOISTURE CONTENT % w.b	52.36%
…MOISTURE CONTENT % d b	5.49%

… OF THE COFFEE BEANS SAMPLE

…OF DRYING	MASS OF SAMPLE (g)	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
		m/s	TEMP oC	RH %	TEMP oC	RH %	TEMP oC	RH %	TEMP oC	% d.b	
0	150.01	0.62	27.50	44.50	13.70	100	31.45	30.00	31.37	109.91%	1.00
10	148.98	0.62	27.50	44.50	13.90	99	31.49	29.00	31.42	108.47%	0.99
20	147.97	0.62	27.50	44.50	14.20	100	31.28	29.00	31.21	107.05%	0.97
30	147.05	0.62	27.50	41.50	14.60	100	31.30	29.00	31.23	105.77%	0.96
40	146.02	0.64	27.50	41.50	15.00	99	31.13	29.00	30.69	104.32%	0.95
50	145.04	0.64	27.50	41.50	15.20	100	31.15	28.00	30.60	102.95%	0.93
60	144.18	0.64	27.00	41.00	15.60	99	31.15	27.00	30.82	101.75%	0.92
90	141.36	0.64	26.50	43.00	15.60	100	31.42	28.00	31.05	97.80%	0.88
120	138.62	0.64	25.00	47.00	14.90	98	31.37	30.00	30.96	93.97%	0.85
180	133.89	0.64	23.00	52.00	14.80	99	31.30	30.00	31.09	87.35%	0.78
300	127.09	0.64	21.00	61.00	14.00	99	31.28	34.00	31.07	77.84%	0.69
840	98.15	0.64	18.00	76.00	14.00	99	31.35	35.00	31.21	37.34%	0.31
960	94.80	0.62	18.00	76.00	14.30	100	31.23	36.00	31.07	32.65%	0.26
1,080	91.65	0.64	22.50	76.00	14.00	98	31.09	37.00	30.93	28.25%	0.22
1,200	88.16	0.64	25.00	54.00	14.20	98	31.28	32.00	31.23	23.36%	0.17

...3.2

... green coffee beans dried a 0.68 Oc AND RELATIVE HUMIDITY OF 31.10%
...humidity of 31%. Replicate 2

...ATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

...AGE INITIAL MOISTURE CONTENT % w.b	52.23%
...MOISTURE CONTENT % d.b	5.27%

...ING OF THE COFFEE BEANS SAMPLE

		AIR CONDITIONS										
...OF ...NG	MASS OF SAMPLE	DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET	MOISTURE CONTENT	MOISTURE RATIO
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
[illegible]	140.51	0.59	16.00	70.00	13.50	100.00	29.11	32.00	28.92	109.34%	1.00
10	139.18	0.59	16.00	75.00	13.60	100.00	29.39	30.00	29.26	107.35%	0.98
20	139.52	0.59	16.50	76.00	13.70	99.00	29.85	31.00	29.67	107.86%	0.99
30	137.19	0.61	17.00	70.00	13.80	100.00	30.31	30.50	30.14	104.39%	0.95
40	136.52	0.61	17.50	68.00	13.80	100.00	30.11	31.00	29.92	103.39%	0.94
50	135.86	0.61	18.00	65.00	13.90	99.00	30.28	32.00	30.04	102.41%	0.93
60	134.53	0.62	18.00	65.00	14.00	99.00	31.45	32.00	31.33	100.43%	0.91
90	131.87	0.64	18.00	81.00	14.20	98.00	31.25	28.60	31.09	96.46%	0.88
120	129.22	0.66	18.50	79.00	14.30	97.00	32.25	31.00	31.71	92.52%	0.84
180	125.23	0.66	19.50	78.00	14.40	98.00	32.49	28.50	32.01	86.57%	0.78
300	118.59	0.67	25.50	54.00	14.60	98.00	32.35	31.00	32.19	76.68%	0.69
400	113.27	0.67	27.00	50.00	14.60	100.00	33.28	31.00	32.76	68.75%	0.61
600	101.98	0.66	28.50	47.00	14.60	100.00	33.31	28.00	33.04	51.93%	0.45
840	91.35	0.64	22.00	51.00	14.60	99.00	30.45	27.50	29.70	36.10%	0.30
960	88.69	0.59	19.50	60.00	14.50	98.00	27.39	31.50	26.89	32.13%	0.26
1080	85.37	0.57	18.00	62.00	14.00	99.00	27.21	32.00	26.75	27.19%	0.21
1200	82.05	0.55	16.00	80.00	13.80	100.00	26.90	33.00	26.54	22.24%	0.16
1400	78.73	0.57	17.00	70.00	13.60	99.00	29.31	34.00	29.07	17.29%	0.12
1800	75.4	0.64	26.00	69.00	14.70	100.00	31.35	32.00	31.08	12.33%	0.07
2000	75.01	0.66	29.00	42.00	14.80	99.00	32.32	36.00	31.85	11.75%	0.06
2200	74.87	0.64	25.00	49.00	14.70	98.00	30.97	34.00	30.50	11.54%	0.06
2400	74.54	0.62	19.50	60.00	14.00	97.00	29.41	35.00	28.92	11.05%	0.06

[illegible] 4.3.3

[illegible] of green coffee beans dried at an average drying air temperature of 31 °C and [illegible] humidity of 31%. Replicate 3

[illegible]ATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

[illegible] AVERAGE INITIAL MOISTURE CONTENT % w.b	47.42%
[illegible] MOISTURE CONTENT % d.b	5.26%

[illegible] OF THE COFFEE BEANS SAMPLE

[illegible]	MASS OF SAMPLE	AIR CONDITIONS									MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET			
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP			
	(g)	m/s	oC	%	oC	%	oC	%	oC		% d.b	
0	143.71	0.55	15.50	80.00	14.00	99.00	27.46	32.00	26.97		90.19%	1.00
10	143.10	0.58	15.50	80.00	14.00	99.00	27.70	37.00	27.23		89.38%	0.99
20	142.57	0.59	15.50	79.00	13.90	100.00	28.02	44.00	27.63		88.68%	0.98
30	141.27	0.59	16.00	78.00	14.20	100.00	28.21	34.00	27.72		86.96%	0.96
40	140.66	0.61	16.00	77.00	14.20	99.00	28.40	30.00	27.70		86.15%	0.95
50	142.05	0.62	16.50	76.00	14.10	98.00	28.43	29.00	27.78		87.99%	0.97
60	138.83	0.62	16.50	75.00	14.20	97.00	29.18	27.00	28.70		83.73%	0.92
90	136.39	0.62	16.50	74.00	14.40	98.00	30.32	28.00	29.77		80.50%	0.89
120	133.96	0.64	18.50	76.00	14.50	99.00	31.10	29.00	30.75		77.28%	0.85
180	130.30	0.64	20.00	77.00	14.50	100.00	31.89	29.50	31.55		72.44%	0.79
300	124.20	0.66	24.60	65.00	14.70	99.00	32.54	31.50	31.90		64.37%	0.70
[illegible]	119.33	0.67	27.00	58.00	14.80	99.00	32.67	30.00	31.96		57.92%	0.62
[illegible]	109.57	0.68	28.50	52.00	14.90	99.00	32.78	30.34	32.05		45.01%	0.47
840	99.21	0.67	22.50	62.00	14.50	100.00	29.65	30.35	26.18		31.29%	0.31
[illegible]	96.77	0.66	21.00	69.00	14.00	100.00	29.48	30.97	29.14		28.07%	0.27
1080	93.72	0.64	19.50	82.00	13.80	99.00	29.46	31.03	28.04		24.03%	0.22
1200	90.68	0.61	17.50	83.00	13.80	98.00	29.41	30.81	28.96		20.01%	0.17
1400	87.14	0.59	16.50	78.00	13.60	99.00	30.86	31.65	30.65		15.32%	0.12
[illegible]	84.09	0.64	25.00	62.00	14.50	99.00	32.32	28.00	30.82		11.29%	0.07
2000	83.61	0.66	27.50	49.00	14.50	98.00	31.78	31.40	31.23		10.65%	0.06
2200	83.50	0.67	22.50	69.00	14.40	99.00	31.66	32.50	30.86		10.50%	0.06
2400	83.20	0.61	20.00	79.00	14.00	100.00	31.53	31.50	30.91		10.11%	0.06

e A3.4

ng data of green coffee beans dried at an average drying air temperature of 38 °C and e humidity of 24%. Replicate 1

ETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

ED AVERAGE INITIAL MOISTURE CONTENT % w.b	55.00%
LIBRIUM MOISTURE CONTENT % d.b	4.33%

NG OF THE COFFEE BEANS SAMPLE

OF G	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
ni	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	112.98	0.54	17.00	80.00	13.20	100.00	35.93	27.00	35.71	122.22%	1.00
5	109.00	0.54	17.00	80.00	13.30	100.00	36.17	26.00	36.05	114.39%	0.93
10	107.64	0.54	17.00	79.00	13.30	100.00	37.13	25.00	36.78	111.72%	0.91
20	106.18	0.54	17.00	78.00	13.30	100.00	37.49	24.50	37.25	108.85%	0.89
30	105.26	0.54	17.00	77.00	13.30	100.00	36.99	25.00	36.65	107.04%	0.87
45	104.22	0.54	17.00	76.00	13.30	100.00	36.29	26.00	35.74	104.99%	0.85
60	103.38	0.54	18.00	71.00	13.30	100.00	36.05	26.00	35.47	103.34%	0.84
90	101.56	0.54	19.50	67.00	13.30	99.00	35.83	26.50	35.69	99.76%	0.81
120	99.72	0.54	21.00	65.00	13.50	100.00	35.65	26.60	35.22	96.14%	0.78
180	95.76	0.56	23.50	59.50	14.00	100.00	35.43	26.60	35.28	88.35%	0.71
240	91.66	0.64	25.50	51.50	14.50	100.00	36.48	26.00	36.42	80.29%	0.64
300	87.66	0.66	27.00	47.00	14.50	99.00	36.84	25.00	36.65	72.42%	0.58
360	83.58	0.68	28.50	42.50	14.60	99.00	39.82	21.00	39.73	64.39%	0.51
420	79.52	0.68	29.50	41.00	14.70	100.00	39.75	21.00	39.45	56.41%	0.44
485	75.54	0.68	29.50	41.00	14.80	100.00	40.06	20.50	39.85	48.58%	0.38
550	71.90	0.67	28.50	45.50	15.00	100.00	39.16	21.00	38.87	41.42%	0.31
613	68.92	0.66	27.00	50.00	15.00	99.00	37.47	24.50	36.42	35.56%	0.26
671	66.76	0.66	25.00	47.00	15.00	100.00	36.05	25.90	35.81	31.31%	0.23
755	64.78	0.61	22.50	51.50	14.00	100.00	35.43	26.50	35.28	27.42%	0.20
1,369	58.08	0.55	18.00	71.00	14.50	99.00	36.89	25.00	36.65	14.24%	0.08
1,441	57.96	0.55	18.00	76.00	15.00	100.00	36.04	26.00	35.84	14.00%	0.08
1,560	57.68	0.57	21.50	69.50	15.00	99.00	37.20	25.00	36.60	13.45%	0.08
1,890	56.94	0.59	29.00	40.00	15.50	100.00	40.18	20.50	39.92	12.00%	0.07
2,028	56.62	0.59	27.50	47.50	15.80	99.00	39.23	22.00	38.90	11.37%	0.06
2,220	56.48	0.59	22.50	55.00	15.00	100.00	36.78	25.00	35.81	11.09%	0.06

...e A3.5

...ing data of green coffee beans dried at an average drying air temperature of 38 °C and ...e humidity of 24%. Replicate 2

...ERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

...TED AVERAGE INITIAL MOISTURE CONTENT % w.b	54.07%
...BRIUM MOISTURE CONTENT % d.b	4.52%

...ING OF THE COFFEE BEANS SAMPLE

...OF ...ING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	144.77	0.59	17.50	68.00	14.00	100.00	36.13	26.50	35.98	117.72%	1.00
5	139.73	0.59	17.50	68.00	14.20	100.00	37.24	25.40	37.18	110.14%	0.93
10	137.56	0.61	17.50	70.00	14.50	99.00	38.78	22.50	38.43	106.88%	0.90
20	136.12	0.61	17.50	70.00	14.50	99.00	39.14	22.00	38.90	104.71%	0.89
30	134.68	0.62	17.50	67.00	14.60	99.00	38.65	22.50	37.30	102.55%	0.87
45	133.24	0.62	18.00	67.00	14.60	99.00	37.94	24.50	37.39	100.38%	0.85
[illegible]	132.52	0.64	18.00	72.00	14.50	100.00	37.72	24.50	37.09	99.30%	0.84
90	130.36	0.64	18.50	68.00	14.50	99.00	37.48	24.60	37.34	96.05%	0.81
120	127.48	0.66	19.00	69.00	14.50	99.00	37.30	24.80	36.87	91.72%	0.77
180	122.43	0.66	20.00	67.00	14.60	100.00	37.08	25.20	36.93	84.13%	0.70
240	117.39	0.67	21.00	52.00	14.70	100.00	38.13	23.50	38.07	76.55%	0.64
300	112.34	0.67	26.50	54.00	14.80	99.00	38.49	23.50	38.30	68.95%	0.57
360	102.26	0.67	28.00	47.00	14.80	100.00	39.00	22.00	37.79	53.79%	0.44
420	97.21	0.67	28.00	47.00	14.80	99.00	38.25	23.60	38.02	46.20%	0.37
480	92.[illegible]	0.67	28.00	47.00	14.60	100.00	36.85	25.00	36.49	39.70%	0.31
550	88.57	0.67	27.50	46.00	14.50	100.00	30.09	22.30	38.63	33.20%	0.25
610	86.40	0.67	27.50	42.00	14.50	100.00	38.38	23.40	38.05	29.94%	0.22
670	83.52	0.67	24.00	49.00	14.30	99.00	37.38	24.40	37.42	25.61%	0.19
760	75.16	0.66	21.00	51.00	14.30	100.00	37.35	24.20	36.49	13.03%	0.08
1,370	74.80	0.62	17.00	62.00	14.30	100.00	38.17	23.50	37.86	12.49%	0.07
1,440	74.59	0.64	18.00	60.00	14.50	99.00	38.02	23.80	37.66	12.18%	0.07
1.560	73.72	0.67	21.00	63.00	14.60	100.00	37.59	24.50	37.42	10.87%	0.06
1.890	73.58	0.67	29.00	41.00	14.60	100.00	37.84	24.30	37.48	10.66%	0.05
2,030	73.43	0.67	27.00	46.00	14.60	100.00	38.19	23.50	37.95	10.43%	0.05
2,220	73.29	0.61	22.00	50.00	14.40	99.00	37.69	24.30	37.30	10.22%	0.05

…436

…data of green coffee beans dried at an average drying air temperature of 38 °C and …humidity of 24%. Replicate 3

…NATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

…AVERAGE INITIAL MOISTURE CONTENT % w.b	51.16%
…MOISTURE CONTENT % d.b	4.30%

…OF THE COFFEE BEANS SAMPLE

…F …E	MASS OF SAMPLE	AIR CONDITIONS							MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	147.43	0.59	17	65	14.1	100	36.11	26	35.54	104.75%	1.00
5	143.27	0.59	17	65	14.3	100	39.76	21.9	39.73	98.97%	0.94
10	141.19	0.59	18	70	14.3	100	38.33	23.9	38.11	96.08%	0.91
20	139.80	0.59	18	70	14.4	99	39.56	22.1	39.21	94.15%	0.89
30	138.42	0.61	18	66	14.4	100	37.94	25.4	31.58	92.24%	0.88
45	137.03	0.61	19	66	14.5	100	38.06	23.9	37.46	90.31%	0.86
60	136.34	0.62	19	60	14.5	100	36.41	26.8	35.97	89.35%	0.85
90	134.26	0.64	19	58	14.5	100	37.75	25.4	37.54	86.46%	0.82
120	131.48	0.66	20	65	14.5	100	36.92	26.1	36.67	82.60%	0.78
180	126.63	0.67	20	66	14.6	100	37.76	24.7	37.52	75.86%	0.71
240	121.78	0.70	21	60	14.6	100	38.39	23.1	38.33	69.13%	0.65
300	116.93	0.73	22	51	14.7	99	36.16	22	37.92	62.39%	0.58
360	112.07	0.68	29	48	14.7	100	38.41	23.2	38.18	55.64%	0.51
420	102.37	0.68	28.5	46	14.6	98	37.2	25.8	36.65	42.17%	0.38
480	98.21	0.67	28.5	44	14.6	100	39.25	21.8	38.78	36.39%	0.32
550	94.05	0.67	26.5	52	14.6	99	38.54	23.4	38.19	30.62%	0.26
610	91.97	0.67	24	49	14.6	98	38	24.1	37.58	27.73%	0.23
670	89.19	0.66	22.5	53	14.5	99	37.5	24.4	36.61	23.87%	0.19
760	81.15	0.62	22	49	14.4	100	38.33	23.1	38.01	12.70%	0.08
1,370	80.81	0.61	17.5	68	14.2	100	38.18	23	38.8	12.23%	0.08
1,440	80.60	0.62	18	67	14.3	100	37.75	24.6	37.54	11.94%	0.08
1,560	79.77	0.64	21	65	14.5	99	37.39	25.2	37.33	10.78%	0.06
1,890	79.63	0.67	28.5	42	14.6	99	36.29	26.7	36.1	10.59%	0.06
2,030	79.49	0.67	27.5	47	14.5	99	35.94	27.1	35.79	10.40%	0.06
2,220	79.47	0.64	21	59	14.3	100	37.1	25.8	36.99	10.37%	0.06

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...data of green coffee beans dried at an average drying air temperature of 46 °C and ...humidity of 13.4%. Replicate 1

...TERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

...AVERAGE INITIAL MOISTURE CONTENT % w.b	52.96%
...MOISTURE CONTENT % d.b	3.10%

...ING OF THE COFFEE BEANS SAMPLE

...DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenu		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
-	145.61	0.61	26.50	43.00	14.00	99	47.01	11.00	46.36	112.59%	1.00
10	139.92	0.61	26.50	43.00	14.20	99	46.2	12.00	46.67	104.28%	0.92
20	136.23	0.61	26.50	43.00	14.40	98	46.85	13.00	46.14	98.89%	0.87
30	132.93	0.61	26.50	40.00	14.60	99	46.14	13.50	45.51	94.07%	0.83
40	129.25	0.61	26.50	40.00	14.60	99	46.12	13.00	45.44	88.70%	0.78
50	126.08	0.61	26.50	40.00	14.60	99	46.28	13.50	45.49	84.07%	0.74
60	122.73	0.61	26.50	41.00	14.70	99	46.5	13.50	45.89	79.18%	0.69
90	113.50	0.61	26.50	43.00	14.60	100	46.19	13.00	45.2	65.71%	0.57
120	104.05	0.62	25.50	45.00	14.60	99	49.19	12.00	47.74	51.91%	0.45
150	97.56	0.64	25.00	45.00	14.60	100	47.91	13.00	47.25	42.43%	0.36
180	92.17	0.64	24.50	46.50	15.00	100	47.15	13.50	46.52	34.56%	0.29
240	86.12	0.64	22.00	54.00	14.10	100	46.21	14.50	45.58	25.73%	0.21
300	83.49	0.64	20.50	60.00	13.50	98	46.01	15.00	45.38	21.89%	0.17
360	82.08	0.66	20.00	60.00	14.00	99	45.99	15.50	45.32	19.83%	0.15
420	80.63	0.62	19.50	22.50	14.30	99	45.6	15.50	44.97	17.72%	0.13
900	74.77	0.62	17.50	80.00	14.50	98	45.24	15.00	44.63	9.16%	0.06
1,020	74.57	0.61	18.00	76.00	14.80	99	46.14	14.50	45.55	8.87%	0.05
1,140	74.18	0.61	22.50	60.00	15.00	98	45.91	15.00	45.44	8.30%	0.05

[illegible] of green coffee beans dried at an average drying air temperature of 46 °C and [illegible] humidity of 13.4%. Replicate 2

[illegible] OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

[illegible] AVERAGE INITIAL MOISTURE CONTENT % w.b	51.33%
[illegible] MOISTURE CONTENT % d.b	3.09%

[illegible] OF THE COFFEE BEANS SAMPLE

[illegible]	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
	[illegible]	m/s	oC	%	oC	%	oC	%	oC	% d.b	
[illegible]	144.44	0.62	17.00	80.00	13.50	100	44.02	11.0	12.94	105.47%	1.00
[illegible]	138.86	0.62	17.00	80.00	13.50	99	44.73	11.5	43.50	97.53%	0.92
[illegible]	135.37	0.64	17.00	79.00	13.60	99	45.58	11.5	44.56	92.56%	0.87
[illegible]	131.88	0.64	17.50	78.00	13.60	99	44.78	12.0	43.74	87.60%	0.83
[illegible]	128.39	0.64	17.50	78.00	13.60	100	46.91	13.0	45.91	82.63%	0.78
[illegible]	125.60	0.66	17.50	75.00	13.70	99	47.41	12.0	47.25	78.67%	0.74
[illegible]	122.11	0.66	18.00	79.00	14.00	98	46.14	12.5	45.18	73.70%	0.69
[illegible]	113.04	0.66	18.00	79.00	14.50	98	47.9	11.5	46.86	60.80%	0.56
[illegible]	103.97	0.64	18.00	79.00	14.60	98	46.99	12.5	46.20	47.90%	0.44
[illegible]	97.69	0.62	18.50	79.00	14.60	99	47.78	14.0	46.52	38.96%	0.35
[illegible]	92.81	0.62	18.50	75.00	14.60	100	46.97	15.5	45.99	32.02%	0.28
[illegible]	87.22	0.61	18.50	74.00	14.70	99	47.51	14.0	46.50	24.07%	0.20
[illegible]	84.43	0.61	19.50	76.00	14.70	99	46.69	16.0	46.40	20.10%	0.17
[illegible]	83.04	0.62	21.50	74.00	14.70	98	47.91	13.0	47.25	18.12%	0.15
[illegible]	81.64	0.61	23.00	68.00	14.70	99	47.32	14.0	46.26	16.13%	0.13
[illegible]	76.06	0.59	20.00	63.00	14.20	100	47.74	14.5	46.70	8.20%	0.05
[illegible]	76.03	0.59	19.50	72.00	14.20	100	47.6	12.0	46.51	8.15%	0.05
[illegible]	75.36	0.59	17.00	80.00	14.10	100	48.48	13.0	47.22	7.20%	0.04

coffee beans dried at an average drying air temperature of 46 °C and 13.4%. Replicate 3

ITIAL AND EQUILIBRIUM MOISTURE CONTENT

IAL MOISTURE CONTENT % w.b	53.22%
CONTENT % d.b	3.11%

EE BEANS SAMPLE

	AIR CONDITIONS									MOISTURE CONTENT	MOISTURE RATIO
	DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET			
		TEMP	RH	TEMP	RH	TEMP	RH	TEMP			
	m/s	oC	%	oC	%	oC	%	oC		% d.b	
1	0.57	16.00	76.00	13.90	100	44.73	14.20	43.31		113.77%	1.00
[illegible]	0.57	16.00	76.00	13.90	100	44.99	14.70	43.97		106.25%	0.93
01	0.57	16.00	75.00	14.00	100	45.67	14.20	44.6		100.89%	0.88
21	5.90	16.00	74.00	13.90	100	45.81	13.70	44.79		95.52%	0.84
12	0.59	16.50	81.00	14.00	100	46.26	11.70	45.57		90.16%	0.79
39	0.59	16.00	90.00	14.00	100	46.24	11.20	45.61		85.87%	0.75
59	0.59	17.00	80.00	14.00	99	46.14	13.20	45.67		80.49%	0.70
73	0.59	17.00	79.00	14.20	98	47.08	12.70	43.61		66.55%	0.57
87	0.61	17.50	76.00	14.20	99	46.14	14.70	45.32		52.60%	0.45
04	0.61	18.00	72.00	12.30	97	46.20	15.70	45.2		42.94%	0.36
73	0.61	19.50	70.00	14.40	99	46.44	17.20	45.61		35.42%	0.29
67	0.61	23.50	60.00	14.50	98	45.82	15.70	44.79		26.85%	0.21
63	0.62	25.50	54.00	14.60	98	47.54	16.70	45.99		22.55%	0.18
11	0.64	27.00	48.00	14.70	97	46.51	17.70	45.72		20.40%	0.16
[illegible]	0.66	28.50	46.00	14.80	99	45.99	13.70	45.42		18.26%	0.14
53	0.61	20.00	63.00	14.50	99	44.50	13.70	43.29		9.68%	0.06
49	0.59	19.50	65.00	14.30	100	45.21	12.70	44.12		9.62%	0.06
.77	0.59	19.00	67.00	14.20	100	43.90	11.70	42.72		8.60%	0.05

Table A3.10

Drying data of green coffee beans dried at an average drying air temperature of 50 °C and relative humidity of 12.8%. Replicate 1

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	55.00%
EQUILIBRIUM MOISTURE CONTENT % d.b	2.32%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS							MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	125.34	0.57	18	80	13.5	100	48.46	11.6	47.71	122.22%	1.00
10	116.78	0.57	18	80	13.5	100	48.43	12.5	47.72	107.05%	0.87
20	113.64	0.59	18	80	13.6	100	48.47	13	47.72	101.48%	0.83
30	110.72	0.59	18.5	76	13.8	99	48.5	12.5	47.81	96.30%	0.78
45	106.74	0.61	18.5	76	13.8	100	48.72	11.8	47.99	89.25%	0.72
60	103.02	0.62	18.5	80.5	13.8	100	48.91	12.5	48.21	82.65%	0.67
75	99.36	0.64	18.5	81	13.8	100	49.31	13	48.52	76.16%	0.62
90	96.14	0.64	19	81	13.9	100	49.51	13.8	48.83	70.45%	0.57
105	92.84	0.64	19	81	14	99	49.42	14	48.25	64.60%	0.52
120	89.80	0.64	19.5	81	14.3	97	49.22	12	48.51	59.21%	0.47
135	86.98	0.66	19.5	81	14.4	98	49.37	13	48.91	54.21%	0.43
150	84.30	0.66	20.5	77.5	14.8	99	49.57	15	48.82	49.46%	0.39
165	81.58	0.66	20.8	77.5	14.9	98	49.53	14	48.72	44.64%	0.35
180	78.94	0.66	21.5	73.5	14.9	98	49.61	16	48.84	39.96%	0.31
195	76.58	0.66	21.5	73.5	14.8	99	49.97	14	49.21	35.77%	0.28
210	74.56	0.66	22	74	14.9	98	50.31	11.2	49.71	32.19%	0.25
235	72.78	0.66	22	74	15	97	50.49	11.4	49.93	29.04%	0.22
240	71.20	0.66	23	67	15.1	98	50.61	12	50.05	26.23%	0.20
270	68.74	0.66	24.5	57.5	15	99	51.7	11.8	51.39	21.87%	0.16
300	66.92	0.66	25	61	15	100	52.47	11	51.87	18.65%	0.14
330	65.58	0.66	26	62	15	99	52.5	12.5	51.75	16.27%	0.12
360	64.72	0.66	27	56	15	99	52.56	12.6	51.66	14.75%	0.10
496	62.56	0.67	28	54	15	99	52.89	12.5	52.19	10.92%	0.07
660	61.50	0.64	24.5	50.5	14.1	100	49.91	12.8	49.73	9.04%	0.06
975	60.94	0.62	19.5	72.5	13.3	100	49.61	12.6	49.42	8.04%	0.05

Table A3.11

Drying data of green coffee beans dried at an average drying air temperature of 50 °C and relative humidity of 12.8%. Replicate 2

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	53.83%
EQUILIBRIUM MOISTURE CONTENT % d.b	2.31%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	139.97	0.62	17.50	82.00	13.90	100.00	49.45	12.80	48.73	116.59%	1.00
10	129.94	0.62	17.50	81.00	13.00	100.00	49.45	12.50	48.74	101.07%	0.86
20	127.08	0.64	17.50	81.00	13.90	99.00	49.21	13.00	48.50	96.64%	0.83
30	123.50	0.64	17.50	78.00	14.00	99.00	49.24	12.40	48.49	91.11%	0.78
45	119.20	0.64	18.00	75.00	14.00	99.00	49.25	12.50	48.60	84.45%	0.72
60	114.90	0.62	18.00	78.00	14.20	98.00	49.98	11.90	49.21	77.80%	0.66
75	111.32	0.64	18.00	77.00	14.40	99.00	50.55	11.50	49.40	72.26%	0.61
90	107.74	0.64	18.00	76.00	14.50	99.00	50.75	11.40	49.76	66.72%	0.56
105	110.16	0.66	18.00	76.00	14.50	98.00	50.79	11.80	50.07	70.46%	0.60
120	100.58	0.66	18.50	75.00	14.50	99.00	50.67	13.00	49.49	55.64%	0.47
135	97.71	0.66	18.50	74.00	14.50	100.00	50.66	13.00	49.70	51.20%	0.43
150	94.85	0.66	19.00	72.00	14.50	100.00	50.60	12.00	50.10	46.77%	0.39
165	91.98	0.66	19.00	74.00	14.60	99.00	50.60	12.60	50.20	42.33%	0.35
190	89.12	0.66	19.00	73.50	14.70	99.00	50.79	12.70	49.99	37.91%	0.31
195	86.25	0.67	19.50	72.00	14.50	99.00	50.76	12.00	50.07	33.46%	0.27
210	84.11	0.67	20.00	71.00	14.50	100.00	50.84	14.00	50.43	30.15%	0.24
235	81.96	0.67	20.50	70.00	14.60	100.00	51.20	15.00	50.91	26.83%	0.21
240	80.53	0.67	21.00	68.00	14.50	100.00	51.71	16.00	51.09	24.61%	0.20
270	77.66	0.67	21.50	65.00	14.60	100.00	51.79	14.00	51.29	20.17%	0.16
300	75.51	0.67	22.00	62.00	14.70	100.00	52.89	13.50	52.63	16.84%	0.13
330	74.08	0.67	22.00	62.00	14.50	99.00	53.72	11.00	53.10	14.63%	0.11
360	73.36	0.68	23.00	60.00	14.50	100.00	53.69	11.40	52.99	13.52%	0.10
500	71.21	0.68	24.50	55.00	14.60	99.00	50.81	12.00	50.61	10.19%	0.07
560	69.78	0.64	23.00	60.00	14.70	100.00	50.49	12.40	50.13	7.98%	0.05
975	69.07	0.62	19.50	73.00	14.20	99.00	49.45	13.50	48.70	6.88%	0.04

Table A3.12

Drying data of green coffee beans dried at an average drying air temperature of 50 °C and relative humidity of 12.8%. Replicate 3

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	51.77%
EQUILIBRIUM MOISTURE CONTENT % d.b	2.34%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING (min)	MASS OF SAMPLE (g)	AIR CONDITIONS: DRYING AIR FLOW RATE m/s	AMBIENT TEMP oC	AMBIENT RH %	TOWER OUTLET TEMP oC	TOWER OUTLET RH %	DRYING AIR (Plenum) TEMP oC	DRYING AIR (Plenum) RH %	DRYER OUTLET TEMP oC	MOISTURE CONTENT % d.b	MOISTURE RATIO
0	141.41	0.61	16.00	70.00	14.00	100.00	48.70	12.00	47.41	107.34%	1.00
10	132.39	0.61	16.50	71.00	14.10	99.00	48.89	12.40	48.24	94.11%	0.87
20	129.61	0.61	16.50	69.00	14.00	100.00	49.04	12.40	48.75	90.04%	0.84
30	126.14	0.62	16.50	70.00	13.90	100.00	50.62	12.30	49.74	84.95%	0.79
45	121.98	0.62	16.50	68.00	14.00	99.00	50.46	12.40	49.98	78.85%	0.73
60	117.81	0.62	17.00	71.00	14.10	98.00	50.34	13.00	49.72	72.74%	0.67
75	114.34	0.62	17.00	75.00	14.20	98.00	50.81	12.50	50.23	67.65%	0.62
90	110.87	0.64	17.50	74.00	14.40	99.00	50.44	13.50	49.97	62.56%	0.57
105	107.40	0.64	17.50	76.00	14.50	98.00	50.81	14.00	50.11	57.47%	0.53
120	103.93	0.64	18.00	74.00	14.50	99.00	50.44	14.30	49.99	52.39%	0.48
135	101.16	0.64	18.50	77.00	14.50	100.00	50.36	14.50	49.66	48.32%	0.44
150	98.38	0.64	19.00	72.00	14.60	100.00	52.32	13.00	51.53	44.25%	0.40
165	95.60	0.64	19.50	71.00	14.50	100.00	50.68	12.50	49.99	40.17%	0.36
180	92.83	0.64	20.00	72.00	14.60	99.00	51.04	12.80	50.57	36.11%	0.32
195	90.05	0.66	21.00	68.00	14.60	100.00	50.93	11.90	49.75	32.03%	0.28
210	87.97	0.66	22.50	58.00	14.70	100.00	51.40	13.20	50.11	28.98%	0.25
235	85.89	0.66	24.00	61.00	14.80	99.00	51.21	14.00	50.40	25.93%	0.22
240	84.50	6.69	24.50	58.00	14.90	99.00	51.27	14.50	50.57	23.90%	0.21
270	81.72	0.67	25.00	55.00	14.90	100.00	50.91	14.00	49.99	19.82%	0.17
300	79.64	0.67	26.00	52.00	14.80	98.00	50.44	15.40	49.67	16.77%	0.14
330	78.25	0.68	26.50	50.00	14.70	98.00	50.97	14.50	49.85	14.73%	0.12
360	77.56	0.67	27.00	50.00	14.60	99.00	49.89	14.00	48.94	13.72%	0.11
500	75.48	0.64	29.00	42.00	14.70	100.00	50.23	13.80	48.83	10.67%	0.08
660	74.09	0.62	27.00	44.00	14.80	100.00	49.76	14.50	48.81	8.63%	0.06
975	73.39	0.61	19.50	61.00	14.90	100.00	48.94	14.00	48.10	7.61%	0.05

Table A3.13

Drying data of green coffee beans dried at an average drying air temperature of 66 °C and relative humidity of 3.2%. Replicate 1

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	55.21%
EQUILIBRIUM MOISTURE CONTENT % d.b	1.77%

B. DRYING OF THE COFFEE BEANS SAMPLE

		AIR CONDITIONS									
TIME OF DRYING	MASS OF SAMPLE	DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET	MOISTURE CONTENT	MOISTURE RATIO
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	137.58	0.62	18.50	80.50	14.10	99.00	63.01	4.00	62.24	123.26%	1.00
5	127.38	0.62	18.50	80.50	14.10	100.00	64.31	3.60	61.98	106.71%	0.86
10	122.64	0.62	18.50	80.50	14.10	100.00	64.22	3.70	62.02	99.02%	0.80
20	114.32	0.62	18.50	80.50	14.10	100.00	65.12	3.50	64.12	85.52%	0.69
30	106.82	0.62	19.00	81.00	14.20	99.00	65.50	3.50	63.48	73.35%	0.59
40	99.90	0.62	19.00	81.00	14.20	100.00	65.09	3.70	64.22	62.12%	0.50
51	93.67	0.62	19.00	81.00	14.20	100.00	65.11	3.60	63.22	52.01%	0.41
60	89.58	0.62	20.00	77.00	14.40	99.00	65.35	3.60	62.89	45.37%	0.36
75	83.96	0.62	20.00	77.00	14.40	100.00	65.21	3.40	63.19	36.25%	0.28
90	80.06	0.64	20.50	73.00	14.45	100.00	65.31	3.30	64.22	29.92%	0.23
105	76.92	0.64	20.50	73.00	14.80	99.00	65.83	3.40	63.99	24.83%	0.19
120	74.90	0.66	21.50	73.50	14.80	99.00	65.92	3.50	63.57	21.55%	0.16
150	71.90	0.66	23.00	67.00	14.80	99.00	65.98	3.00	64.85	16.68%	0.12
181	70.20	0.67	24.00	64.00	14.40	100.00	65.17	3.70	64.51	13.92%	0.10
240	68.48	0.67	25.50	65.50	14.30	100.00	66.02	3.00	65.35	11.13%	0.08
300	67.44	0.68	27.00	56.00	14.40	99.00	68.44	2.40	67.72	9.44%	0.06
483	65.94	0.67	28.50	51.50	14.50	99.00	66.21	3.00	65.07	7.01%	0.04
705	65.34	0.66	22.50	62.50	14.40	99.00	65.98	3.00	63.51	6.03%	0.04
960	64.96	0.61	20.50	73.00	14.20	100.00	66.88	2.90	66.55	5.42%	0.03

Table A3.14

Drying data of green coffee beans dried at an average drying air temperature of 66 °C and relative humidity of 3.2%. Replicate 2

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	54.45%
EQUILIBRIUM MOISTURE CONTENT % d.b	1.78%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	145.65	0.57	17.00	89.00	13.80	100.00	61.54	6.00	60.69	119.54%	1.00
5	134.97	0.57	17.00	89.00	13.90	100.00	64.38	3.00	61.58	103.44%	0.86
10	129.64	0.57	17.00	89.00	14.10	100.00	62.34	5.00	61.57	95.41%	0.80
20	121.25	0.57	17.50	84.00	14.30	98.00	63.64	4.00	61.31	82.76%	0.69
30	112.86	0.59	17.50	88.00	14.50	99.00	63.55	3.80	61.35	70.11%	0.58
40	106.86	0.59	18.00	82.00	14.50	99.00	64.45	3.20	63.45	61.07%	0.50
50	99.13	0.59	18.00	82.00	14.50	98.00	64.83	3.00	62.81	49.42%	0.40
60	95.32	0.61	18.50	79.00	14.50	99.00	64.42	3.00	63.55	43.68%	0.36
75	89.22	0.61	19.00	81.00	14.60	99.00	64.44	3.10	62.55	34.48%	0.28
90	85.40	0.61	19.50	77.00	14.50	99.00	64.48	3.20	62.22	28.72%	0.23
105	82.35	0.61	20.00	79.00	14.50	100.00	64.54	3.10	62.52	24.13%	0.19
120	80.07	0.61	20.00	79.00	14.60	100.00	64.63	3.05	63.53	20.69%	0.16
150	77.02	0.62	20.00	79.00	14.60	100.00	65.16	2.50	63.32	16.09%	0.12
180	74.73	0.64	21.00	75.00	14.70	99.00	65.25	2.60	63.57	12.64%	0.09
240	73.20	0.66	21.50	76.00	17.70	99.00	64.83	2.90	62.54	10.33%	0.07
300	72.44	0.67	22.00	72.00	14.90	99.00	65.06	3.20	62.81	9.19%	0.06
480	70.92	0.67	27.00	57.00	14.90	99.00	65.54	2.90	64.86	6.90%	0.04
705	70.15	0.66	26.00	58.00	17.70	99.00	66.01	2.40	65.10	5.74%	0.03
960	69.73	0.62	18.00	79.00	14.50	100.00	66.08	2.30	64.38	5.10%	0.03

Table A3.15

Drying data of green coffee beans dried at an average drying air temperature of 66 °C and relative humidity of 3.2%. Replicate 3

A. DETERMINATION OF INITIAL AND EQUILIBRIUM MOISTURE CONTENT

WEIGHTED AVERAGE INITIAL MOISTURE CONTENT % w.b	53.72%
EQUILIBRIUM MOISTURE CONTENT % d.b	1.79%

B. DRYING OF THE COFFEE BEANS SAMPLE

TIME OF DRYING	MASS OF SAMPLE	AIR CONDITIONS								MOISTURE CONTENT	MOISTURE RATIO
		DRYING AIR FLOW RATE	AMBIENT		TOWER OUTLET		DRYING AIR (Plenum)		DRYER OUTLET		
			TEMP	RH	TEMP	RH	TEMP	RH	TEMP		
(min)	(g)	m/s	oC	%	oC	%	oC	%	oC	% d.b	
0	146.53	0.55	17.00	65.00	13.70	100.00	63.97	5.00	61.77	116.08%	1.00
5	136.67	0.57	17.00	66.00	13.70	100.00	64.84	4.80	63.99	101.54%	0.87
10	130.60	0.57	17.00	64.00	13.70	100.00	64.88	4.00	63.87	92.59%	0.79
20	123.01	0.59	17.00	64.00	13.80	100.00	65.26	3.20	62.97	81.39%	0.70
30	113.90	0.59	17.50	62.00	14.00	99.00	65.49	3.00	63.24	67.96%	0.58
40	107.83	0.61	17.50	69.00	14.10	98.00	65.97	2.50	65.29	59.01%	0.50
51	100.25	0.62	18.00	62.00	14.30	98.00	66.44	2.50	65.53	47.83%	0.40
60	96.45	0.64	18.00	68.00	14.50	99.00	66.51	3.00	64.81	42.23%	0.35
75	91.14	0.64	18.00	69.00	14.50	98.00	66.66	2.80	65.57	34.40%	0.29
90	86.59	0.64	18.00	72.00	14.60	99.00	64.87	3.50	63.74	27.69%	0.23
105	83.55	0.64	18.00	72.00	14.70	99.00	65.31	2.40	63.11	23.20%	0.19
120	81.28	0.66	18.00	73.00	14.80	99.00	66.21	2.20	65.20	19.86%	0.16
150	78.24	0.64	18.50	84.00	14.80	99.00	66.18	2.90	65.29	15.37%	0.12
181	75.96	0.67	19.50	78.00	14.80	98.00	66.19	2.80	64.31	12.01%	0.09
240	74.45	0.67	22.50	58.00	14.90	99.00	66.43	2.90	63.98	9.79%	0.07
300	73.69	0.67	25.50	52.00	15.00	99.00	66.30	3.00	64.28	8.66%	0.06
483	72.17	0.68	26.50	47.00	15.10	99.00	66.48	2.50	65.30	6.42%	0.04
705	72.09	0.66	22.00	55.00	14.70	100.00	65.30	3.50	62.98	6.31%	0.04
960	71.41	0.61	20.00	62.00	14.50	100.00	64.01	4.00	63.24	5.30%	0.03

APPENDIX 4

Table A4.1
Mean constants determined for the models

Drying air conditions		Average Initial Moisture Content % d.b	Average Equilibrium Moisture Content % d.b	K Values determined from the drying data								
Dry Bulb Temp oC	Relative Humidity											
T	%Rh	Mo	Me	K1	K2	K3	K4	K6	K7	K8	K9	K10
31	31.1	98%	5.9%	0.79	0.0011	0.0143	0.639	0.0019	0.000614	0.9051	0.09	0.0049
38	24.4	85%	5.0%	0.79	0.0022	0.0017	1.0066	0.0022	0.001238	0.8765	0.01	0.1135
46	13.4	87%	3.5%	0.77	0.0045	0.0076	0.9279	0.0051	0.003993	0.7155	0.012	0.2725
50	12.8	91%	3.3%	0.795	0.0051	0.007	0.9728	0.0061	0.003313	0.7345	0.02	0.2455
66	3.2	91%	1.8%	0.785	0.0126	0.0157	0.9797	0.0099	0.011517	0.432	0.02	0.548

APPENDIX 5

Table A5.1

Comparison of experimental moisture ratios and those predicted using the diffusion model for parchment coffee beans dried at an average plenum temperature of 31 °C and relative humidity of 31%. This includes the analysis of variance.

ANOVA of the Diffusion model

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Diffusion
0	1.00	0.99
10	0.90	0.98
20	0.88	0.97
30	0.87	0.96
40	0.85	0.95
50	0.84	0.94
60	0.84	0.93
80	0.82	0.91
100	0.80	0.89
120	0.79	0.88
150	0.76	0.85
180	0.74	0.83
240	0.70	0.78
300	0.67	0.74
360	0.64	0.70
1080	0.27	0.40
1440	0.20	0.31
1800	0.13	0.24
2160	0.13	0.19
2430	0.07	0.16

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	20	12.89	0.64	0.09
Diffusion	20	14.60	0.73	0.09

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.07	1	0.07	0.84	0.37	4.10
Within Groups	3.34	38	0.09			
Total	3.41	39				

Table A5.2
Comparison of experimental moisture ratios and those predicted using the Page equation for parchment coffee beans dried at an average plenum temperature of 31 °C and relative humidity of 31%. This includes the analysis of variance.

ANOVA of the Page Equation

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Page Equation
0	1.00	1.00
10	0.90	0.95
20	0.88	0.91
30	0.87	0.89
40	0.85	0.86
50	0.84	0.84
60	0.84	0.81
80	0.82	0.77
100	0.80	0.74
120	0.79	0.71
150	0.76	0.66
180	0.74	0.62
240	0.70	0.55
300	0.67	0.50
360	0.64	0.45
1080	0.27	0.16
1440	0.20	0.10
1800	0.13	0.06
2160	0.13	0.04
2430	0.07	0.03

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	20	12.89	0.64	0.09
Page Equation	20	11.65	0.58	0.11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.04	1	0.04	0.38	0.54	4.10
Within Groups	3.81	38	0.10			
Total	3.85	39				

…e A5.3

…parison of experimental moisture ratios and those predicted using the model …eloped for parchment coffee beans dried at an average plenum temperature of 31 °C …d relative humidity of 31%. This includes the analysis of variance.

ANOVA of the proposed model developed

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Model developed
0	1.00	1.00
10	0.90	0.99
20	0.88	0.98
30	0.87	0.96
40	0.85	0.95
50	0.84	0.94
60	0.84	0.93
80	0.82	0.91
100	0.80	0.88
120	0.79	0.86
150	0.76	0.83
180	0.74	0.80
240	0.70	0.74
300	0.67	0.69
360	0.64	0.64
1080	0.27	0.29
1440	0.20	0.20
1800	0.13	0.15
2160	0.13	0.12
2430	0.07	0.11

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	20	12.89	0.64	0.09
Model developed	20	13.97	0.70	0.11

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.03	1	0.03	0.30	0.59	4.10
Within Groups	3.75	38	0.10			
Total	3.78	39				

APPENDIX 6

Table A6.1

Comparison of experimental moisture ratios and those predicted using the diffusion model for parchment coffee beans dried at an average plenum temperature of 38 °C and relative humidity of 24%. This includes the analysis of variance.

ANOVA of the Diffusion model

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Diffusion
0	1.00	0.99
10	0.97	0.95
20	0.96	0.91
30	0.95	0.87
45	0.94	0.82
60	0.92	0.78
120	0.87	0.63
180	0.81	0.52
240	0.74	0.43
310	0.66	0.35
360	0.61	0.31
420	0.54	0.26
480	0.47	0.22
540	0.41	0.19
600	0.36	0.16
720	0.29	0.12
900	0.21	0.07
1296	0.11	0.03
1320	0.11	0.02
1513	0.09	0.01
1680	0.08	0.01
2110	0.06	0.00

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	22	12.17	0.55	0.12
Diffusion	22	8.66	0.39	0.12

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.28	1	0.28	2.29	0.14	4.07
Within Groups	5.13	42	0.12			
Total	5.41	43				

Table A6.2

Comparison of experimental moisture ratios and those predicted using the Page equation for parchment coffee beans dried at an average plenum temperature of 38 °C and relative humidity of 24%. This includes the analysis of variance.

ANOVA of the Page Equation

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Page Equation
0	1.00	1.00
10	0.97	0.94
20	0.96	0.90
30	0.95	0.86
45	0.94	0.81
60	0.92	0.76
120	0.87	0.62
180	0.81	0.51
240	0.74	0.43
310	0.66	0.35
360	0.61	0.30
420	0.54	0.26
480	0.47	0.22
540	0.41	0.19
600	0.36	0.16
720	0.29	0.12
900	0.21	0.08
1296	0.11	0.03
1320	0.11	0.03
1513	0.09	0.02
1680	0.08	0.01
2110	0.06	0.01

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	22	12.17	0.55	0.12
Page Equation	22	8.59	0.39	0.12

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.29	1	0.29	2.41	0.13	4.07
Within Groups	5.07	42	0.12			
Total	5.36	43				

Table A6.3

Comparison of experimental moisture ratios and those predicted using the proposed model for parchment coffee beans dried at an average plenum temperature of 38°C and relative humidity of 24%. This includes the analysis of variance.

ANOVA of the proposed model developed

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Proposed Model
0	1.00	1.00
10	0.97	0.96
20	0.96	0.92
30	0.95	0.89
45	0.94	0.84
60	0.92	0.80
120	0.87	0.65
180	0.81	0.53
240	0.74	0.44
310	0.66	0.36
360	0.61	0.31
420	0.54	0.26
480	0.47	0.22
540	0.41	0.18
600	0.36	0.15
720	0.29	0.11
900	0.21	0.06
1296	0.11	0.02
1320	0.11	0.02
1513	0.09	0.01
1680	0.08	0.01
2110	0.06	0.00

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	22	12.17	0.55	0.12
Proposed Model	22	8.74	0.40	0.13

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.27	1	0.27	2.13	0.15	4.07
Within Groups	5.28	42	0.13			
Total	5.54	43				

APPENDIX 7

.1

-on of experimental moisture ratios and those predicted using the diffusion r parchment coffee beans dried at an average plenum temperature of 46 °C and umidity of 13.4%. This includes the analysis of variance.

ANOVA of the Diffusion model

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Diffusion
0	1.00	0.96
20	0.87	0.85
30	0.84	0.81
40	0.81	0.76
50	0.77	0.72
60	0.73	0.68
70	0.70	0.65
80	0.66	0.62
90	0.63	0.59
100	0.59	0.56
110	0.56	0.54
120	0.52	0.51
140	0.46	0.47
160	0.42	0.43
180	0.37	0.39
210	0.31	0.35
240	0.31	0.31
300	0.22	0.24
840	0.03	0.03
960	0.03	0.02
1080	0.02	0.01

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	21	10.89	0.52	0.08
Diffusion	21	10.49	0.50	0.07

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00	1	0.00	0.05	0.83	4.08
Within Groups	3.13	40	0.08			
Total	3.13	41				

...A7.2

...arison of experimental moisture ratios and those predicted using the Page equation ...rchment coffee beans dried at an average plenum temperature of 46 °C and relative ...dity of 13.4%. This includes the analysis of variance.

ANOVA of the Page Equation

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Page Equation
0	1.00	1.00
20	0.87	0.91
30	0.84	0.87
40	0.81	0.83
50	0.77	0.79
60	0.73	0.75
70	0.70	0.72
80	0.66	0.69
90	0.63	0.66
100	0.59	0.63
110	0.56	0.60
120	0.52	0.57
140	0.46	0.52
160	0.42	0.48
180	0.37	0.44
210	0.31	0.38
240	0.31	0.33
300	0.22	0.26
840	0.03	0.02
960	0.03	0.01
1080	0.02	0.01

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	21	10.89	0.52	0.08
Page Equation	21	11.46	0.55	0.09

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01	1	0.01	0.09	0.76	4.08
Within Groups	3.36	40	0.08			
Total	3.37	41				

A7.3

...arison of experimental moisture ratios and those predicted using the model ...ped for parchment coffee beans dried at an average plenum temperature of 46 °C ...elative humidity of 13.4%. This includes the analysis of variance.

ANOVA of the proposed model developed

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Model developed
0	1.00	1.00
20	0.87	0.85
30	0.84	0.78
40	0.81	0.73
50	0.77	0.68
60	0.73	0.63
70	0.70	0.59
80	0.66	0.56
90	0.63	0.52
100	0.59	0.49
110	0.56	0.46
120	0.52	0.44
140	0.46	0.39
160	0.42	0.35
180	0.37	0.31
210	0.31	0.27
240	0.31	0.23
300	0.22	0.17
840	0.03	0.01
960	0.03	0.01
1080	0.02	0.00

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	21	10.89	0.52	0.08
Model developed	21	9.48	0.45	0.08

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.05	1	0.05	0.58	0.45	4.08
Within Groups	3.21	40	0.08			
Total	3.26	41				

APPENDIX 8

e A8.1

arison of experimental moisture ratios and those predicted using the diffusion
el for parchment coffee beans dried at an average plenum temperature of 50 °C and
ve humidity of 12.8%. This includes the analysis of variance.

ANOVA of the Diffusion model

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Diffusion
0	1.00	0.99
10	0.93	0.90
20	0.88	0.83
30	0.84	0.76
40	0.80	0.70
50	0.76	0.65
60	0.73	0.60
80	0.65	0.52
100	0.58	0.45
120	0.51	0.40
140	0.44	0.35
165	0.37	0.30
180	0.33	0.27
200	0.28	0.24
220	0.25	0.21
240	0.22	0.19
270	0.18	0.16
300	0.15	0.13
330	0.12	0.11
360	0.11	0.09
423	0.08	0.06
600	0.07	0.02
786	0.04	0.01
815	0.04	0.01

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	24	10.38	0.43	0.10
Diffusion	24	8.95	0.37	0.09

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.04	1	0.04	0.43	0.51	4.05
Within Groups	4.49	46	0.10			
Total	4.53	47				

e A8.2

...arison of experimental moisture ratios and those predicted using the Page equation ...rchment coffee beans dried at an average plenum temperature of 50 °C and relative ...dity of 12.8%. This includes the analysis of variance.

ANOVA of the Page Equation

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Page Equation
0	1.00	1.00
10	0.93	0.93
20	0.88	0.86
30	0.84	0.80
40	0.80	0.75
50	0.76	0.70
60	0.73	0.65
80	0.65	0.57
100	0.58	0.50
120	0.51	0.44
140	0.44	0.38
165	0.37	0.33
180	0.33	0.30
200	0.28	0.26
220	0.25	0.23
240	0.22	0.20
270	0.18	0.17
300	0.15	0.14
330	0.12	0.11
360	0.11	0.10
423	0.08	0.06
600	0.07	0.02
786	0.04	0.01
815	0.04	0.01

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	24	10.38	0.43	0.10
Page Equation	24	9.51	0.40	0.10

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.02	1	0.02	0.16	0.70	4.05
Within Groups	4.65	46	0.10			
Total	4.67	47				

e A8.3

...arison of experimental moisture ratios and those predicted using the model ...oped for parchment coffee beans dried at an average plenum temperature of 50 °C ... relative humidity of 12.8%. This includes the analysis of variance.

ANOVA of the proposed model developed

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Model developed
0	1.00	1.00
10	0.93	0.90
20	0.88	0.81
30	0.84	0.73
40	0.80	0.67
50	0.76	0.61
60	0.73	0.56
80	0.65	0.48
100	0.58	0.41
120	0.51	0.36
140	0.44	0.32
165	0.37	0.27
180	0.33	0.24
200	0.28	0.22
220	0.25	0.19
240	0.22	0.17
270	0.18	0.14
300	0.15	0.12
330	0.12	0.10
360	0.11	0.08
423	0.08	0.06
600	0.07	0.02
786	0.04	0.01
815	0.04	0.01

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	24	10.38	0.43	0.10
Model developed	24	8.48	0.35	0.09

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.08	1	0.08	0.78	0.38	4.05
Within Groups	4.43	46	0.10			
Total	4.51	47				

APPENDIX 9

;A9.1

arison of experimental moisture ratios and those predicted using the diffusion for parchment coffee beans dried at an average plenum temperature of 66 °C elative humidity of 3%. This includes the analysis of variance.

ANOVA of the Diffusion model

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Diffusion
0	1.00	0.98
5	0.92	0.89
10	0.87	0.81
15	0.82	0.75
20	0.77	0.69
25	0.72	0.64
30	0.68	0.59
40	0.59	0.51
50	0.51	0.44
60	0.43	0.39
75	0.33	0.32
90	0.26	0.26
105	0.20	0.22
120	0.17	0.18
150	0.12	0.12
180	0.10	0.09
302	0.06	0.02

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	17	8.53	0.50	0.10
Diffusion	17	7.89	0.46	0.09

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.01	1	0.01	0.13	0.72	4.15
Within Groups	3.03	32	0.09			
Total	3.04	33				

9.2

...son of experimental moisture ratios and those predicted using the Page equation ...ment coffee beans dried at an average plenum temperature of 66 °C and relative ... of 3%. This includes the analysis of variance.

ANOVA of the Page Equation

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Page Equation
-	1.00	1.00
5.00	0.92	0.93
10.00	0.87	0.86
15.00	0.82	0.80
20.00	0.77	0.75
25.00	0.72	0.69
30.00	0.68	0.64
40.00	0.59	0.56
50.00	0.51	0.48
60.00	0.43	0.41
75.00	0.33	0.33
90.00	0.26	0.26
105.00	0.20	0.21
120.00	0.17	0.17
150.00	0.12	0.11
180.00	0.10	0.07
302.00	0.06	0.01

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	17	8.53	0.50	0.10
Page Equation	17	8.30	0.49	0.10

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00	1	0.00	0.02	0.90	4.15
Within Groups	3.26	32	0.10			
Total	3.26	33				

e A9.3

parison of experimental moisture ratios and those predicted using the model oped for parchment coffee beans dried at an average plenum temperature of 66 °C elative humidity of 3%. This includes the analysis of variance.

ANOVA of the proposed model developed

Time (mins)	Moisture Ratio - Experimental	Moisture Ratio - Model developed
0	1.00	1.00
5	0.92	0.88
10	0.87	0.78
15	0.82	0.70
20	0.77	0.63
25	0.72	0.56
30	0.68	0.51
40	0.59	0.43
50	0.51	0.36
60	0.43	0.31
75	0.33	0.25
90	0.26	0.21
105	0.20	0.17
120	0.17	0.15
150	0.12	0.11
180	0.10	0.08
300	0.06	0.02

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Experimental	17	8.53	0.50	0.10
Model developed	17	7.15	0.42	0.09

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.06	1	0.06	0.59	0.45	4.15
Within Groups	3.04	32	0.09			
Total	3.10	33				