SOLAR DRYING OF COCOA BEANS
(*Theobroma cacao*)
IN ST. LUCIA

by

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ABSTRACT

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Solar Drying of Cocoa Beans (*Theobroma cacao*) in St. Lucia.

An indirectly heated solar drier fitted with a flat plate collector and a directly heated solar drier were compared with open air sun drying of cocoa beans under field conditions in St.Lucia. Sun drying was conducted on two surfaces, perforated steel and non perforated wood. The methods were examined for the ability to adequately dry fermented beans and effect on quality. Loading rates of 13.5, 26.9 and 40.4 kg /m^2 were examined.

Temperature increases of 15 ^{o}C and 20 ^{o}C above ambient were achieved in the indirect and direct drier, respectively. The solar driers were more efficient than sun drying units at removing moisture throughout at loading rates of 26.9 and 40.4 kg /m^2 but only in the initial stages at 13.5 kg. External mould development was therefore reduced. Open air sun drying on the wooden surface proved more effective in the final stages at 13.5 kg /m^2.

The dried beans were of similar internal quality despite faster drying in the driers. The various drying methods and loading rates produced beans of similar pH while only loading rates affected titratable acidity differently. The direct solar drier achieved lower final moisture levels at high loads and was the cheaper alternative.

RÉSUMÉ

Anthony Bonaparte M.Sc. (Agric. Eng.)

Séchage solaire de fèves de cacao (*Theobroma cacao*) à Ste-Lucie.

Un séchoir solaire équipé d'un collecteur solaire plat à chauffage indirect, de même qu'un séchoir solaire à chauffage direct ont été comparés avec le séchage solaire à aire ouverte pour le séchage de fèves de cacao dans des conditions climatiques retrouvées à Ste-Lucie. Le séchage solaire à aire ouverte a été effectué sur deux types de surface soit de l'acier inoxydable perforé de même que du bois plein. Ces méthodes de séchage ont été testées pour leur capacité à sécher efficacement des fèves de cacao fermentées de qualité. Des charges de 13.5, 26.9 et 40.4 kg/m^2 ont été testées.

Des augmentations de 15° et 20°C au dessus de la température ambiante ont été obtenues avec les séchoirs solaires par chauffage indirect et direct respectivement. Une efficacité accrue du séchage a été obtenue par les séchoirs à chauffage indirect et direct, et ce durant toute la période de séchage avec des charges de 26.9 et 40.4 kg/m^2, tandis qu'avec une charge de 13.5 kg/m^2 l'augmentation de l'efficacité n'a été obtenue qu'aux premiers stades du séchage. Il y a donc eu une diminution de l'incidence de la moisissure à la surface des fèves. Le séchage solaire à aire ouverte sur une surface de bois s'est avéré être plus efficace dans les derniers stade du séchage avec une charge de 13.5 kg/m^2.

Les fèves de cacao séchées de diverses manières ont obtenu des résultats semblables lors de l'évaluation de leur qualité. Le séchoir solaire par chauffage direct a produit des fèves de cacao avec le plus bas taux d'humidité, même à charge élevée, tout en étant la méthode la plus économique.

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List of Figures

List of Tables

List of Symbols

^{o}C	degree celsius
cm	centimetre
g	gram
J	joule
kg	kilogram
m^2	square meter
meq/ 100 g	milli equivalents per 100 gram
nm	nanometer
ml	milli litres
w.b	moisture on a wet basis
RH	relative humidity
TA	titratable acidity
kg/m^2	kilograms per square meter
L-a-b	Hunter colour index

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 General

The cocoa (*Theobroma cacoa*) has long been cultivated in St.Lucia and the other Windward Islands for local consumption and export. Its importance however waned as the economic value and cultivation of bananas - the major export crop - improved. Banana exports of St.Lucia grew to record levels in the mid 1970's and the revenues earned kept agriculture as the single most important sector of the economy. By the late 1980's however the long term forecasts for bananas in traditional markets were bleak.

To buffer the effects that the expected decline of bananas might have on their collective economy, the Windward Islands embarked on a crop diversification programme.

One aspect of the plan was the rehabilitation of existing cocoa fields and the expansion of cocoa production. Under a project implemented by the Pan American Development Foundation with funding from the United States Agency For International Development (USAID) the cocoa effort gained momentum. Communication material for extension officers as well as planting material for farmers were produced (Hess 1990).

Of the Windward Islands, cocoa production was perhaps the least important in St.Lucia, where previously it was a major crop. This country produced approximately 50% of the Windward Islands banana output in the period 1987-1993.

Currently most of St. Lucia's cocoa is produced on relatively large estates where it is inter-cropped with coconuts. Since the end of the above mentioned project the acreage of cocoa in St. Lucia has increased, encouraged by the promise of good marketing prospects and the expected further decline of bananas.

A major drawback to previous agricultural diversification efforts in St. Lucia has been inadequate preparedness for the post-harvest handling and marketing of produce resulting from the various production drives. Concurrently, the expectation for new production enterprises is influenced by the banana experience - i.e. farmers expect well developed post-harvest and marketing arrangements for any new enterprise they are encouraged to enter. Unfortunately no new enterprise introduced to date has offered the comprehensive input supply and marketing arrangements existing in the banana industry. Consequently commercial crop diversification in St.Lucia has remained precariously rudimentary as new enterprises have not survived.

Cocoa has the added disadvantage of a relatively long gestation period. Despite these problems, acreage under cocoa has increased with a number of small farmers attracted. It is imperative that steps are taken to ensure proper post harvest handling of the increased production and the delivery of product of acceptable quality. This objective shall be the impetus for the increased production necessary for the economic viability of post harvest operations in cocoa.

1.2 Aspects of Cocoa Handling in St. Lucia

In commercial cocoa production, ripe cocoa pods are harvested and are cracked by the following day. The beans are stripped from the placenta and placed in large boxes measuring approximately 1.25m x 1m x 1m and covered with banana leaves. This is the "box fermentation" technique (Wood and Lass 1985, Hess 1990). Fermentation is allowed to continue for a period of 6-8 days but more commonly 8 days. During that time the bean mass is mixed either in place or by transfer to adjacent boxes using a wooden shovel. At the end of the fermentation the beans are spread on a flat surface and fully exposed to sunshine under ambient conditions. The layer of beans to be dried is very often thin but actual thickness depends on the space available.

The Union Vale Estate, the source of beans for this experiment, is seen as the model for cocoa producers in St.Lucia. This is due to their long experience in cocoa production and the consistent fermentation and drying quality. A strict eight day fermentation period is observed using the box fermentation technique.

All beans exported from St.Lucia are handled by The St. Lucia Agriculturalist Association. This farmer organization undertakes inspection and accumulation of stock, and the exportation to chocolate manufacturers.

1.3 Importance of the Study

The importance of this study lies in the fact that it takes place at an early stage of development of an enterprise and adoption of an appropriate technology is perhaps more likely. In this regard the field approach provides an opportunity for demonstration and immediate application. The study gives an idea of the quality of cocoa in St.Lucia in general and points to areas of improvement. The rapport developed with individuals involved in the cocoa industry may facilitate continuing development work in this area.

Pre-processing of primary products increases the value of products leaving the farm gate. Post harvest losses are reduced, thereby total farm income is likely to increase. The quality of small farmer cocoa is currently highly variable and rejection at the exporters warehouse is common. This is mainly due to poor drying. Success with solar driers could demonstrate the use of a low cost technology which could stabilize the value and reduce the costs associated with small farmer cocoa production. The benefit may be extended to other products where the value-added may also be increased because of product diversification facilitated by drying.

The possibility of drying cocoa using low cost artificial driers is a challenging alternative due to the lack of a cheap fuel source. The most available cheap source of cheap fuel on farms is perhaps coconut husk and shells. Husk (coir) is not utilized at all, as it is a low quality fuel. A percentage of shells is used for firing copra kilns but they are likely to be very corrosive on metal flues of artificial driers. The coconut industry is itself in decline and this may impact the availability of shells. Procuring fuel is an added labour requirement and presently, an aversion to haulage type labour makes farm labour very expensive in St. Lucia. Therefore a drying system reliant on wood or coir supply is unlikely to be sustainable in this socioeconomic climate.

1.4 Objectives

This study aimed primarily at determining whether solar drying technology can be used as an improved drying method over open air sun drying under conditions existing in St.Lucia. Thus the capacity to dry fermented cocoa to safe moisture levels under field conditions was examined.

Specifically the study aimed to :-

(1) Assess the performance of solar driers for the drying of fermented cocoa under field conditions.

(2) Compare the quality of cocoa beans dried in the solar driers to that dried by the open sun drying method.

1.5 Scope

This study was conducted under the Sustainable Hillside Farming Systems Project which sought to promote the use of sustainable agricultural practices in St.Lucia.

Fermented beans were obtained from Union Vale Estates which gave the assurance of a consistent supply of uniformly fermented beans. The study was restricted to drying and examined the solar drying of fermented cocoa beans under the variability of weather, humidity, temperature and air velocity conditions existing under field conditions.

Data were examined for a single harvesting season and therefore the inferences which can be drawn are restricted by how favourable the drying conditions were deemed to be. A drought in the early part of 1994 delayed the harvesting season by approximately four months and the worst of the rainy season was over by the time of drying. Some of the drying occurred under rainy conditions but these adverse conditions were generally not available for the higher loading rates. In addition the number of drying runs was limited by the length of the season.

The drying runs were exposed to variable conditions. The wet bulb temperature of the air inside the driers was not measured. Thus the effects of precise physical parameters like temperature, wind speed and humidity could not be isolated.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Drying, the removal of volatiles, generally water, to yield a stable product (Menon and Mujumdar 1987), is perhaps the most widely used method of long term preservation of food products worldwide. Meats, fruits, timber, cereals, pulses and oilseeds are amongst products commonly dried in various parts of the world. Drying is required for long term preservation thereby extending availability. It facilitates processing into various forms (Sokhansanj and Jayas 1987), therefore widening the demand for the primary product. In addition, decreased moisture reduces bulk and lowers transportation costs.

Since every operation in the production chain utilizes resources and adds to cost, it is necessary that the drying process, as it relates to a specific product, be clearly understood. This knowledge helps process optimization for a given set of drying conditions. The drying process involves both heat and mass transfer. The moisture to be removed may exist both on the surface and within the product, and drying is normally examined in terms of moisture removal at these two levels (Garg and Bhargava 1989; Menon and Mujumdar 1987).

Lower moisture levels at the surface is the force drawing moisture from within the product. The extent to which internal moisture sources feed surface moisture extraction depends on the nature of the product being dried (Keey 1978; Sodha et al. 1987). Outward moisture migration is retarded by the product's attraction for water molecules. The extent of this attraction, and hence the internal resistance to moisture loss, depends on the hygroscopic and colloidal properties and the size of the pores which govern the capillary movement of fluid (Karel et al. 1975; Garg and Bhargava 1989). The more moisture which has been removed, the stronger is the attraction to that remaining. Thus drying is itself influenced by the amount of drying that has already taken place (Keey 1978).

Moisture transfer to the surface of the drying solid occurs through various mechanisms including diffusion, capillarity, and internal pressures set up by shrinkage during drying - these factors possibly act in combination (Menon and Mujumdar 1987). The extent and nature of these processes and their efficiency in transferring moisture outward depends on internal heat transfer, the degree of porosity and hygroscopicity of the material and the nature of the solid moisture boundary (Keey 1978; Menon and Mujumdar 1987). Consequently, though there may be general similarities in drying behaviour, each product under a particular set of conditions may be expected to be unique (Savracos and Charm 1962; Sodha et al. 1987).

Moisture loss from the product surface depends on drying air conditions while surface moisture conditions influence the mass transfer from the inside to the surface. The removal of moisture at the product-air interface depends on the temperatures of the product and drying medium, air humidity, air flow rates and volume pressure conditions, and the amount of product surface exposed to the drying medium (Menon and Mujumdar 1987; Jayas 1987).

The effects of temperature and humidity of drying air on moisture removal are interrelated. Increases in air temperature effectively lowers the relative humidity of a given volume of air, and thereby increases its capacity to hold moisture. Higher air temperature adds the possibility of heat transfer to the product. When the latter occurs, the vapour pressure within the product increases and the evaporation of moisture from the surface is facilitated (Menon and Mujumdar 1987; Brooker et al. 1992).

As moisture evaporation continues and the moisture content of a fixed volume of air increases, its capacity to accommodate more moisture decreases. The continued extraction of surface moisture under the above mentioned conditions is driven by the maintenance of a water vapour deficit between the product surface and the drying air (Keey 1978). This dictates the removal of saturated air in the immediate vicinity of the product, replacing it with drier air of higher moisture carrying capacity. Thus under a given set of temperature and humidity conditions the amount of moisture removed depends on the volume of air brought into contact with the product. Once evaporation of moisture is not limiting, maintaining or increasing air flow rates ensures continuation of the drying process.

Agricultural products are hygroscopic. For a particular set of physical conditions hygroscopic products will lose moisture to, or gain moisture from the atmosphere until a state of equilibrium is achieved. Vegetable substances during drying tend towards a residual moisture content at which the vapour pressure of the adsorbed moisture is equal to the vapour pressure of the surroundings (Keey 1978). The equilibrium level of moisture achieved in the product depends on the temperature (Brooker et al. 1992; Sodha et al. 1987; Karel et al. 1975). The variation of the equilibrium with small changes in temperature however is small.

Keey (1978) noted that changes in the equilibrium moisture content for temperature changes of up to ten degrees celsius are usually ignored. The significance of this product behaviour is the limit it sets on moisture removal at a fixed set of temperature and humidity conditions. At a given dry bulb temperature and humidity the rate of moisture loss is in proportion to the moisture content of the material and the characteristic moisture content at equilibrium with the air (Hukill 1947).

Keey (1978) noted that for potatoes at a relative humidity of 50% there was a 0.75% fall in moisture content for each 1 ^{o}C rise in temperature. Thus the equilibrium moisture level for a product at fixed relative humidity is higher at lower temperature.

2.1.1 Drying rates and patterns

The rate at which a product dries is an important criterion in selecting a drying method. For high moisture products, when moisture content at successive time intervals is plotted against time, the pattern revealed is a period of constant drying and one of decreasing drying rate (Booker et al. 1992).

In the constant period the rate of moisture loss as well as product surface temperature tend to remain constant at a temperature which approximates the wet bulb temperature of the drying air (Garg and Bhargava 1989).

The rate of moisture loss is given by

$$dM/dt = [A^{*}h_m / Rv\ T_{abs}](P_{Tb} - T_{Ti})$$

and $$dM/dt = [\ A^{*}h_c / L\ ]\ (Ti - Tb)$$

where

M - moisture content

A - surface area of the substance

h_m - mass transfer coefficient

h_c - convective heat transfer coefficient

P_{Ti} - vapour pressure of water at air temperature

Tb - wet bulb temperature

Ti - air temperature

P_{Tb} - vapour pressure of water at surface of the product at wet bulb temperature

Rv - gas constant for water vapour.

T_{abs} - absolute temperature

L - latent heat of vaporization

Since h_m, h_c, L and A are considered constant for the drying process the variables driving moisture loss are (P_{Tb} - T_{Ti}) and (Ti - Tb) (Garg and Bhargava 1989).

The limit to constant rate drying occurs when the internal resistances to moisture movement become significant enough to limit its availability for evaporation at the product surface (Keey 1978; Menon and Mujumdar 1987). Thus the "falling rate" drying period sets in.

The influence of physical factors on the rate of drying during the two phases have been examined for various crops. Westerman et al. (1973)

examined the effects of temperature and relative humidity in the range of 10 - 85% on the drying rate of corn. For the same temperature of drying air, drying rate was found to decrease with an increase in relative humidity. Conversely an increase in temperature at approximately constant humidity increases the drying rate. Similar results with respect to temperature were reported for sugar beet (Mitchell and Potts 1958), soy beans, and nutmegs (Mc Gaw 1979).

2.1.2 Air flow rates

Removal of moisture from the drying product environment is effected by air change. Mitchell and Potts (1958a) found a proportionate increase in moisture loss with increased air flow. Ede (1958) noted that at low moisture contents, air flow and air velocity had no influence on the rate of drying. Shakya and Flink (1986) reported increased drying rates of potato when air flow rates were increased but this effect declined as the product moisture ratio decreased.

In the initial stages of drying when the surfaces of cocoa beans are saturated, the rate of moisture loss increases with increased air flow (Bravo and Mc Gaw 1974). There is a limit to which increased air flow rate will increase drying rate and this varies with the product moisture content and the air flow rate itself. Thus increasing air flow above nominal rates of 0.17 m/s had no effect below 35% moisture (w.b) while air flows below 0.01 m/s controls drying rate down to 11% moisture content (McDonald and Freire 1982). The experience is that overall, once surface moisture has been dried, variation in air flow rates is insignificant in the removal of moisture of agricultural products including cocoa (Mitchell and Potts 1958; Wood 1961).

The failure of air flow rate to influence drying rate at low moisture levels is also an indication that at low internal moisture, internal forces control moisture movement to the surface. At this stage, only an increase in dry bulb temperature was found to increase drying rate (Ede 1958). Rapid rates of drying of cocoa have been achieved by increased temperatures in the latter stages of drying (Bravo and Mc Gaw 1974; McDonald and Freire 1981). Air flow replaces saturated air with air of lower vapour pressure and maintains the driving force ($P_{ti} - P_{tb}$). As the product dries at constant temperature ($P_{ti} - P_{tb}$) decreases and hence moisture extraction power decreases. At that stage increases in temperature will increase the driving force ($P_{ti} - P_{tb}$).

The actual extent to which physical factors can be controlled to improve the efficiency of drying depends on available technology and available methods to enhance moisture loss. Variables which can be manipulated include the amount of surface area exposed to the drying air, the volume of air available for carrying moisture, the temperature, and by extension, the relative humidity. Limits to manipulation are dictated by product behaviour and the extent to which operating conditions affect final product quality (Bruin and Luyben 1980; Keey 1978).

2.1.3 Drying and product quality

High temperatures increase drying rates but the temperature which can be employed is limited by potential heat damage to product quality.

Nutrients in food products may become denatured and producer seed may lose their viability. High temperatures tend to damage the surface of the product thereby impeding further moisture loss, a phenomenon known as case hardening (Van Arsdel 1973).

Harvey et al. (1985) observed improved quality of sorrel when dried at slow rates using low temperatures. Mc Gaw (1979) found drying at temperatures above 40 ^{o}C detrimental to nutmeg quality. Timber when dried at rapid rates develop stresses due to differential moisture levels between the surface and the interior. As a result the product warps and its quality is ruined (Keey 1978). Similar differential stresses result in cracking of maize, reducing the assessed quality (Brooker et al. 1992). In general, high temperatures during drying may be detrimental to the quality of primary agricultural products and drying temperature must be chosen with care. On the other hand, low temperature is synonymous with low drying capacity and higher cost under given humidity ratio conditions.

2.1.4 Drying and cocoa bean quality

Drying practices influence market quality, the development of flavour, final bean acidity, mouldiness and the presence of off-flavour in the beans. Under adverse weather conditions, the slow rate of sun drying results in mouldiness and the development of off-flavour (Ghosh and Cunha 1975). The beans are also more likely to be adulterated by dust and other debris during sun drying.

Artificially dried beans are inferior to sun dried beans in chocolate flavour development (Quesnel and Jugmohunsingh 1970; Shelton 1967). Artificial drying increases brittleness and produces a high proportion of cracked and broken beans (Urquhart 1961; Ghosh 1972; 1973) and beans with a wrinkled appearance (Bravo and Mc Gaw 1974).

The causes of the inferior quality of artificially dried beans have been investigated by many authors, with an emphasis on reducing acidity. DeVos (1956) (as cited by Quesnel and Jugmohunsingh 1970), found that under certain conditions temperatures between 60 ^{o}C to 90 ^{o}C gave unacceptable product. Chocolate flavour development, which begins during fermentation, continues during drying and the mediating enzymes are destroyed by temperature over 60 ^{o}C (Quesnel and Jugmohunhsingh 1970).

Bravo and Mc Gaw (1974) found bean testas to dry more quickly compared to the nibs at high temperatures. At the high temperatures used in artificial driers, rapid drying of the testa and case hardening (Ghosh 1972; Urquhart 1961) prevents outward migration of acetic acid from the beans, (Jinap et al. 1994). Although case hardening is mentioned in the literature and freshly fermented beans are covered in hot weather during sun drying to prevent it (Hess 1990), there is no documented proof that it occurs in cocoa (Wood and Lass 1985).

The literature points to the physical loss of acidity through outward migration (Jinap et al. 1994), but this may not be the most important process. Laiu (1978) provided much evidence that the reduction of acidity during drying is mainly an oxidation process brought about by enzymes. Consequently factors which inhibit enzyme activity, eg. high temperature and reduced moisture, contribute to acid retention. Thus the rate of moisture removal and the temperature employed should be balanced so that adequate acid removal and flavour development are both assured.

Jinap et al. (1994) found the pH of sun-dried beans not significantly higher than that of beans that were air-blown for 72 hours and subsequently heated at 60 ^{o}C. But both these categories were significantly less acid than beans which were oven dried at 60 ^{o}C. In this same study, the pH of mould-affected, shade-dried beans was higher than that of sun-dried beans. Despite the higher pH the mouldy beans had higher total volatile acidity than sun-dried or air-blown beans in addition to an objectionable flavour. Beans which were oven-dried at 60 ^{o}C had a significantly higher total volatile acidity than all the other categories in that experiment.

The practical consensus is that temperatures beyond 60 ^{o}C generally impair cocoa quality. Having to operate below 60 ^{o}C makes the use of artificial driers thermally inefficient (Ghosh 1973), while conversely, the problems with sun drying makes artificial drying economical under the circumstances existing in several countries.

Thus drying practice may influence the development of flavour, bean acidity, mouldiness and the presence of off-flavours (Jinap and Dimick 1994). Acidity of cocoa liquor as measured by pH was found to be positively related to acidity scores obtained from taste tests (Baigrie and Rumbelow 1987). Several studies have found that the main factor in acidity of cocoa is volatile acidity of which acetic acid forms 95%. Rapid drying at high temperature is known to lower the pH of the dried beans (Shelton 1967). The relatively high acidity of beans from Malaysia and Brazil is attributed to the high proportion of artificially dried beans (Jinap et al. 1994) and the market expectation is that artificially dried beans are likely to be acidic.

2.2 Solar Energy for Drying

Methods in which the sun's heat is managed and utilized for drying while providing protection for the product is referred to as solar drying. The potential for solar drying in the tropics has been mentioned by several authors (Arinze 1986; Sodha et al. 1987). Womac et al. (1985) reported success in using solar energy for crop drying on farms in North America where solar energy is less available. This success, even on cloudy days, is due to the ability of the infra red solar fraction to penetrate clouds (Raghavan 1987).

Sun drying, i.e. exposing the product directly to sunshine, is the most widely used form of solar energy in the post harvest processing of crops. It is hampered by a number of factors. These include slow drying rates, low efficiency in the use of space and poor quality (Minka 1986; Arizne 1986). The low efficiency of this drying process itself is inherent in the heating method and the mass transport method which operate (Othieno 1986). Raghavan (1987) noted that simply placing crops in perforated or ventilated containers above the ground was more effective than sun drying. Heating from above as occurs in sun drying is a most inefficient process when compared to moving warm air through the crop (Ghosh 1972). Thus once it can supply adequately heated air, a solar drier can be expected to provide improvements over sun drying.

2.2.1 Types of solar driers

Solar driers may be classified primarily according to the mode of heat collection employed and secondarily on the mode of heat transfer (Sodha et al. 1987). A direct-mode solar drier is a closed chamber which contains the product, covered by a transparent sheet of either glass or plastic and ventilated by a series of holes. Thus heating is by direct absorption of radiation by the crop (Bhatnagar and Ali 1989). In an indirect-mode drier, the air is heated in a collector and is directed to a dehydration chamber containing a batch or batches of the product (Maulbauher 1986). Where an air heating collector is coupled with a drying chamber which exposes the product to solar radiation the drier is termed "mixed-mode".

Natural convection driers in either of the above mentioned modes depend on naturally induced air currents to move moisture from the product environment (Bassey et al. 1986). Forced draught or forced circulation driers utilize fans to move drying air through the product (Sodha et al. 1987) and are usually indirect mode.

A myriad of solar driers has been designed taking into account several aspects of particular drying situations (Bhatnagar and Ali 1989; Anwar et al. 1989; Thanvi and Pande 1989). Ease of construction, cost and availability of material are among the socioeconomic factors influencing final drier design (Sebbowa 1986; Bassey et al. 1986) while product type and sensitivity and scale of operation influence the physical parameters like temperature and air flow control.

2.2.2 Cabinet solar driers

Several variations of the "cabinet drier" exist. Early versions of this drier consisted essentially of rectangular boxes perforated on the sides and /or underneath and covered with transparent material which protects the crop from rain (Minka 1986; Othieno 1986). The drying air comes into contact with the product once and is expelled (Singh and Manan 1989). The earliest designs of cabinet driers have been modified to include black-painted inside surfaces, chimneys and varied modes of heating. Fans have also been installed to improve performance with certain products (Mc Gaw et al. 1989)

Three of the most promising configurations of the cabinet drier have been tested for drying copra in the Caribbean (Mc Gaw et al. 1989). The simplest configuration is a single level box with a base of corrugated galvanized steel. The box is supported on a 10^{o} incline plane and is ventilated at the lower end. The second and third are shelf type driers. In the second, shelves are arranged on an inclined frame to prevent mutual shading while allowing vertical movement of air through the drying product. Temperatures of 50-57 ^{o}C were realized between 10:00 am and 3:00 pm while the first drier achieved 38-48 ^{o}C during that time at ambient temperatures of 28 - 30 ^{o}C (Mc Gaw et al. 1989). Similar performance of an inclined-plane shelf drier was reported by Singh and Manan (1989) and Goyal and Mathew (1989).

Shelf type cabinet driers were developed out of a need to meet requirements of simplicity, and economy in material and land use (Selçuk et al. 1974). Vertical alignment of shelves is the most economical use of space. Under natural convection conditions this latter configuration achieved lower temperatures than the previous two (Mc Gaw et al. 1989) when operated in indirect mode.

In the indirect driers, the drying chamber not only shelters the product from weather but also from direct solar radiation (Sodha et al. 1987). Heat collection may be by the use of a flat plate, inflated tube or other type of collector which heats up the drying air. Air flow in the cabinet drier is usually by natural convection, but in some situations forced convection is used (Huang 1986).

2.2.3 Capacity of natural convection driers.

The capacity of a solar drier depends on the volume of heated air which can be moved through the product per unit time and the temperatures which can be achieved. Where air flow is naturally induced the capacity of dryers is generally low and drying is slow due to the low air velocities (Othieno 1986; Bhatnagar and Ali 1989). Temperature and air flow are interdependent in natural convection drying and the two parameters can be manipulated by the selection and design of components such as collector, chimney, ventilator and drying chamber etc. (Bassey et al. 1986; Goswami 1986).

Imre (1987) suggested undertaking solar drying in periods of maximum radiation intensity due to the low energy flux of solar radiation. Compared to sun drying, however, a 10 ^{o}C increase in air temperature during periods of low insolation can lower the humidity of the drying air sufficiently to double its drying potential (Yaou et al. 1986). The moderate temperatures of about 60 ^{o}C at which many agricultural products are dried can be met by driers using simple flat plate collectors (Imre 1987; Goswami 1986).

2.3 Cocoa Drying

Cocoa drying technology varies from the simple surfaces and equipment used in sun drying to large scale mechanical or artificial driers with a few modifications in this continuum.

2.3.1 Sun- drying

Sun-drying is still the most common form of drying in cocoa areas of the world. Sun-drying involves placing the fermented beans on a drying surface, which varies from a concrete platform, corrugated metal sheets or a number of boards laid side by side. Wooden boards are the surface of choice in many countries as they are more absorbent compared to concrete. Some metal surfaces impart a purple discoloration to wet beans especially in the freshly fermented state (Hess 1990) which remains upon drying. Purple beans are associated with poor fermentation which is an important quality parameter affecting price (Wood and Lass 1985). Tarpaulins are often employed in covering the product at nights or in bad weather (Hess 1990).

Raised wooden racks which support drying mats made of bamboo are common in many African cocoa producing areas. The mats provide ventilation holes beneath the layer of beans and can easily be rolled up into a small heap which is easier to handle at nights and in adverse weather (Wood and Lass 1985).

Smoother operation of sun-drying in large scale production is accomplished with a "barcaca" as it is known in Brazil or "boucan" or "cocoa house" as it is known elsewhere. Ghosh and Cunha (1975) described it as a flat smooth horizontal platform made of wooden planks joined together and mounted on pillars of brick or stone above ground level. A roof sloping on both sides, built on a triangular frame and made of corrugated galvanized iron is moved over the product during bad weather and at nights and is pulled away from the platform during drying. Movement is facilitated by rails and or wheels (Ghosh 1973; Urquhart 1961). Drying is enhanced by periodic mixing of the beans with a higher frequency in the early stages. The beans are ridged to allow drying of the furrows (Hess 1990) with the ridge and furrow positions being interchanged with each mixing.

On some farms, the shelter is stationary and the beans are dried on trays which can be wheeled beneath it when required.

In large commercial operations the beans are polished. Polishing is a labour intensive operation where workers literally dance on the beans with their bare feet imparting a smooth appearance to the final product (Maravalhas 1966). Mould attached to the beans are removed by this process (Ghosh and Cunha 1975) and the practice can be deliberately employed for just this purpose under poor drying conditions. The beans are simply rewetted and danced. Machines for polishing cocoa have been introduced in some countries but, although they have replaced dancing in some locations, little has been written of their performance.

Sun-drying has several drawbacks which has encouraged efforts at finding suitable artificial driers (Arinze 1986). The most obvious is that it is intermittent. Drying is interrupted by rain, on cloudy days and at nights. Sun drying can take place only in thin layers of 4-5 cm (Ghosh, 1973) and thus requires very large surface areas in commercial settings. The time to satisfactory drying is variable, five to ten days (Hess 1990). During inclement weather drying time may be as long as three weeks (Ghosh 1973). Such prolonged drying encourages mould growth and if the cotyledons are attacked, flavour is affected (Powell 1982). Although rewetting and dancing may be used to remove mould, discoloration may not be completely removed. Sun drying demands much labour for turning the beans and protecting them from rain. In addition, installations built to speedily protect the beans (the barcaca or mobile trays) can be immense and costly when drying surfaces are large.

Where the throughput is large, especially when part of the crop matures in the rainy season, serious problems can result. As with sun dried products in general, sun-dried cocoa is exposed to dust and debris increasing the foreign matter fraction (Powell 1982). Despite these problems most of the world's cocoa output is sun-dried. This can be explained by the difficulty of balancing socioeconomic and bioengineering factors associated with cocoa production and drying.

2.3.2 Artificial drying

Artificial drying of cocoa is a rather old practice (Mcdonald and Freire 1981) and is important especially in Malaysia and Latin America. Driers in this category vary from the simple to very sophisticated utilizing various modes of heating and types of fuel.

The simplicity of the "Samoan" drier allows its adaptation for use in remote areas and on many farm sizes. The drier as described (Urquhart 1961) consists of a flue fitted in a trench and made of oil drums connected linearly. A wooden platform above the flue holds the cocoa and below the platform, the sides are blocked down to the ground level to contain the warm air. The indirectly heated air rises through the cocoa layer by convection and the fumes are expelled via a chimney connected to the terminal end of the flue. The Samoan drier is usually fuelled by wood (Wood and Lass 1985).

Another common artificial drier which is used in Brazil is the "Secador" which consist of a wood burning flue connected to a chimney made of masonry, aluminum or corrugated iron. Three to four metres above the flue is a drying platform which is either solid or slatted. A thin layer of beans placed on the platform is heated by conduction and raked frequently (Wood and Lass 1985; Ghosh 1972).

Ghosh (1972) designed a gas drier which utilized household cooking gas. Heaters located 1.2 m below a drying platform burned the fuel and the warm air along with the combustion gases rose through the beans. Operators accessed the burners in a plenum chamber which was vented with cold air. Each heater could effectively heat an area of 2 m^2. Ghosh extended this system by covering the platform with glass allowing the beans to be heated by the sun in good drying weather, while providing artificial heat beneath the platform in unfavourable conditions. This system eliminated the need to move the barcaca in inclement weather.

In the artificial driers mentioned above stirring of the beans is a problem. A circular platform drier was designed with a rotary device mounted over the bean layer to mix it as desired (Wood and Lass 1985).

Today many circular driers are employed in Malaysia (Jinap et al. 1994). Various other driers have been used for cocoa drying. These include rotary drum driers, tunnel driers, and a continuous drier which carried 40 kg trays down a tower through which hot air is blown. The latter was reported to be the only one of its kind (Wood and Lass 1985).

The impetus for artificial drying is the need to accelerate drying, prevent spoilage and thus maintain quality where poor weather and high output are important considerations. However artificial drying poses other important quality as well as cost concerns. Primarily, the temperatures used are much higher and the enzymatic flavour and colour enhancement processes are stopped (Quesnel and Jugmohunsingh 1970). Had et al. (1957) dried West African cocoa beans in 14 hours and found no definite reduction in flavour but the beans had a strong acid taste. Other researchers have confirmed the high acidity (Urquhart 1961; Jinap et al. 1994) and although this can be substantially reduced during the manufacturing process, cocoa buyers still treat it as undesirable (Powell 1982). Understandably the more acid present in the bean the higher the residual acid content in the product. (Jinap et al. 1994).

Cocoa is easily tainted and artificially dried beans are often tainted by smoke originating from the fuel used, oil or wood (Ghosh 1972; Ghosh 1973; Powell 1982). Most artificial driers use heat exchangers and theoretically should operate free of taint. Maintenance of driers is often deferred however and, in a complex set-up, repairs are difficult to effect (Ghosh 1973). Often flues become corroded and the smoke moves through the drying product.

Most artificial driers require an initial capital investment which is beyond the finance most small farmers can afford or attract. Though these driers require less labour to operate overall, some require readily available technical support service during the drying process. Furthermore many of the systems require costly adaptations for operation in rural areas of many cocoa producing countries eg. electricity, engines to operate fans and motors to drive mechanical parts.

Another major drawback of artificial drying systems is the breakage caused by over drying and excessive mechanical handling (Ghosh 1973). Artificially dried beans are described as brittle and are said to lack lustre (Urquhart 1961). A high proportion of broken beans presents problems during roasting (Urquhart 1961) and while in storage, are more liable to be attacked by insect pests (Wardsworth 1955). Broken beans are available for less valuable product lines and represent a reduction in value to the farmer.

Ghosh (1973) noted that economic - sized artificial driers may be of excess capacity for the needs of most farmers. This and other needs for example, to allow versatility with respect to farm size must have, in part, inspired his work on combining sun drying with gas drying. Prolonged drying during the rainy season in the humid tropics is also a very important factor and Wardsworth (1958) has attributed most mould growth affecting quality to this problem.

2.4 The Quality of Commercial Cocoa Beans

The grading criteria and quality categories of commercial cocoa beans are specified in the International Cocoa Ordinance (Wood and Lass 1985). International cocoa trading bodies define quality in terms of degree of fermentation and the extent of defects present. Criteria at fermentation, proportion of broken beans, and the degree of moulding and insect infestation and other adulteration (Wood and Lass 1985; Crespo 1985). Other aspects of quality include fat percent, cocoa butter hardness, level of acidity, low shell percent, and absence of off-odours (Powell 1982; Crespo 1985), and flavour.

Flavour potential of cocoa is measured by the degree of fermentation and this in turn is measured by a colour index called the fermentation index. At a visual level the overall colour of cocoa beans is measured as part of a cut test (Crespo 1985; Wood and Lass 1985). Unfermented beans have a slaty appearance, purple beans are poorly fermented, while increased browning and the reduction of purple coloration in the dried beans indicate increased degree of fermentation (Wood and Lass 1985). The fermentation index is determined spectrophotometrically as the ratio of absorbance of cocoa pigments at 460nm to that at 530nm; a ratio of one indicates fully fermented beans (Ilangantileke et al. 1991). It is a more objective measure of fermentation compared to the simple cut test but has no practical application in the field. Therefore the less objective cut test is the method used during purchase. A similar index is calculated with results from the cut test (Tomlins et al. 1993).

Several researchers have related poor chocolate flavour to low pH of the beans used in manufacture. Acidity of cocoa liquor, as measured by pH, has been correlated to acidity scores obtained from parallel taste tests (Baigrie and Rumbelow 1987). Other studies have found volatile acids, of which acetic acid is 95% or more, responsible for the acidity detected in cocoa extracts and liquors (Jinap and Dimick 1990; Liau 1978; Jinap et al. 1994).

Several other factors influence the final quality of raw cocoa beans. These include genotype (Clapperton et al. 1991) growing conditions including rainfall (Crespo 1985; Egbe and Owolabi 1972), harvesting and pre-fermentation treatments (Mayer et al. 1989), fermentation method (Howat et al. 1957; Tomlins et al. 1993), drying technique and storage practices (Wood and Lass 1985; Tomlins et al. 1993).

CHAPTER 3

MATERIALS AND METHODS

The study was conducted at the Ministry of Agriculture research station at Union, St Lucia. The location has a latitude 14° 01′N and 60° 51′W (Appendix A). The driers were placed on a concrete platform about 60 m from a meteorological station. The study began in November 1994 and ended in June 1995.

3.1 Materials

Four drying units were constructed for this study. Two of these units were cabinet-type solar driers, and the others were units for open air sun drying. They were all built with a 5cm x 5cm (2" x 2") wooden frame plywood and fibreglass glazing, utilizing local labour.

One solar drier was supplied with heat indirectly by a flat plate collector which captured the sun's energy. In it, the drying beans were completely sheltered from the sun's rays. The 135.6 cm x 70.6 cm x 165.7 cm (54.25" x 28.25" x 65.25") drying chamber comprised two shelves each holding two adjacent trays. The top of this chamber was fitted with a wind assisted ventilator when preliminary drying runs showed it imperative to reduce high night-time humidity especially in the early stages of drying. The collector measured 195.5 cm x 119.5 cm x 23 cm (77" x 47" x 9") with a fibreglass glazing on the top and long sides. The glazing was a glass fibre reinforced polymer (Sun-Lite' HP) manufactured by Solar Components Corporation of Manchester. Manufacturers claim 85-90% solar transmission, including most of the infrared and visible region, and excellent UV resistance. Loss of transmissivity is less than 10% over a 15-20 year period and the material is shatterproof.

The absorber was a 109 cm x 190.5 cm (43" x 75") black painted, flat sheet galvanized steel, fastened to the floor of the collector which was tilted at an angle of 30°. The base of the collector was insulated with fibreglass foam. Ambient air entered the collector through a 1.25 cm (0.5") square mesh and rose to enter the 40.6 cm (16") high plenum beneath the first shelf by natural convection. The indirect drier is depicted in Fig. 3.1.

The second unit (Fig. 3.2) was a solar direct drier i.e. the beans contained were exposed to the sun's rays. It comprised a single level chamber with a roof tilted at an angle of 30°. The sides of the drying chamber and the roof were made of the fibreglass glazing mentioned above. Two movable, drying trays formed the bottom of the drier and completed the drying chamber. The drying beans were heated through the glazing.

The third and fourth units each comprised a frame, similar to the direct drier in size and elevation, but with open roof and sides (Fig. 3.3) and were used for open air sun drying. The frame allowed covering the beans with a plastic sheeting during bad weather and at nights.

Two types of drying trays were used to hold the product. They were all built of a wooden frame measuring 60cm x 60cm x 10cm. Beans were dried in the two solar driers in trays of perforated steel bases (Fig. 3.4) and sun dried in open air in trays of perforated stainless steel base and of solid non perforated wooden bases. The latter was used to simulate

Fig. 3.1 The indirect solar drier.

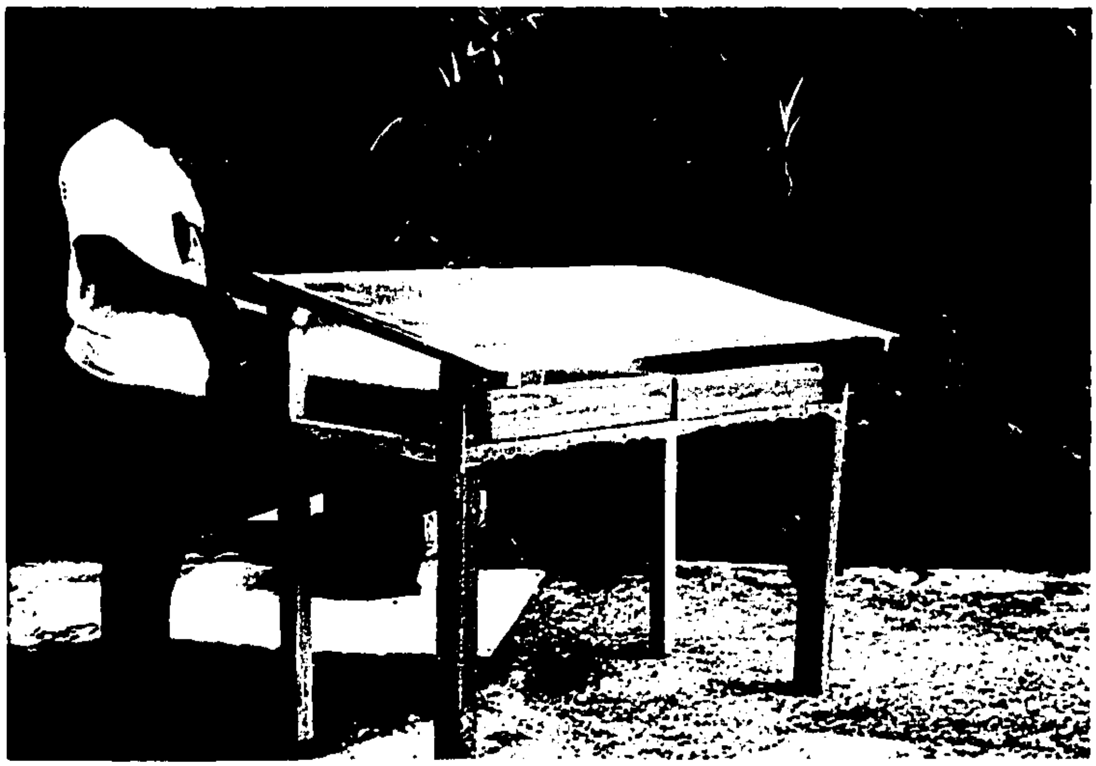

Fig. 3.2 The direct solar drier.

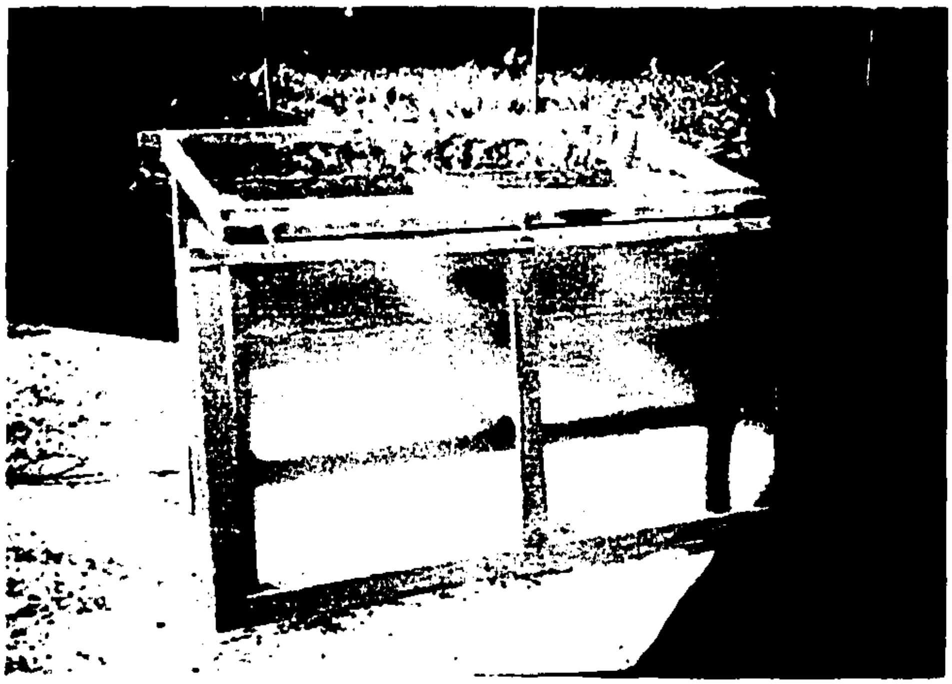

Fig. 3.3 The open air-sun drying unit.

farm conditions where beans are dried on unperforated wooden platforms or trays. These drying surfaces conveniently provided a total of four drying methods. For clarity of description the drying methods were as follows:-

Solar driers	i)	indirect drier	(ID)
	ii)	direct	(DD)
Open air units	i)	perforated steel surface	(OA)
	iii)	solid wooden surface	(OA-SB)

The beans were of a mixed variety and were supplied, after fermentation, by Union Vale Estates located on the west coast of the island. Fermentation on this estate followed a strict 8-day routine. The fresh beans were placed in deep wooden boxes to a volume measuring 66 cm x 91.5 cm x 122 cm (26" x 36" x 48") and turned by transferring to an adjacent box. These transfers, and hence mixing of the beans, were done on the second and fourth days, and every 24 hours subsequently to the end of fermentation. At the end of fermentation the beans were about 48% moisture (w.b). A portion of the fermented beans was transferred to the experimental site in new sacks, weighed and placed in the drying trays.

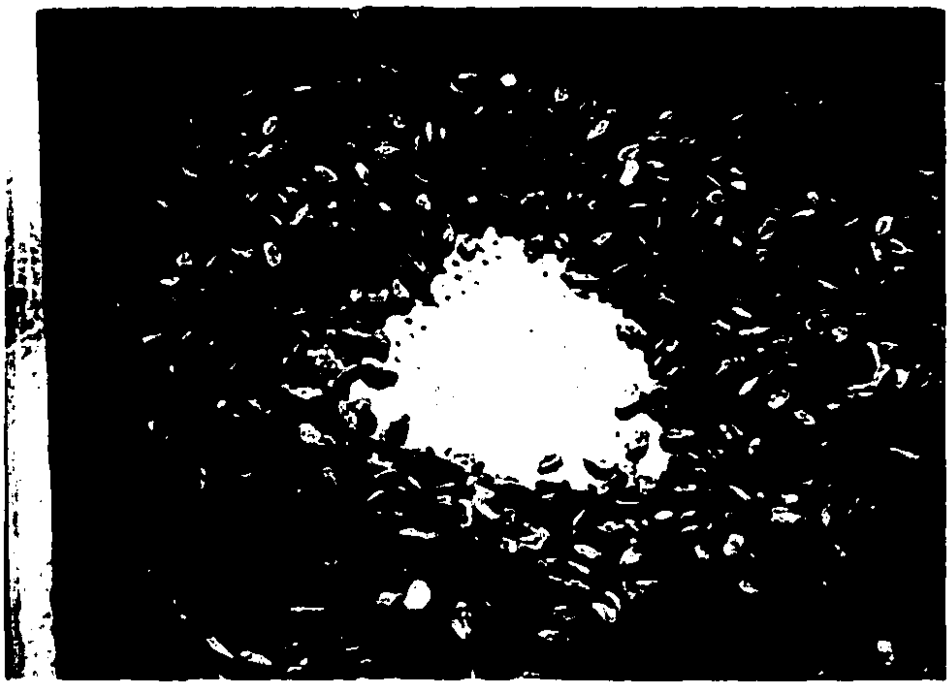

Fig. 3.4 The stainless steel drying tray.

3.2 Methodology

3.2.1 Drying

After some preliminary drying, a total of seven batches of fermented beans was dried by the four methods mentioned above. Three loading rates, 13.5 kg/m^2, 26.9 kg/m^2 and 40.4 kg/m^2, were examined for each method.

The contents of all trays were hand stirred daily about every three hours. A sample of beans was taken at the time of loading for moisture determination by the oven method. The trays were weighed twice daily and the progress of moisture loss thus monitored. Drying was stopped after moisture content fell below 8% (w.b). Drying of each batch was continued for 6 - 12 days.

Temperature measurements were made with a Cole- Parmer Digi Sense Scanning Thermocouple thermometer model 37000-00. Thermocouples were positioned on the collector, in the plenum, above the trays, and outside the drier to monitor ambient conditions. A hygrometer was placed in the plenum to monitor the humidity inside the indirect drier. Periodically air speed was measured with a Cole- Parmer Probe Anemometer model 3700-60 and humidity sensor model RH-30-3. Technical difficulties however aborted continuous measurement of solar radiation and air velocity. The meteorological station located nearby provided back up data.

3.2.2 Physical quality assessment

The cut test used in this study is a slight modification of standard cut test. This modification called the Cut Test Score method was reported by Shamsuddin and Dimick (1986), and Ilangantileke et al. (1991). In the cut-test-score method, 100 beans were cut lengthwise to expose maximum cotyledon surface and the colour assessed as fully brown, 3/4 brown, half purple half brown, 3/4 purple, fully purple, slaty or bleached. Scores of 6, 5, 4, 3, 2 and 1 were allotted to the respective colour categories in that order. The number of beans in each category was multiplied by the category score to obtain the cut test score for the particular drying run (Shamsuddin and Dimick 1986). The cut test scores indicated the level of browning of the beans as well as the degree of fermentation. Comparisons of the various drying methods were made using the cut test scores. During the cut test, which was done in normal daylight, the beans were checked for internal moulding and insect infestation.

The colour of the freshly cut internal surfaces of the nibs were measured using a Minolta CR-300 colorimeter. The measurements read were L-a-b values defined by the Hunter colour solid. In this system the L-values indicate lightness or darkness, +a and -a indicate degree of redness and greenness respectively and, +b and -b, degree of yellowness and blueness respectively (Francis 1991). The results were compared to the same nibs but grounded to select an approach for comparing the colours of the various groups of beans. Preliminary results indicated that for samples of equal size ground nibs gave more reliable results. In addition the results indicated that samples of 20-25 beans adequately represented a batch of beans from the experiment. therefore, using 30 beans was considered to be a reasonable sample size for making comparisons.

For the comparisons the instrument was calibrated using 8 nibs within the range of colours present. Each of 30 beans from a random sample was shelled, grounded and sieved through sieve No.48, and the L-a-b colour was measured using the Minolta CR-300 colorimeter with illuminant C as the light source. Shamsuddin and Dimick (1986) found decreasing variability of L-a-b colour values with decreased particle size. Colour measurements for two batches or drying runs in each drying method were used for the comparisons. Bleached beans were excluded from both the cut test assessment and the colorimeter assessments. A visual assessment was made of the external mouldiness of the beans dried by the various means in this experiment.

Crushing strength was used to indicate whether beans dried at the higher temperature of the solar driers were any different from that dried under ambient conditions. The beans were tested at final moisture content. Preliminary compression tests were carried out using an Instron Universal Testing Machine modified model 4502. The beans were compressed along three axes and the results examined. Compression along the longest axis was selected for the comparisons. When compressed in this manner, the bean shell breaks under loading and the cotyledon falls apart. The energy at this point which was read off the machine was used for the comparison.

A random sample of about 2 kg from each method of drying was taken by repeated coning, quartering,and selecting one quarter. From the final quarter, beans between 22 mm and 24 mm in length were taken and equilibrated to the desired moisture level by adding water as a spray and conditioning for 48 hours in a cold room. Beans were tested for strength at the moisture at final drying (6%). In addition beans from the driers were rewetted to 8% moisture (w.b) and at 16% (w.b) to determine whether moisture levels made any difference.

3.2.3 Chemical assessments

Chemical assessments were carried out in the Food Science Laboratory, Department of Food Science and Agricultural Chemistry, Macdonald Campus of McGill University. The chemical evaluation was confined to pH and titratable acidity.

About 100 beans were shelled and the nibs were finely grounded. Ten grams of ground nibs were immediately blended in 100 cc of distilled water for about two minutes. The blended liquid was made up to 200 ml in a flask and stirred every five minutes for at least half an hour. The suspension was then filtered under vacuum through Whatman No. 4 filter paper. Three 25 ml aliquots were used for pH determination. On those same samples the titratable acidity was assessed against 0.01 N Sodium Hydroxide solution and titrated to pH of 8 using a Fisher Accumet[R] Selective Ion Analyzer model pH meter. The above procedure (Jinap and Dimick 1994) was performed in duplicate. Chemical analyses were conducted at the end of all the drying.

3.3 Data Analysis

The pH and titratable acidity data were analyzed using the SAS[R] statistical package. Visual colour by the cut test score and the shell strength of the beans was analyzed using a simple comparison of means as beans were lumped together for assessment according to drying method with no regard for the depth of loading. Colorimeter colour measurements were analyzed by simple comparison of means.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical Aspects

4.1.1 Drying conditions

Daily ambient temperature between fluctuated between 25 ^{o}C and 32 ^{o}C while night-time temperature fell to as low as 20 ^{o}C. The average number of sunshine hours per drying run ranged between 6.6 to 10.5 hours per day. Under these conditions temperature rises of up to 15 ^{o}C above ambient were realized in the indirect drier while rises were up to 20 ^{o}C in the direct drier. Differences of as low as 4 ^{o}C between ambient and heated air were also observed in the indirect drier. Daytime temperature in the two driers over one typical drying period is given in Fig. 4.1.

Night time relative humidity (6:00 pm to 6:00 am) fluctuated between 70% and 92%. Nightly RH fell below 70% for only a brief period during the experiment and never fell below 65%. The lowest ambient RH recorded was 48%. Daytime RH fell below 60% for only short spells of 4 hours or less. For the whole experiment, the total exposure of any batch of beans to less than 60% ambient RH was 6 1/2 hours. Where 4 hours or more of exposure to 60% RH or less was recorded, it was in the later stages of drying. Average ambient RH during drying is given in Appendix B.

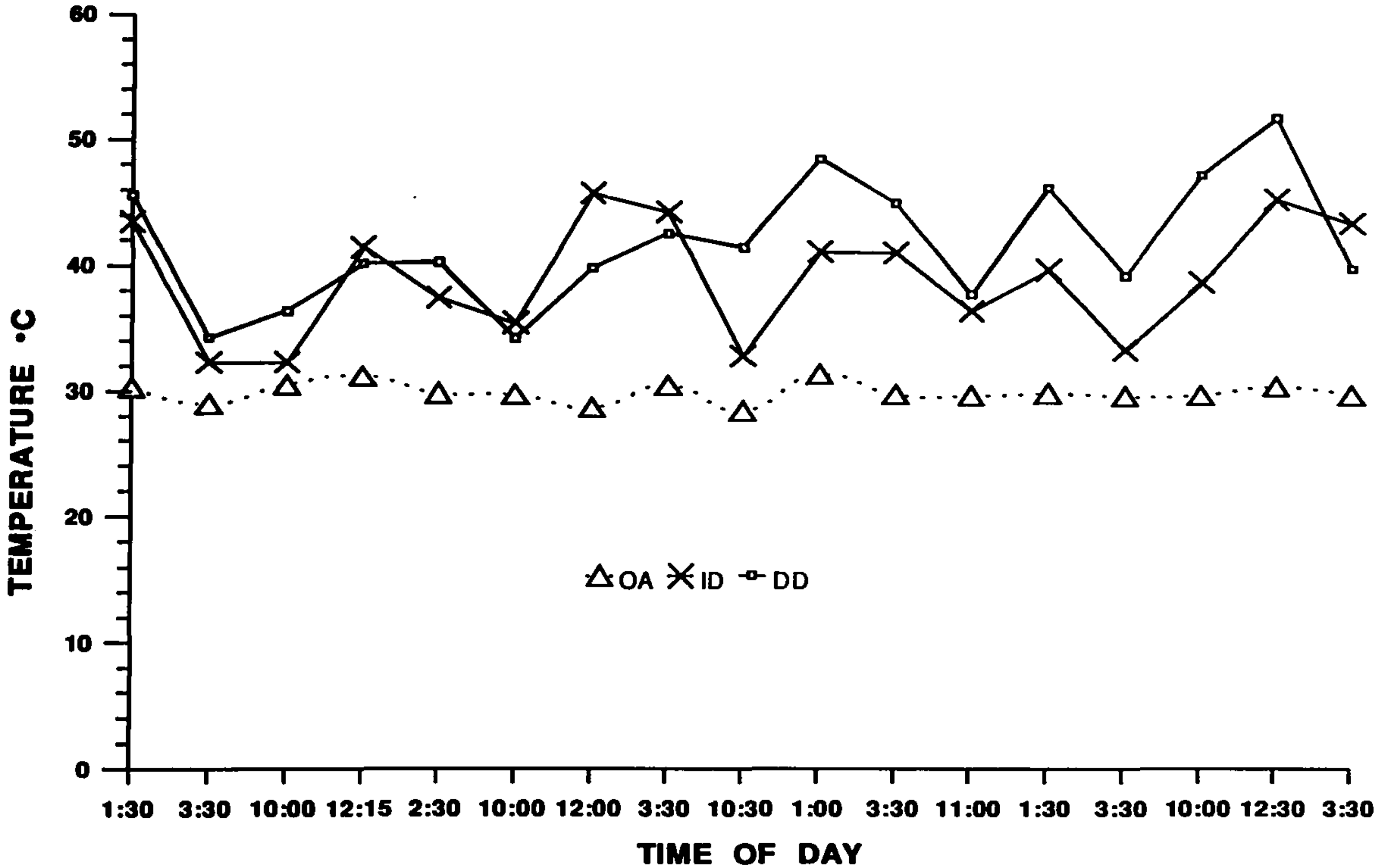

FIG 4.1 COMPARATIVE DAYTIME TEMPERATURES IN DRIERS

Given the uncontrolled conditions, the RH exposure varied from run to run. In one run for example, except for a two hour period in which ambient RH fell below 60%, daytime recordings were consistently between 60 - 70%. In another run, daytime RH never fell below 60%, and in a third the beans were exposed to about 90 hours above 80% relative humidity. In general, however, the drying runs were similar in relative humidity exposure, especially in the first three days of drying. The relative humidity inside the indirect drier during the drying of two batches at the higher loading rates are depicted in Figs. 4.2 and 4.3.

Except for a few short periods, daytime relative humidity of drying air inside the indirect was below 60%. The lowest relative humidity recorded in the plenum chamber of this drier was 35% while the highest was 90 %. Thus the indirect drier was capable of increasing the drying capacity of the incoming air by maintaining its humidity low relative to ambient conditions.

4.1.2 Drying behaviour

Beans were weighed at least twice per day, about midday and after sunset to observe moisture loss. The general pattern observed was one of a relatively constant period followed by an increasing period and then, a decreasing period. This was more obvious at the higher loading rates. Given the interval between the measurements the precise length of a constant drying period could not be estimated. The patterns depicted by the drying curves reflect changes in conditions rather than fundamental drying behaviour.

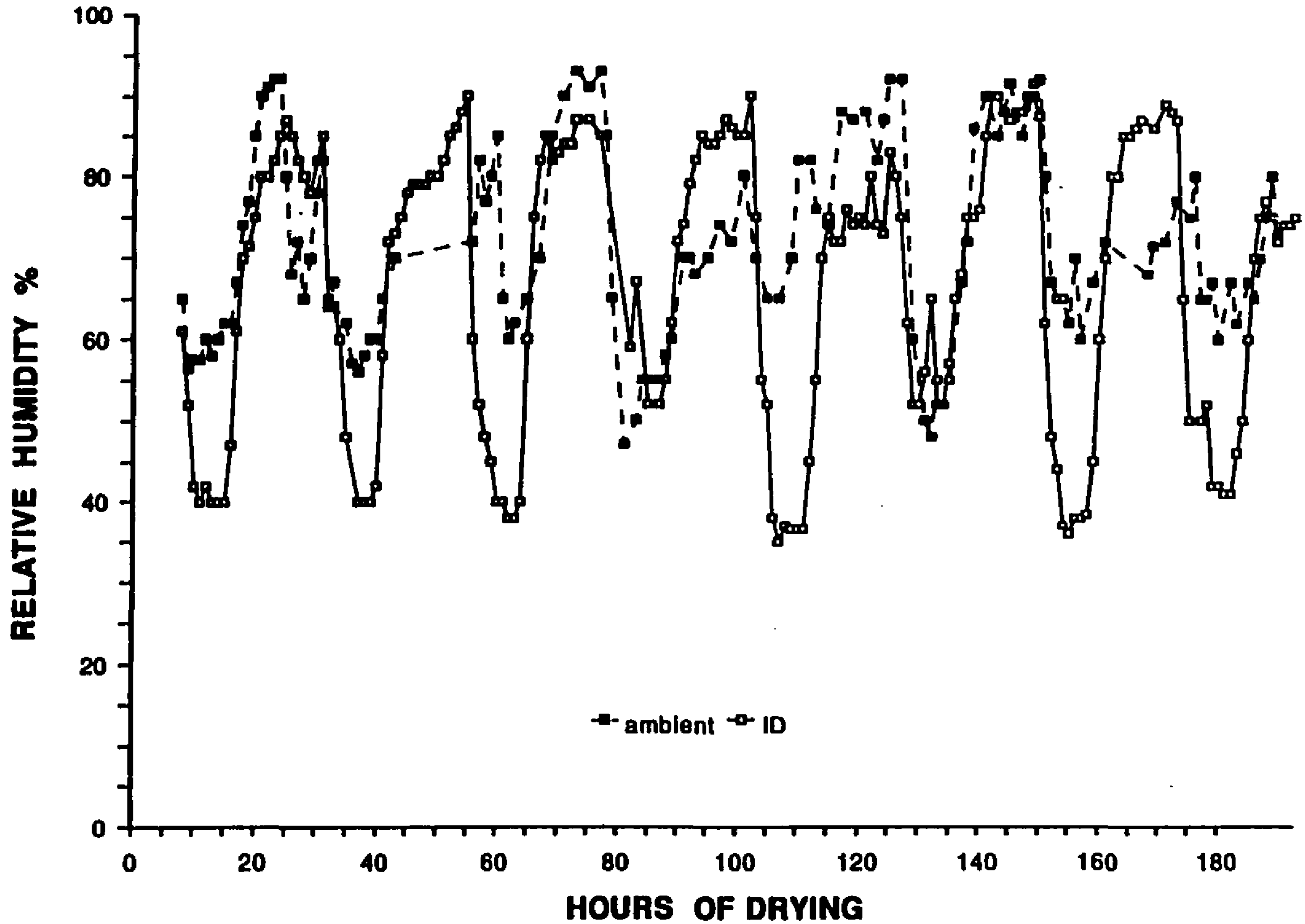

FIG 4.2 RELATIVE HUMIDITY FLUCTUATIONS
BATCH 2 26.9 kg/m²

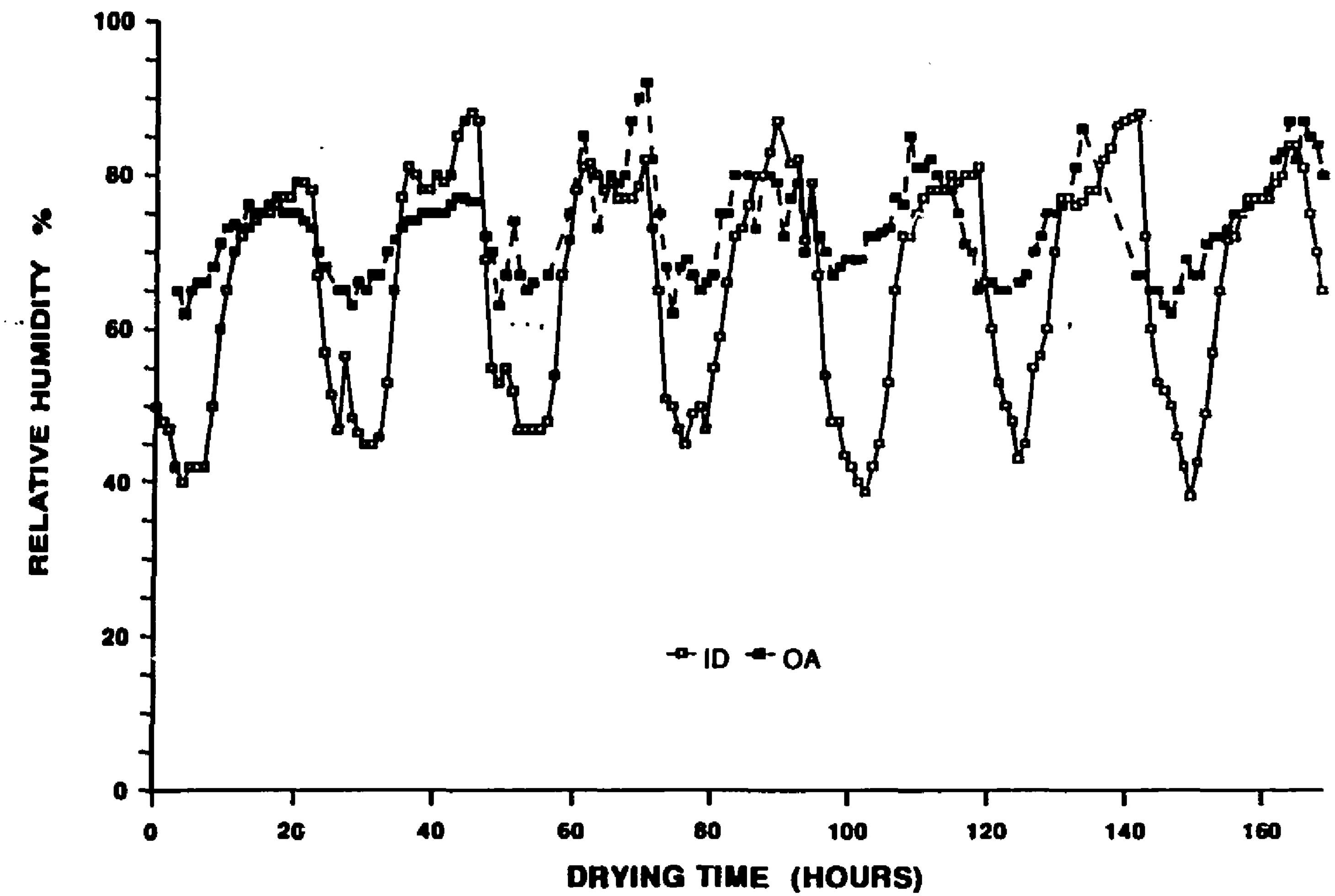

FIG 4.3 RELATIVE HUMIDITY FLUCTUATIONS
BATCH 7 40.4 kg/m²

At the lowest loading rate (13.5 kg/m^2), the initial moisture loss was most dramatic, falling to 26%-34% (w.b) in the first 24 hours. At the higher loading rates the moisture content remained above 35%-40% (w.b) in the first 24 hours. For convenience, the behaviour of the treatments shall be described with respect to the lower (13.5 kg/m^2) and higher (26.9 and 40.4 kg/m^2) loading rates, respectively.

At the lowest loading rate (13.5 kg/m^2) there was little difference in moisture loss amongst the treatments (Figs. 4.4 and 4.5) in the early stages although the beans sun-dried on a solid wooden surface (treatment OA-SB) lagged behind slightly. From Fig. 4.5 it is obvious that after 140 hours of drying the solid wooden surface achieved lower levels of moisture than the other three drying treatments despite the unfavourable drying conditions. Under the more favourable conditions which existed for the drying run depicted in Fig.4.4, (compared to Fig. 4.5), sun drying on the wooden surface achieved the lowest moisture levels amongst the treatments from 96 hours onwards.

Under the conditions which existed during low load drying (13.5 kg/m^2) the performance of the indirect drier relative to other treatments was not consistent. Given rainy, high humidity conditions with relatively fewer sunshine hours (Fig. 4.5) the indirect drier performed better than either the direct drier or open air sun drying on a perforated surface. Under the relatively favourable drying conditions (Fig. 4.4) in which all treatments reached 8% (w.b) in under 120 hours, the indirect drier was the least impressive.

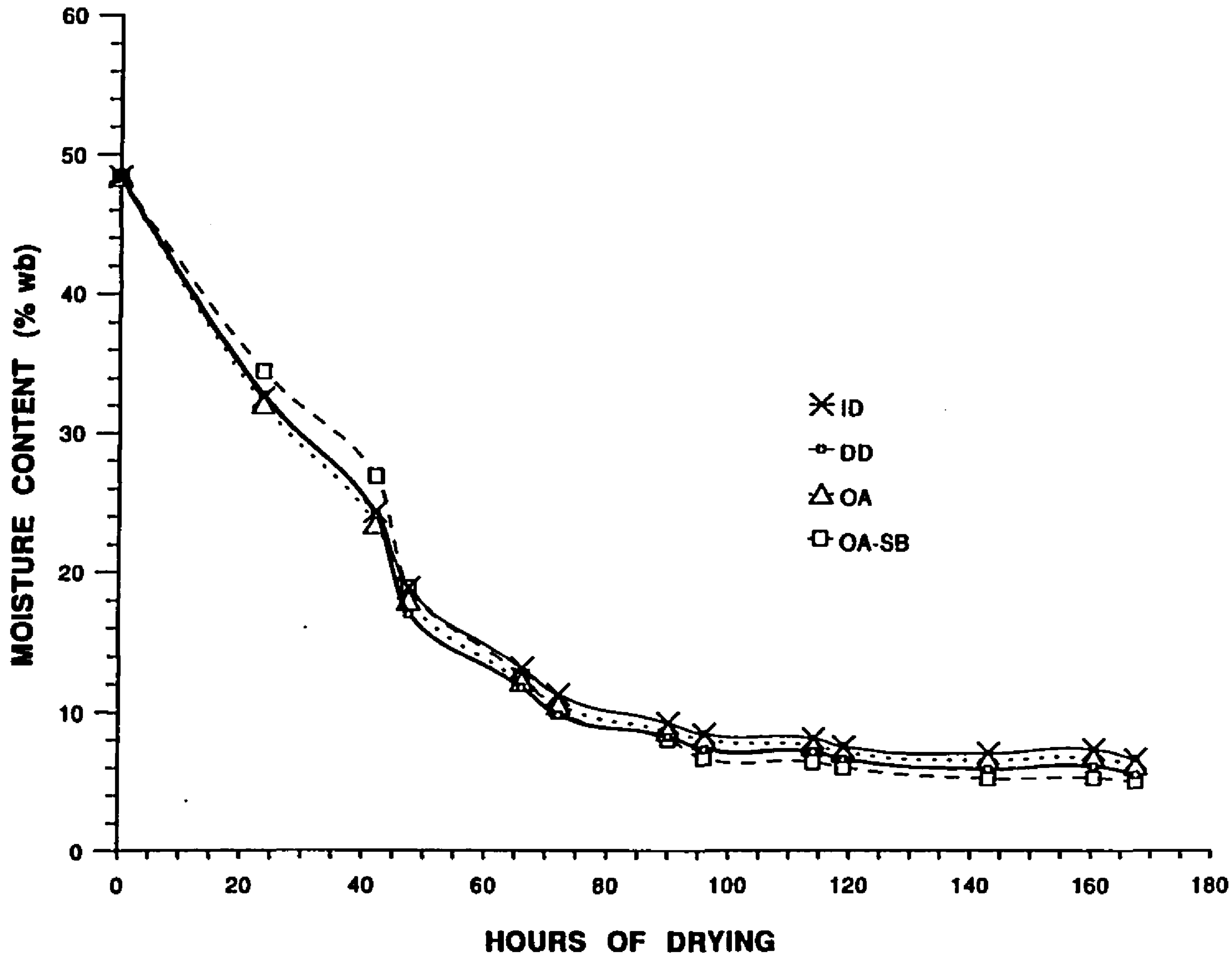

FIG. 4.4 COMPARATIVE MOISTURE LOSS (13.7 kg/m²)

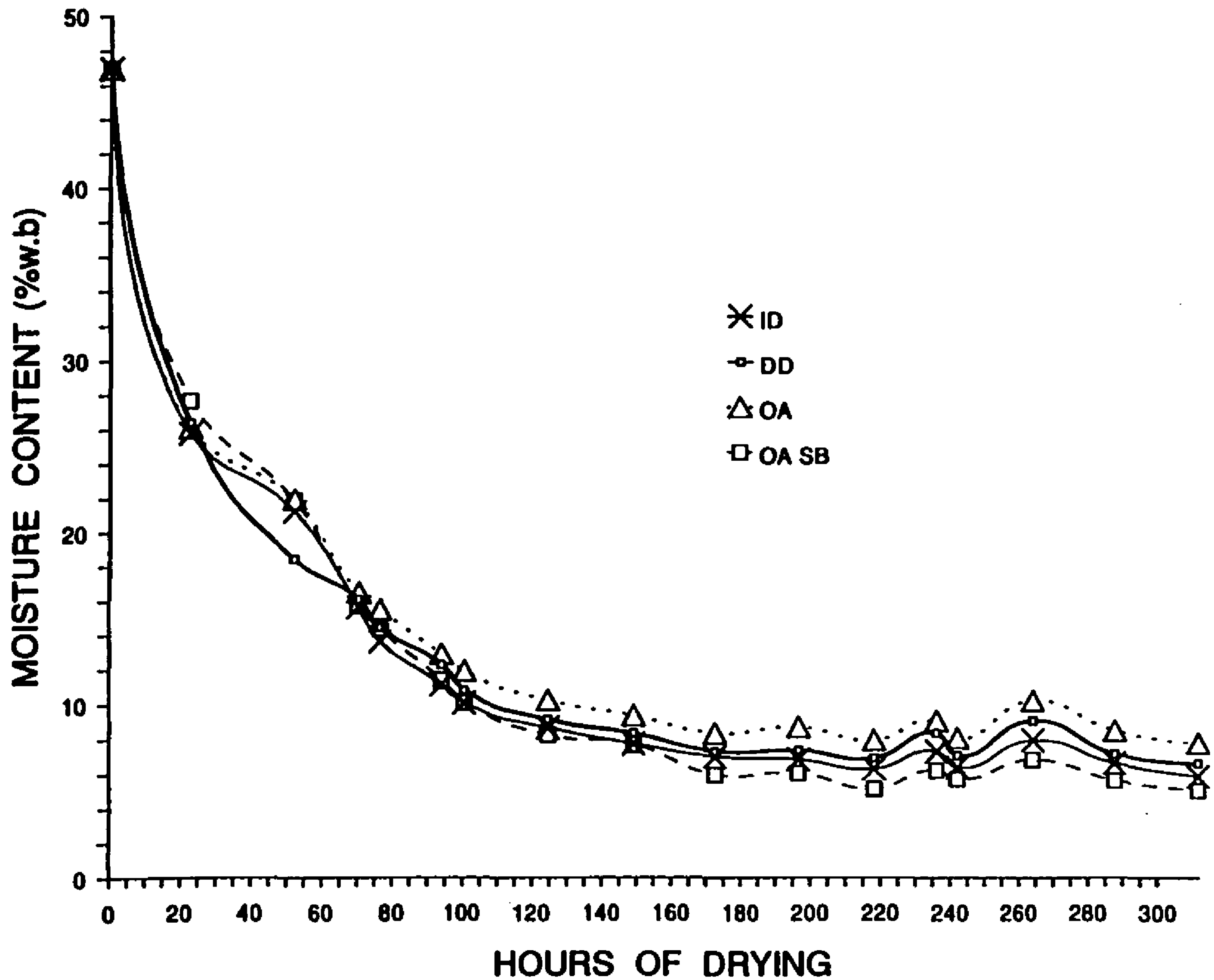

FIG 4.5 DRYING IN ADVERSE WEATHER (13.7 kg/m²)

Under the less favourable conditions depicted in Fig. 4.5, beans sun-dried on a perforated surface hardly fell below 8% moisture (w.b) before 300 hours of drying. At the same time all of the three other treatments fell below the 8% threshold in about 156 hours. During that drying run there were three days of four or fewer sunshine hours and between 17-27 mm of rain (Appendix A). Beans in all treatments gained enough moisture to exceed the 8% during the poor drying conditions depicted in Fig. 4.5.

At low loading rates the drying surfaces in treatments exposed to direct radiation become heated and transfer extra heat to the beans. Since small loads expose a relatively high bean surface to moving air, humidity build up in the beans mass did not hinder moisture loss. The perforations in the steel surface, its lower total area and superior heat conductivity made it a poor insulator. The steel surface lost heat faster than the wood in response to intermittent changes in air conditions, which in turn affected the beans. The wooden surface tended to provide better insulation thereby keeping the beans at a lower moisture level when air conditions changed. Thus, beans dried on the perforated steel surface retained relatively higher levels of moisture.

At 26.9 kg/m^2 moisture levels remained above 35% in the first day of drying with little difference between the direct solar drier and open sun drying irrespective of drying surface (Fig. 4.6). At 40.4 kg/m^2 all the methods of drying employed kept bean moisture content above 40% (w.b) during the first day of drying (Figs. 4.7 and 4.8).

At higher loadings (26.9 kg/m^2 and 40.4 kg/m^2) the rate of moisture loss in the indirect solar drier closely coincided with the sun drying control at the initial stages in drying. For the same period the direct solar drier

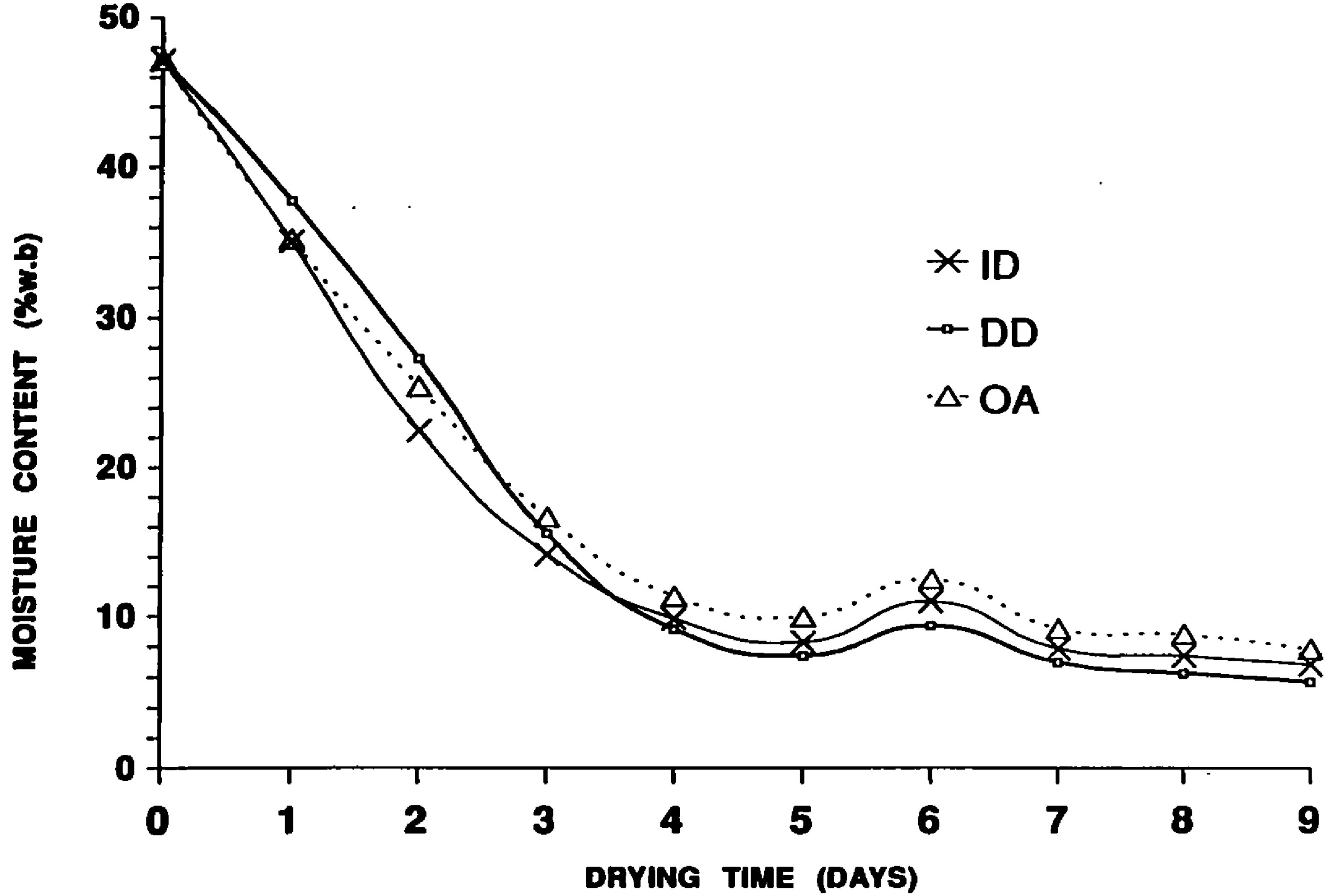

FIG 4. 6 COMPARATIVE MOISTURE CONTENTS (26.9 kg/m²)

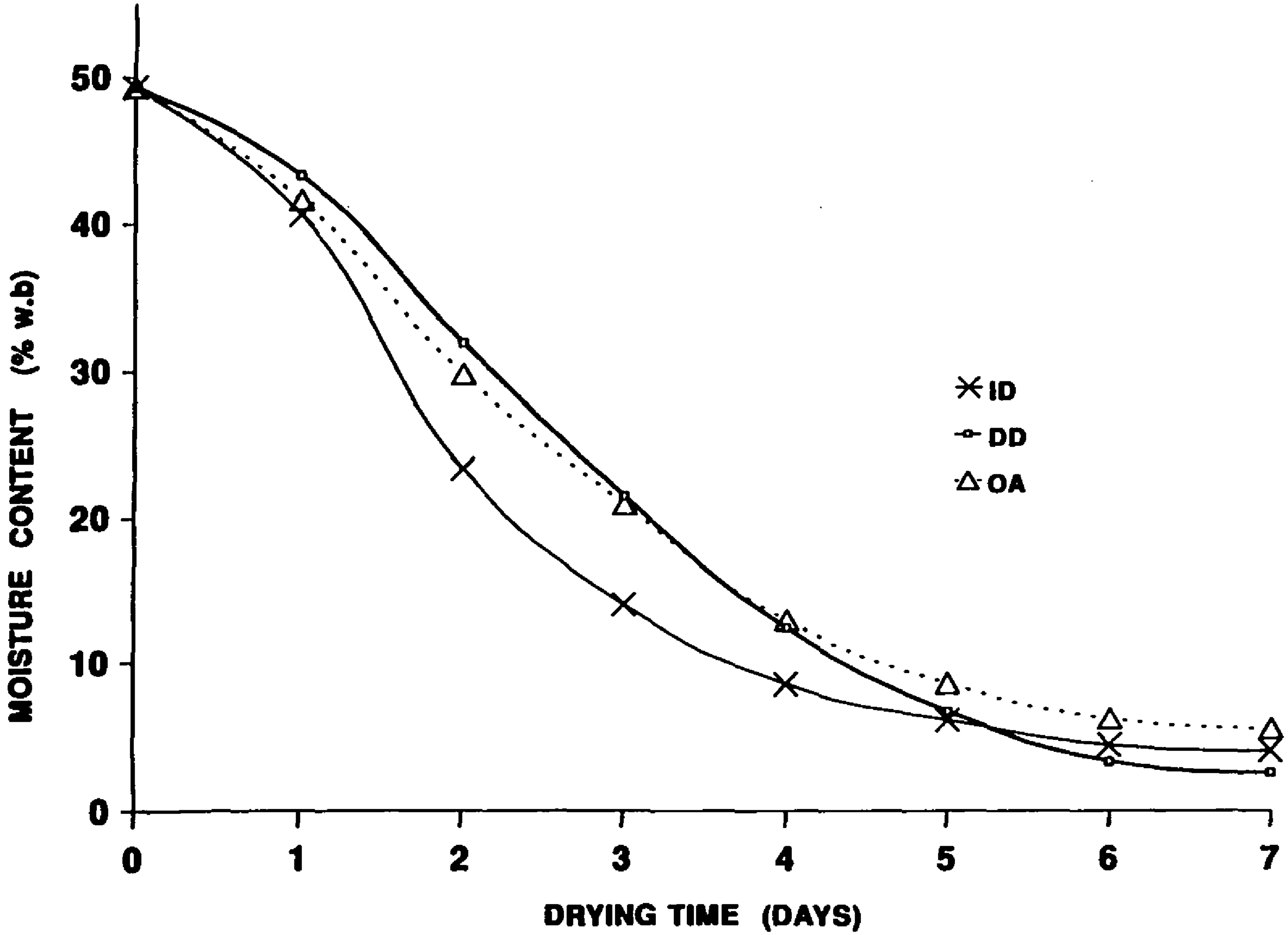

FIG 4. 7 COMPARATIVE MOISTURE LOSS (40.4 kg/m²)

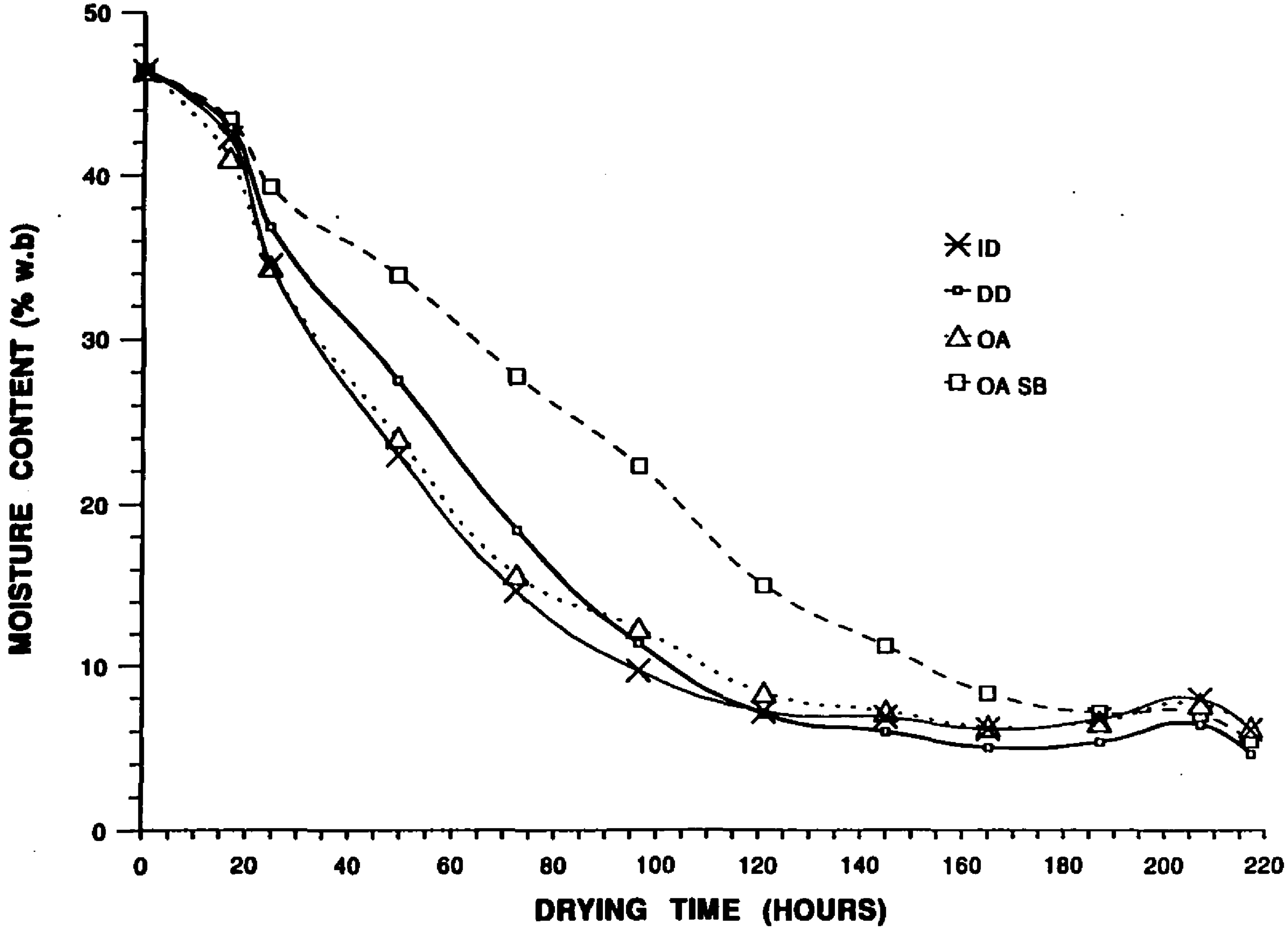

FIG 4. 8 COMPARATIVE MOISTURE LOSS (40.4 kg/m²)

removed moisture at a slower rate. In the first three days the moisture levels of beans in the direct drier were generally higher (Figs. 4.6, 4.7 and 4.8) than that sun-dried on a perforated surface. At the higher loading rates the indirect drier achieved a higher rate of moisture loss for the first 4-5 days of drying (Figs. 4.6, 4.7 and 4.8). After this period moisture loss rates in the direct drier tended to be higher, resulting in lower levels of moisture in the later stages of drying.

In the later stages i.e. after the fourth drying day, the lower humidity and higher temperature in the solar driers provide conditions better suited to remove residual moisture. Since temperature rises in the direct drier were higher it was the most capable in the later drying stage at those higher loading rates. The humidity build-up which hampered initial drying even at relatively higher air temperatures in the direct solar drier was no longer a problem in the final drying period.

The data indicates that under unfavourable conditions eg. poor weather and high loading rates, the solar driers are expected to dry cocoa beans more efficiently compared to sun drying, especially in the early stages.

At lower loading rates the advantage gained from insulation and direct radiation outweigh any disadvantages due to reduced air circulation through the beans. Thus at low loading, open air sun drying on a solid surface was more efficient in removing moisture in the late stages of drying. At higher loading rates however moving air through the beans was clearly more efficient resulting in both driers performing better than sun drying irrespective of the drying surface.

The temperature rises of achieved in the driers are similar to that recorded elsewhere (Goyal and Mathew 1989). The highest air temperatures observed were below the levels considered detrimental to the quality of cocoa. Given the depth of the collector and the basal position of the absorber, its ability to warm incoming air can be considered limited. Other more efficient and yet simple designs eg. a suspended absorber, could have placed a larger proportion of the incoming air in contact with the heated surface (Muhlbauer 1986). Thus the potential exists for achieving temperature rises in the indirect drier closer to that achieved in the direct drier without complicating the drier design.

4.1.3 Internal colour and cut-test

Larger variation was observed in colour meter L-a-b values for bean surfaces measured compared to that of those same nibs when grounded and sieved. Measurements showed decreasing coefficient of variation (c.v) of L-a-b values as nibs were ground to increasingly finer textures. This relationship between L-a-b values and particle size was reported by Shamsuddin and Dimick (1986). When beans were ground, mixtures of nibs had L-a-b results that were very different from the average of the individual nibs in a particular sample. L-values of bean internal surfaces approached values for corresponding ground nibs in samples of about 20 beans or more with a difference of less than 1 unit. The a-values of the cut bean surfaces were an average 4.3 units lower than measurements on the same nibs when ground. The b-values of the surfaces were also lower than that of resulting powders by an average 4.5 units in representative samples. The relationship between L-a-b measurements of ground nibs and the surface of those same nibs before they were ground is given in Table 1. Based on these results 30 beans per sample were taken for assessing colour differences amongst the drying treatments.

Table 1. Comparison of Colour of Ground Nibs and Nib Surfaces.

		L	a	b
Bean surface	s	4.16	1.41	3.69
	c.v	0.13	0.12	0.35
Powder	s	3.23	0.898	3.66
	c.v.	0.09	0.057	0.22

In most comparisons of corresponding L-a-b colour values for solar dried and sun dried bean treatments, the L-values were similar. L-values were found to be significantly different in only one comparison and at the 5% level (Table 2). Wide numerical variability of the L-values observed in individual samples as well as white pigmentation which gave high L-values indicate that non drying factors may be an influence. If L-values are important in quality this may not be influenced by drying. Beans with high (over 37) L-values appeared to be low in both brown and purple pigments. There were significant differences in a-values and b-values in some comparisons (Table 2). These differences were not perceptible when the cut test was performed. Purple pigments were more perceptible and increasingly masked the brown pigments as b-values decreased below 10 on the colour meter.

Table 2. Hunter L-a-b Colour Comparison - ground nibs

Loading	comparison		L	a	b
(kg/m^2)	ID vs OA	s	4.076	1.119	4.025
13.5		t	2.97*	<1	<1
	ID vs OA-SB	s	3.998	1.409	4.285
		t	<1	3.37*	2.78*
	ID vs OA	s	3.903	1.21	4.156
		t	<1	1.7	3.034*
	ID VS OA-SB	s	4.819	1.145	3.618
26.9		t	<1	2.17	4.77*
	DD vs OA	s	3.59	1.889	4.129
		t	2.19	3.08*	2.16
	DD vs OA-SB	s	4.574	1.848	3.589
		t	1.03	1.34	4.81*
	ID VS OA	s	17.374	1.257	10.28
		t	<1	3.40*	<1
	ID vs OA-SB	s	14.576	1.211	8.609
40.4		t	<1	4.19*	<1
	DD vs OA	s	4.704	1.485	3.74
		t	1.09	<1	1.02
	DD vs OA-SB	s	4.24	1.451	3.506
		t	<1	<1	<1

* Difference significant at t ≤ 0.05

At 13.5 kg/m^2 loading average a- and b-values of sun dried beans were both different from that of solar dried beans in only one comparison. In all other comparisons where there were differences either the a- or the b-value was significant. This latter was observed for other loading rates. However a consistent pattern could not be established.

Mean cut test scores for the drying methods ranged from 576.8 to 590.3 (Table 3). These scores indicate a high proportion of fully brown beans in the samples from all the drying treatments. The cut-test score as applied revealed no statistical differences amongst the drying methods (Table 4).

Shamsuddin and Dimick (1986) used the cut test score to assess the degree of fermentation and hence the flavour potential of the beans. Thus the very high test score observed is a reflection of the high degree of fermentation of the beans used in the experiment. A high level of fermentation was attributed to the long period (8 days) of fermentation used. Ilangantileke et al. (1991) showed that the fermentation index (A_{460}/A_{530}) increased with increased levels of browning.

The beans showed no signs of insect infestation or insect damage, and negligible levels of internal moulding. The very few beans affected by mould showed signs of external defect and their mouldiness could have occurred before drying. These defects were judged to be due to pre-fermentation problems. Thus the rates of drying achieved in all drying methods, under the conditions, were sufficiently rapid to prevent internal mould build up.

Table 3. Cut Test Score of Dried Beans

Category	n	Mean score
Indirect drier(ID)	6	590.3 ± 7.61
Direct drier (DD)	7	576.8 ± 35.48
Sun dried (OA)	7	580.3 ± 21.52
Sun dried (OA-SB)	5	579.6 ± 14.84

n = no of 100-bean samples

Table 4. Comparison of Drying Method by Cut Test Score.

Drying Method	d.f	t
OA vs ID	8	1.48 (ns)
OA vs DD	6	<1 (ns)
ID vs DD	7	<1 (ns)
OA-SB) vs ID	4	1.46

ns - not significant at $t \leq 0.05$

4.1.4 External appearance

The external appearance of beans dried in the indirect drier was much more acceptable than that dried in the open sun. Beans dried in the solar driers had few signs of external moulding. At 13.5 kg/m^2 there were no discernible differences in the external appearance of beans dried by the four methods and no signs of external mould. At 26.9 kg/m^2 there were no obvious differences between beans from the two solar driers. At the two higher loading rates, 26.9 kg/m^2 and 40.4 kg/m^2, differences between the two sun drying surfaces were variable from one run to the next. Beans from the indirect drier did not require polishing for the removal of mould. The sun dried beans were deemed to require polishing to reach export quality and cocoa beans dried on the solid surface had the most dull appearance overall. Overall, the level of moulding in the experiment was very low. In comparison, samples from identical fermented batches dried at the estate had a relatively higher level of external mould.

Surface moulding is a function of very high humidity and low air movement. Fitting the indirect drier with a ventilator resulted in obvious decline in visible surface mould in trial runs. The trays, with their perforated bases produced beans with less visible surface mould compared to solid surfaces under similar drying conditions. In sideline observations, beans on wooden and synthetic sack surfaces showed higher moulding than beans in the driers. Observations that beans dried on tarpaulins by small holders were more mouldy than beans dried on wooden surfaces were consistent with the above.

Perforations of the steel surfaces eliminated the condensation seen under the beans dried on synthetic surfaces. This can be explained by the added ventilation the perforations allow.

4.1.5 Shell strength under compression

The energy levels at which the cocoa bean shell cracks were statistically similar under uniform conditions for the drying methods (Table 6). For any of the drying methods examined, there were differences in the energy to shell cracking due to variation in moisture content. At 6% moisture content, beans were relatively brittle and both shells and nibs yielded relatively early compared to beans of a higher moisture content (Table 5). At 8% and 16% moisture (w.b) there is some deformation of the nib before the shell yields while the drier beans, 6% (w.b), undergo brittle fracture. The energy to yield was statistically higher at 8% and 16% compared to 6% (Table 6). Thus the ability of the beans to withstand loading increases with moisture content at least within the moisture range examined in this experiment.

Table 5. Shell strength of beans - Mean Energy (J). Variation with moisture content (w.b).

Beans	6%		8%		16%	
	ū	s^2	ū	s^2	ū	s^2
OA	0.1272	.00857	0.775	0.096	-	-
DD	0.0713	.00477	.7848	.0795	-	-
ID	0.1459	.01108	.5836	0.08	.785	0.0409

ū = mean measurement

Table 6. Comparison of crushing or shell strength.

Energy used (J)

Comparison	s	d.f	t
ID vs OA (6% w.b)	0.096	30	<1 ns
DD vs OA (6% w.b)	0.8251	28	1.85 ns
6% vs 8% (ID)	0.0243	23	50.6 **
8% vs 16% (ID)	0.0577	25	9.8 **

ns - $t \leq 0.05$ not significant

** $t \leq 0.01$ significant

Drying beans in the solar driers did not cause any differences in brittleness compared to sun dried controls. Neither was there any enhanced capacity to withstand loading. Resistance to fracture and crushing was found to be more related to moisture content than to method of drying. It is expected from the result that below 6% moisture content (w.b), beans will be brittle and the shells will tend to crack relatively early upon application of force. Thus leaving beans in the drier after they have been reduced to safe moisture levels, a practice which is very likely in a small farmer context, may result in increased brittleness and may have implications for polishing. That beans withstand more force when wet, points to the possibility of polishing just before final drying and avoid rewetting and redrying of beans. The risk of further delayed drying may be avoided.

4.2 Chemical Aspects

4.2.1 pH

The pH of solar and sun dried beans were statistically similar. Measured pH varied from 4.6 to 5.6 over the entire experiment. However pH values above 5.0 were recorded for all the treatments in a single drying run. Besides this run, the beans dried by both the solar driers and by open air sun drying treatments can be described as acidic by commercial standards. An acidic odour was obvious during the cut test. There was no statistical difference in pH effect due to the loading rates used in the experiment. High loading rates were expected to slow down drying rates especially in the first few days and therefore allow the pH to rise. Shade, and hence slow initial drying rate, has been shown to produce beans of higher pH when compared to more rapid drying methods (Jinap et al. 1994). The higher loading rates used may not have slowed the rate of early drying long enough to allow any significant increases in the pH of the nibs.

Acidity of beans is influenced by several factors and fermentation method is known to be very important. Fermentation in large boxes have been shown to produce more acid ferments than either heap fermentation as used in Ghana or in tray fermentation (Meyer et al. 1989). Thus in the context of the sun and solar drying treatments used in the experiment, pre-drying factors rather than drying may be responsible for the high acidity of the beans as measured by pH. Storage of pods before cracking is known to reduce acidity but is not practised on this estate and so was not utilized in the studies.

4.2.2 Titratable acidity

Titrated acidity varied from 20.4 - 26.9 meq(NaOH)/100g of ground nibs at the lowest loading rate and 17.98 - 29.09 meq/100g at 26.9 kg/m^2 . At the highest loading rate titrated acidity varied from 12.6 to 25.53 meq/100g of ground nibs.

The drying methods showed no significant differences in titratable acidity. There were differences in titratable acidity due to different loading rates. Across the drying methods, loading rates of 40.4 kg/m^2 gave statistically different levels of titratable acidity than the lower rates examined. There were no differences between loadings of 13.5 kg/m^2 and 26.9 kg/m^2 (Table 7).

Titratable acidity is a better measure of the total acids in cocoa liquor than is pH but both measures have been correlated with taste scores or flavour acidity (Duncan et al. 1989; Chong et al. 1986). That the pH is not significant while the titratable acidity is significant is not very clear. Jinap and Dimick (1990) found a -0.91 correlation coefficient relating titratable acidity and pH of samples. The difference in titratable acidity recorded however was just significant under the variability in physical conditions which existed throughout the experiment. High loading rates have the potential to slow down the initial rate of drying in the bean mass and therefore allow a longer period for the loss of acids either enzymatically (Liau 1978) or physically (Jinap et al. 1994). It is also probable that fermentation factors unknown to the investigator were involved in lowering titratable acidity.

Table 7 Comparison of titratable acidity.

Source	d.f.	SS	MS	f
Method	3	17.09	5.698	<1 (ns)
Loading	2	118.54	59.27	3.58*
13.5 vs 26.9 kg/m^2	1	0.805	0.805	<1 (ns)
26.9 vs 40.4 kg/m^2	1	96.89	96.89	5.85 *

ns - not statistically significant. * significant at 5% level.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

Fermented cocoa beans were dried in two different cabinet solar driers and by open air sun drying under field conditions. A direct drier and an indirectly heated solar drier were used while open air sun drying was performed on a perforated steel and on a solid wooden surface. The drying methods were examined for their ability to reduce the beans to safe moisture levels and for the quality of resulting dried product.

The indirect drier achieved temperature rises of up to 15 °C above ambient thereby reducing relative humidity of drying air while the direct drier achieved increases of up to 20 °C.

At loadings of 13.5 kg/m^2 sun drying on the wooden surface was the most efficient in removing residual moisture in the later stages of drying. This performance can be explained by the superior insulation provided by the wooden surface compared to the perforated steel surface. Beans on the steel surface were more exposed to fluctuations in ambient conditions and therefore lost heat much faster. Under adverse drying conditions, open air sun drying on the perforated steel surface was the least efficient method - the beans were hardly reduced to safe moisture levels in 310 hours of drying.

At higher loadings, the disadvantage of drying on a non perforated surface became apparent and the advantage of moving air through the beans in the indirect solar drier was clear. Despite higher temperatures in the direct solar drier, drying rates in the indirect drier were higher at high loading rates and therefore, the beans reached safe moisture levels earlier. The indirect drier reached safe moisture levels about 16-24 hours before sun drying on a perforated surface and 32 to 64 hours earlier than the wooden surface. The direct drier however removed more moisture in the later stages of drying.

At the higher loading rates the indirect drier in particular produced beans with lower levels of external moulding compared to the sun drying treatments. The removal of moisture in the first two to three days of drying is crucial to reduced mould development. The efficiency of the driers at this stage therefore was effective in reducing mould growth.

There was no significant difference amongst the drying methods with respect to internal quality or shell strength of the beans dried. The cocoa beans dried by the various methods had statistically similar pH, titratable acidity, cut-test score and shell strength.

5.2 CONCLUSIONS

Given the high ambient relative humidity in St. Lucia, solar driers have a role to play in the commercial drying of fermented cocoa beans. This is especially so when the drying surface is limited, loading rates are high and drying conditions are not favourable. Under these conditions, sun drying as practised is very often not "thin layer" and moving air through the beans has a distinct advantage. The generally higher rates of drying achieved in the solar driers at higher loading rates implies less labour is required for stirring to prevent mould build up and to protect the beans from rain. This can help reduce problems associated with labour scheduling and costs. These factors are important in St. Lucia given the high costs of labour relative to other factors of production, and given the fact that the farm workers' day generally ends at 2:00 pm. Solar driers certainly reduce beans to safe moisture levels at high loading with much less detriment to appearance and without adverse changes in quality. Thus the long term storage quality of the beans is improved.

It was obvious that improvements need to be made in designing driers so that higher temperatures can be achieved in the indirect solar drier. It was also clear that inadequate ventilation in the direct drier accounted for its slower rate of initial drying relative to the indirect drier. Thus an improvement in the ventilation of the direct solar drier is expected to improve its drying efficiency. Based on the findings of the study, this improvement in ventilation is desirable only for the first two to three days after which, air flow should be reduced to allow temperature build up.

Techniques which take advantage of the higher temperatures achieved in the direct drier can also be examined. Moving this warm air through the beans would expedite early drying. With these improvements either drier can be considered for drying the higher loads of cocoa beans. The direct drier utilized less resources during construction and, given its performance, may still be the more economical alternative after improvements are effected.

The study pointed to ways of improving open air sun drying, for example, by using a perforated drying surface for high loading rates. In addition, it indicated that the high acidity of beans was due to pre-fermentation factors. The box fermentation technique used was the most likely factor involved. Methods in which a smaller mass of beans is fermented or the aeration of the fermenting bean mass is improved during tend to produce less acid beans (Chong et al. 1978).

CHAPTER 6

RECOMMENDATIONS

From the observations made and lessons learnt during the study the following points are recommended for consideration.

a) The direct solar drier is recommended for use by farmers. This is based on the fact that it is the cheaper alternative in terms of resource and skill requirement. It is also more efficient in the later stages of drying. For smaller loading rates, the solar driers can be considered for the convenience but not for achieving marked improvements in drying rates.

b) The performance of a direct solar drier with down draught ventilation conditions to make better use of the heated air in the early stages of drying should be examined.

c) Farmers with limited space who are considering platforms or tray drying can improve ventilation of drying beans by perforation of these drying surfaces.

d) Fermentation of lower volumes of beans should be examined in an effort to reduce nib acidity. This is important as the box fermentation technique is the proposed method for handling the expanded output expected in St.Lucia.

e) The application of solar drying technology to other crops, for example hot peppers, should be pursued. Shared drier use amongst cocoa and other crops should reduce the cost per unit of output and make adoption more practical. The indirect solar drier has some relevance in this regard as some products are not suitable for direct drying. A full economic analysis of the specific case before recommendations are made is advised.

f) Use of colour meters in assessing the quality of dried cocoa requires further study. Their use, if made more practicable for use with dried beans, may reduce the subjectivity of the cut test especially where cocoa inspectors are not experienced.

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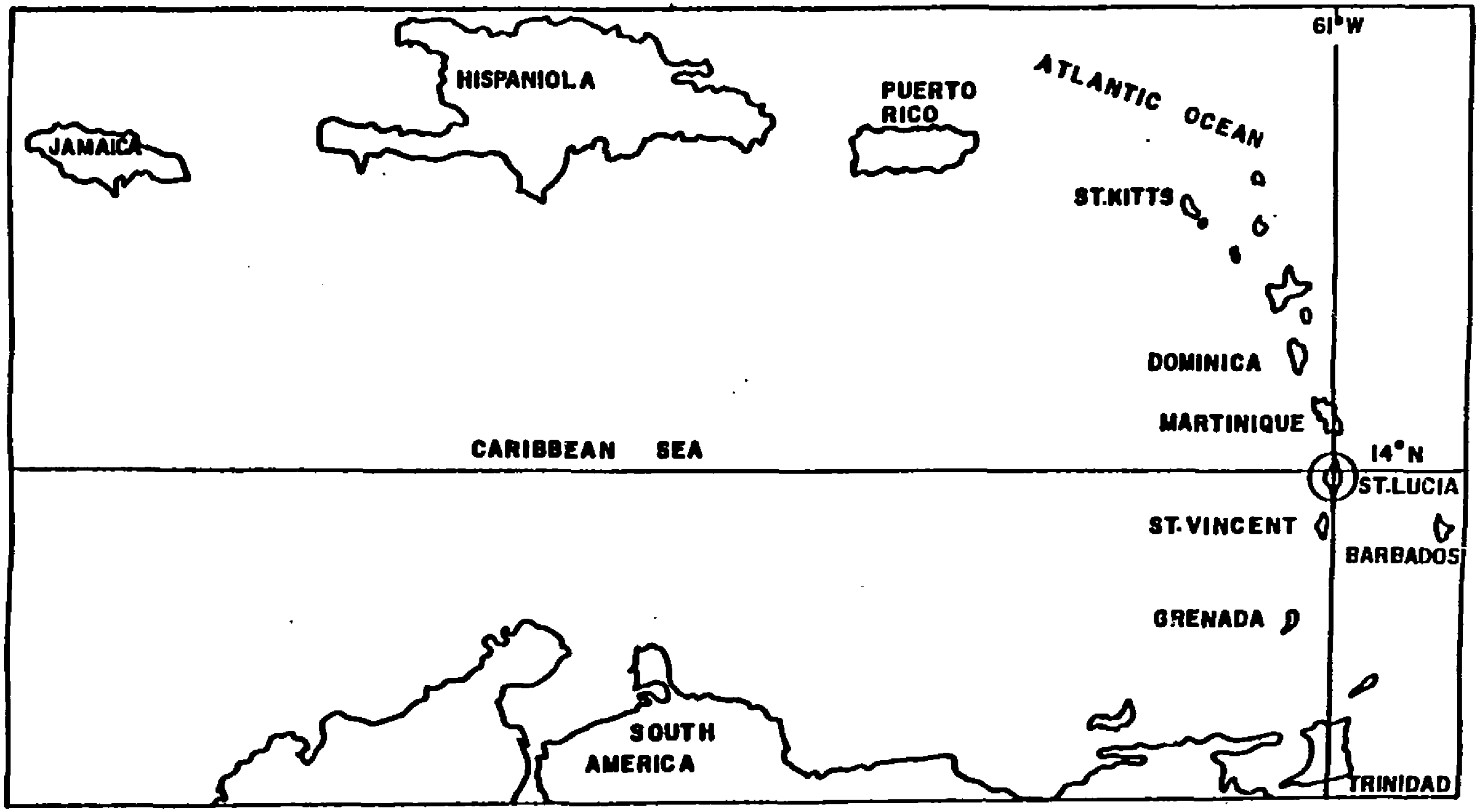
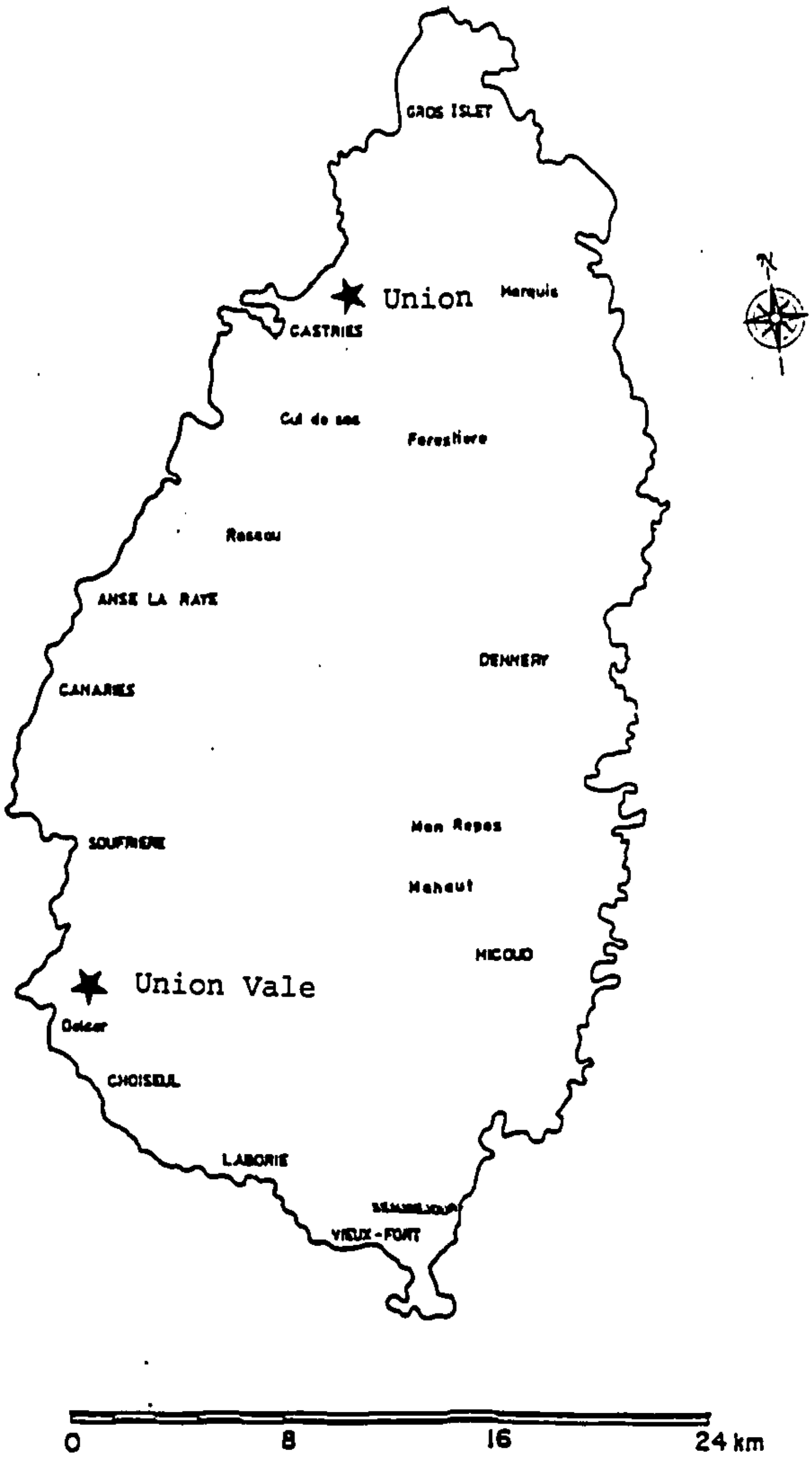
Appendices



Appendix A 1 Location map of St. Lucia



Appendix A 2 Location of study site

Appendix B Weather data for drying period.

(Temperatures refer to 8:00 to 18:00 hours)

Run 1 and 2

date	Sun-shine (hrs)	Avg R.H (%)	Rain fall (mm)	Wind run (km)	Temperature (^{o}C) Max.	min
20.1.95	9.6	77	0	73.4	30	26
21.1.95	9	78	0	76.8	29	26
22.1.95	8.7	72	0.2	74.3	30	26
23.1.95	7.4	73	0.2	110.0	29	27
24.1.95	9.6	72	0	68.4	29.5	26.5
25.1.95	9.2	72	0	50.9	29.5	25
26.1.95	9.6	75	0	77.6	30	23
27.1.95	9.5	71	2.4	91.5	29	26
28.1.95	9.1	71	0.3	121.7	30	25.5
3.2.95	9.8	67	0.5	82.5	29	26
4.2.95	7.4	67	0	115.9	29.5	26
5.2.95	8.5	63	0	115.9	29	26
6.2.95	5.2	82	2.2	70.5	29	27
7.2.95	9.3	58	0.5	109.2	30	26
8.2.95	6.7	76	9.1	91.7	29	26
9.2.95	9.6	67	0.6	81.5	30.5	25.5
10.2.95	9.5	72	0.6	81.5	30	25.5
11.2.95	7.5	85	0	107	29	26

Appendix B. cont'd   Weather data for drying period. Runs 3 and 4.

Date	Sun shine hr	Avg RH %	Rain fall mm	Wind run km	Temperature °C max	min
17.3.95	7.4	77	1.8	112	29.5	26
18.3.95	7.7	74	0.6	88.2	29.5	26.5
19.3.95	9.6	75	0	78.1	29	27
20.3.95	9.7	78	0.3	77.7	30.5	27
21.3.95	8.6	87	6.2	49	31.5	28
22.3.95	0.2	94	0.2	36.8	27	26
23.3.95	2.6	87	14.3	59.9	30	26
24.3.95	0.3	96	18.2	27.9	26.5	25
25.3.95	8.9	73	0.1	69.5	31	27
26.3.95	6.8	67	19.6	40.9	31	26
27.3.95	7.8	78	23.2	63.8	31	27
29.3.95	9.1	73	0.3	96.6	30.5	28
30.3.95	10.1	74	0	111.6	31	28
31.3.95	8.6	71	0.6	105.1	30	27.5
1.4.95	9.6	72	1.6	122.3	30	28
2.4.95	8.8	74	0.3	110.2	30	27
3.4.95	9.5	74	0.3	110.2	30	27.5
4.4.95	10.4	65	1.0	107.6	30	27.5
5.4.95	9.1	74	5.7	147.1	30.5	27.5
6.4.95	8.4	74	1.4	146.3	30	26.5

Appendix B. cont'd. Weather data for drying period.
Runs 5 and 6.

date	sun-shine hr	R.H %	rain-fall mm	Wind run km	temperature °C max	min
7.4.95	7.7	81	0	159	31	28.5
8.4.95	9.8	59	0	98.4	32	29
9.4.95	5.9	69	9.6	101.4	30	28
10.4.95	8.4	85	0	73.2	30	27.5
11.4.95	3.1	74	23.4	43.2	30.5	27.5
12.4.95	7.2	91	17.1	55.9	31	27
13.4.95	9.7	70	5.6	64.1	31	28
14.4.95	3.9	82	0	64.4	30.5	27
15.4.95	6.1	68	11.6	133.2	30.5	27
16.4.95	6.2	79	2.7	86.1	29.5	27
17.4.95	2.3	81	26.6	33.4	30	28
18.4.95	6.0	93	8.1	54.7	30	27
19.5.95	8.6	76	2.4	99	32	29
20.5.95	11.0	74	0	131.5	31.5	29
21.5.95	10.6	72	0	132.1	32	29
22.5.95	9.7	71	2.6	146.1	31	29
23.5.95	11.0	71	9.7	142.2	32	30
24.5.95	11.2	73	0	124.6	32	30
25.5.95	11.1	72	0	99.4	32	30

Appendix B cont'd. Weather data for drying period.

Run 7

Date	Sun-shine	Avg	Rain fall	Wind run	Temperature °C	
	hr	R.H	mm	km	max	min
29.5.95	9.2	69	0	123.1	31.5	29
30.5.95	9.7	72	0	131.1	32	30
31.5.95	-	-	-	-	31.5	30
1.6.95	-	-	7.5	-	32	29
2.6.95	-	77	3.2	146.5	32	30
3.6.95	10.8	70	1.7	124.9	32	30
4.6.95	5.4	70	4.0	84.5	-	-
5.6.95	7.7	76	0.5	112.6	31.5	29
6.6.95	2.8	85	13	94.7	30.5	28