THE EFFECT OF FEED PROPERTIES AND PROCESSING CONDITIONS
ON THE FINAL QUALITY OF LOCAL FRUIT AND VEGETABLE
PRODUCTS DEHYDRATED ON A SINGLE DRUM DRIER
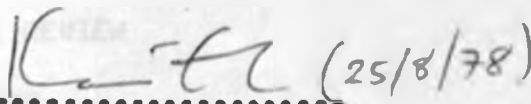
By

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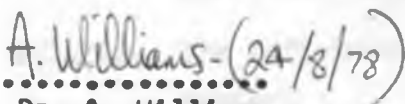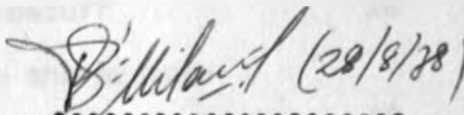
FOOD SCIENCE AND TECHNOLOGY

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DECLARATION

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

.........$\mathcal{Kurl}$.........($25/8/78$)
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ABSTRACT

Various changes occur to foods when they are dehydrated
by any of the existing methods. These changes, both physical
and chemical, depend on the physical and chemical characte-
ristics of the raw materials, the methods of drying and the
characteristics of the drying equipment.

The purpose of this project was to find out the effect
of different feed properties and processing conditions on the
final quality of the drum-dried tropical products (Cassava, horse bean,
banana)

The optimal conditions of production were assessed on
the basis of the final moisture content, bulk density, brow-
ning, nutrient loss, colour, taste and storage life. The
effect of the use of sulphur dioxide (SO_2) were also examined
during the manufacture and storage of cassava, beans and banana
flakes.

Established methods of manufacturing of trade commodities
such as Irish potatoes, sweet potatoes, pumpkins and yams were
consulted and modified to suit the working conditions. Only
for cassava, horse beans and banana
one feed method (the top-roll feed) was tried for all the pro-
ducts. Similar results were obtained with all the materials
dried on the single drum drier. Low drum speeds resulted in
a thick product film, a low production rate and high bulk den-
sity. High puree solids content gave high production rates
and a thinner film. Moisture content varied with film thick-
ness, drum speed, steam pressure and the total puree solids.
The product browning depended on the steam pressure and the
drum speed. The heat damage was reduced considerably by

addition of SO_2 before drying.

"Triangle Taste Tests", carried out between mashed raw
(or cooked) and reconstituted drum dried foods indicated that
the drum-dried products were acceptable ($P \leq 0.05$). This was
encouraging as the panelists represented the local consumers
of the products.

The product quality during storage was affected by tempe-
ratures, light, packing materials as well as the presence of
SO_2.

The cyanide test was positive in both the horse beans
and cassava. However, further tests showed that the precoo-
king step reduced the original content of cyanide by about
ten-fold, which explains why there is no danger in eating the
cooked beans and cassava.

ACKNOWLEDGEMENTS

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1. LITERATURE REVIEW

1.1. Introduction

In the developing countries, where food is in short supply and refrigeration facilities are limited, the drying of foods would appear to be the most suitable form of preservation (1).

An acceptable dehydrated food should, from the point of view of cost and price, be competitive with other types of preserved food; have a taste, odour and appearance comparable with the fresh product or with products processed by other means; reconstitute readily; retain nutritive values, and have good storage stability. These would be some of the criteria to consider if an acceptable and successful dehydrated food product is desired (2).

Methods of dehydration range from the cheap to the very expensive. Drum drying is a high cost method (3) but the quality of the final product is not reproducible by more economical processes. Dried foods have an increased shelf-life under proper storage conditions because a greater degree of inhibition of bacteria, enzymatic and mould actions has been achieved. The degree of concentration through drying is higher than by any other method. According to Luhand Woodroof and Desrosier (4, 2), a dried product has the following advantages:

(a) Low production cost

(b) Consistent quality

(c) Minimum labour

(d) Limited equipment

(e) Minimum storage requirements

(f) Minimum distribution costs

(g) Consumer convenience

Factors contributing to the success of dehydration (5):

(a) Selection of raw materials for drying on the basis of
     characteristics best suited to this method of preserva-
     tion.

(b) Control of undesirable changes in quality during prepara-
     tion for drying and actual drying process.

(c) More rapid reduction of moisture content to the level
     required for optimum storage stability under conditions
     of minimum damage to quality.

(d) Production of porous structure during drying (freeze
     drying, vacuum ovens, etc.).

(e) Retention and restoration of volatile flavours (very
     difficult)(6).

(f) Solvent or liquid carrier dehydration.

(g) Improvements in packaging.

     Owing to a number of reasons, based on the design of the
Pilot Plant, "atmospheric" drum drier, lack of facilities to
compensate for variations in steam pressure, relative humidity,
etc. during the drying process, and poor packaging methods, the
factors (c) - (g) were not controlled.

1.2. The drum drying process

     The drying of liquids on drum driers involves the trans-
fer of heat from condensing steam within the drum, through the

thick metal wall of the drum drier, to the thin layer of feed-
stock on the outer surface of the drum. The composition (mois-
ture content) and temperature of film is progressively changing
from feed point to discharge point. The overall heat transfer
rate as drying proceeds will therefore vary considerably and
will depend on (7):

(a) Solids content and physical properties of the solids.

(b) Steam temperature and quality.

(c) Film thickness of food material being processed.

(d) Metal shell thickness and its thermal conductivity.

Neither the solids content nor the film temperature remains
constant during the drying operation so that determination of
overall heat transfer rates are usually made on a Pilot-scale
unit (7). The overall heat transfer rates have been shown to
depend on the solids content as well as the temperature gra-
dients. There is no general rule of assessing the overall heat
transfer rates for a particular process unless by experiment
with the actual drier in question.

As drying proceeds the conductivity of the product becomes
important. Whereas the temperature difference between the feed-
stock and steam will be a maximum at the feed point, this may
fall to a very few degrees at the discharge point. The heat
transfer coefficient on the steam side is not important except
in cases of extremely high rates of evaporation, although it
is most important to provide adequate means for bleeding off
incondensable gases and condensate.

Metal thickness, however, assumes considerable importance

and should be maintained at a minimum but consistent with sound design and safety requirements.

In the case of very concentrated solutions or suspensions doubling the drum wall thickness may result in almost halving the production rate of dry material. Van Marle, (8) showed that the overall heat transfer coefficient on a double drum drier under optimum conditions varied from 1756 $Kcal.m^{-2}.h^{-1}.^{o}C^{-1}$ at nip to 880 $Kcal.m^{-2}.h^{-1}.^{o}C^{-1}$ at the knife area. Typical temperature drops across the metal wall can range from 36 - 19°C. Under favourable commercial conditions; a maximum evaporation rate of the order of 88.8 kg H_2O . $h^{-1}.m^{-2}$ drum surface has also been recorded (7). These unknown factors such as heat transfer rates and the effect of drum speed and film thickness makes Pilot-scale tests imperative in sizing a drum drier. The thermal efficiency of a drum drier is quite high. Thermal efficiency is the ratio of the nett amount of heat required to evaporate 1 kg. of water from product to the total heat supplied to the apparatus. Values of 80-90% have been reported (7) corresponding to a specific steam ratio of 1.2 - 1.5 kg of steam per kg of moisture evaporated.

The thermal efficiency of a drum drier installation will naturally depend upon the design and type, since the greater the ineffective drum surface area the greater the heat loss. A single drum drier operates as a rule at a higher efficiency than the double drum drier (7).

The throughput of driers can be improved to an optimum level by the most favourable combination of solids concentration,

drum speeds and heating temperatures to suit a particular feedstock.

The rate of transfer of feed to drum surface increases with drum speeds over the lower ranges. Above a certain speed of rotation film thickness usually decreases leading to a loss of capacity unless compensated for by increase in steam temperature. Beyond certain temperatures on the other hand, blistering effects with some feedstocks will result in loss of production (9). The time required for drying specific products depends upon properties of the raw materials including moisture content, composition, and particle size to be dried, and also upon characteristics of the drying system involved (10).

In the drying of milk using a double drum drier (46), high moisture contents were found to be due to either a low temperature, a thick film, a high total solids content or a fast speed.

The throughput of a drum drier depends on the following (7, 9):

(a) - the effective drum surface in contact with feed material.

(b) - drying characteristics of the material.

(c) - temperature of the heating medium.

(d) - thickness of the cylinder wall.

(e) - the solids content of the feed material.

(f) - uniformity and thickness of film which can be applied
       on the drum surface.

(g) - rate of heat transfer obtainable with the heating medium
        employed.

The relationship between drum speed, steam pressure, mash solids, drier output, and sheet density throughout the wide range of conditions was shown by Drazga and Eskew (11). The output of the product was found to be directly proportional to the increase in drum speed. However, above a certain point an increase in the steam pressure could not reduce the product to a desired moisture content in a single pass on the drum drier.

1.3. The drum drier

Heat transfer from the condensing steam to the product on the drum-drier surface is by conduction. Transfer of heat by convection either free or forced as well as radiation heat transfer, dominate on the product side (7).

Rotational speeds of 5 - 20 rpm suggest a short contact time of about 3-12 seconds. As free moisture (12) is present for a substantial portion of this period, the dried product reaches the surface temperature of the cylinder for an exceedingly short time. Drum driers are therefore suitable for most materials which show little or no thermal degradation in the course of drying. Where the material is unduly sensitive to temperature special precautions may be taken.

Processing conditions often dictate the choice of the drier used. For example, drum driers are suitable for small and medium scale productions of a variety of foods.

1.3.1. <u>Factors to be considered during a drying process (7)</u>

(a) <u>Film of feed developed</u>

It is important to note whether the feed material forms an adequate and uniform film on the drum surface.

(b) <u>The drum material</u>

The production of a suitable film of food material is dependent on the type of drum surface.

(c) <u>Product contamination</u>

The contamination of the product with the drum material is to be avoided at all costs. The level of contamination will depend on choice of the drum material. Cast iron, steels of varying quality and chromium-plated iron surfaces are used in practice.

(d) <u>Feed method</u>

The method of feed employed should ensure the production of a good and even film without deterioration of feed material due to a rise in temperature and settlement of material. The requirements being: product composition corresponding to the solids content of the feed material.

(e) <u>Drum steam pressure</u>

If this is excessive it may result in a loss of the film-covering capacity due to blistering of the feed on the hot drum.

(f) <u>Drum speed</u>

The peripheral speed of the drum affects the film pick-up and the thickness of the film. Variations in bulk density

and moisture content of final product are related to the drum
speed.

(g) Environmental effects

Undue dust formation or a product of unsuitable physical
characteristics may result in the use of an alternative method
of dehydration.

The atmospheric conditions of the surroundings may very
much affect the processing conditions.

Once it has been established that the drum drier is the
most suitable method of producing a dehydrated product and the
method of feed has been ascertained, then the production rate
per square metre of effective drying surface can be determined.
It should be noted that a regular and uniform operation of a
full-scale drier will usually give production rates that are
at least equal to that obtained under optimum, small-scale
tests. This means that the scale-up sizing of a drier is rea-
sonably straight forward; a safety factor is normally built
into the process in order to give an adequate degree of flexi-
bility for shut-down periods or changes in marketing demands.

1.3.2. The single drum drier

Some possible feeding systems:

(a) Top-roll feed as practised in the Pilot Plant, University
     of Nairobi (Cording et al, (13)).

(b) Dip method.

(c) Spray method.

(d) Auxiliary roll feed (Anon,(14)).

(e) Modification on (a). Constant feed using volumetric tanks
     or mechanical pumps.

1.4. Theory of drum drying

Dehydration is a unit operation that involves both heat
and mass transfer (15). In a drum drying process heat is trans-
ferred to the product surface by conduction, then into and
through the product by conduction and convection, the latter
resulting from the diffusion of water vapour which is vapou-
rised at the hot surface. Heat is transferred from the product
surface by the diffusion of water vapour out of the product,
by convective cooling from the surrounding air, and by radia-
tion.

Considering mass transfer, water is vapourised at the
hot drum surface, and the vapour diffuses through the food
material. Vapourisation of water at the hot drum surface
establishes a concentration gradient, thereby causing liquid
water to diffuse toward the hot drum surface. The temperature
gradient in the product decreases as one goes further from
the hot drum surface and the water vapour diffuses toward the
lower temperature, thus transferring the heat rapidly through
the product. The product then becomes hotter than the ambient
air and vapourisation also occurs at the food material/air
interface. Therefore, a liquid water concentration gradient
is established and liquid water diffuses toward the food mate-
rial/air interface surface. The situation exists in which

water is being vapourised at both the hot drum surface and food material/air interface surface, liquid water is diffusing toward both surfaces, and water vapour toward the food material/air interface only.

The overall drying rate curve shows the constant rate period and the falling rate period. However the constant rate, contrary to existing theory on the drying rate when convective drying is involved, is not truly constant but tends to decrease slowly (15). Falling rate begins with the disappearance of liquid from the hot surface interface. ("Constant rate" period drying is almost instantaneous compared with "falling rate" period using the drum drier).

1.4.1. Mass balance and heat balance

Figure 1.1. Vertical X-section along the diameter of the single drum drier for mass and heat balance determination.

At the steady state:

(a) Mass balance

Mass in = Mass out

Dry solids in feed = Dry solids
+ Water in feed   in product
+ Steam in   + Water in
                        product
                        + Condensate
                        out
                        + Water
                        evaporated
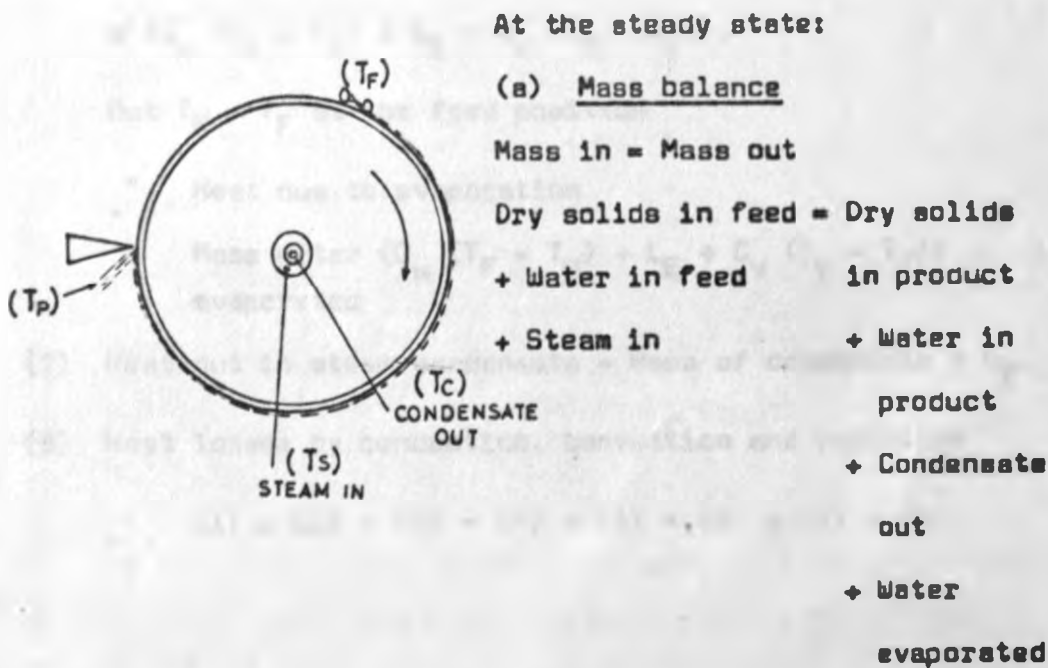
(b) <u>Heat balance</u>

Heat in = heat out

<u>Heat in:</u>

(1) Heat from dry solids in feed = Mass dry solids

$\times C_s (T_F - T_D)$.

(2) Heat from water in feed = Mass water in feed

$\times C_w (T_F - T_D)$.

(3) Heat in from condensing steam = Mass condensate $\times h_g$

(3) is obtained as the difference between the steam consumption of loaded drum and the free run consumption.

<u>Heat out:</u>

(4) Heat from dry solids out = Mass dry solids $\times C_s (T_p - T_D)$.

(5) Heat from water in product out = Mass water in product out

$\times C_w (T_p - T_D)$.

(6) Heat due to water evaporated = Mass water evaporated

$\times (C_w (T_E - T_D) + L_E + C_v (T_p - T_E))$.

But $T_E = T_F$ at the feed position

$\therefore$ Heat due to evaporation

= Mass water $(C_w (T_F - T_D) + L_E + C_v (T_p - T_F))$ evaporated

(7) Heat out in steam condensate = Mass of condensate $\times h_f$.

(8) Heat losses by conduction, convection and radiation

$\therefore$ (1) + (2) + (3) = (4) + (5) + (6) + (7) + (8).

Notation

C_s = Specific heat of dry solids, approx. 0.8 - 0.9 $KJ^{-1}.^oK^{-1}$

C_v = Specific heat of water vapour, 1.8 $KJ.Kg^{-1}.^oK^{-1}$ at 20^oC

C_w = Specific heat of liquid water, 4.18 $KJ.Kg^{-1}.^oK^{-1}$ at 20^oC

T_f = Feed temperature, ^oC

T_p = Product temperature, ^oC

T_c = Steam condensate temperature, ^oC

T_s = Steam temperature, ^oC

T_d = Datum temperature, usually = T_f, ^oC

L_e = Latent heat of vapourisation = (h_{fg}) $KJ.Kg^{-1}$

h_g = Enthalpy of steam at T_s, $KJ.Kg^{-1}$

N.B.

(1) Once the drum has heated up initially one only has to consider the heat required to maintain drum surface temperature and subtract it from the gross heat supplied during dehydration. This gives a nett heat utilisation that although based on incompatible heat loss conditions (i.e. drum surface alone and drum + food will give different heat loss conditions) the author feels the value obtained although erroneous must approximate closely to the actual nett heat utilisation.

(2) For most steam heating situations where very little condensate is in contact with the system it is better to consider h_f at the steam condensing temperature i.e. just use (h_{fg}).

(3) The heat losses and specific heat, C_s, can be determined approximately. With a knowledge of the water content

(dry weight basis) one can determine C_s and consequently one can estimate the heat losses from equation No.8.

1.4.2. The overall heat transfer coefficient

Drum drying 1000 - 1500 Kcal/m^2, h, ^oC (16).

1.4.2.1. The basic equation for the drum drier (17).is

$$\frac{dw}{dt} = \frac{UA\Delta Tm}{\Delta H_v} \quad \ldots\ldots\ldots(1)$$

$\frac{dw}{dt}$ = rate of evaporation, Kg H_2O h^{-1}. M^{-2}

U = the overall heat transfer coefficient
Kcal m^{-2}. h^{-1}. $^oC^{-1}$

ΔT_m = log mean temperature difference, ^oC

A = effective heat transfer surface area, m^2

ΔH_v = latent heat of vapourisation of water from
the product at an arbitery evaporation
temperature, Kcal.Kg^{-1}

For example: Given that

(a) The drum dimensions are as follows:

diameter 2m

length 3 m

and the drum travels one half the circumference before
being scraped.

(b) The slurry contains: 18.5% solids

81.5% moisture (wwb)

(c) The final product contains 3.8% moisture after drying.

Retention time in drying = 15 seconds. Calculate the overall
heat transfer coefficient.

Solution

(a) The original composition in terms of $\dfrac{\text{Kgs of water}}{\text{Kg of dry solid}}$

is given by $\dfrac{81.5}{18.5} = 4.4$

(b) Final composition after drying is reduced to

$\dfrac{3.8}{96.2} = 0.0395$ Kgs. $\dfrac{H_2O}{\text{kg dry solid}}$

(c) Production rate is given as 2.15 $\dfrac{\text{Kg wet product}}{\text{h.m}^2}$

(obtained from curves of drum speed against production

rate).

This is equivalent to 2.15 (1-0.038) = $\dfrac{2.07 \text{ Kg dry solid}}{\text{h.m}^2}$

(d) Thus on one hour basis the amount of moisture entering
drier is 2.07 x 4.4 = 9.11 kg.h^{-1}.m^{-2}
and the amount of moisture leaving drier is
2.07 x 0.082 kg.h^{-1}.m^{-2}

(e) Moisture removed per hour = 9.11 - 0.082
$= 9.03$ kg.h^{-1}.m^{-2}

Consequently, if one carries out the following:

(a) Calculate the effective drum drying surface area.

(b) Determine steam pressure in the drum and the corresponding
steam temperature.

(c) Assume some value for moisture vapourisation temperature
100°C.

(d) Obtain ΔH_v from tables (18) at corresponding temperature, then one can estimate "U" the overall heat transfer coefficient for the conditions used.

1.4.2.2. Alternatively, the drier and the product may be treated from the point of view of radial heat transfer through concentric cylinders (true for infinite thick cylinders)(12, 19, 20). In that case:

$$\frac{dq}{dt} = \frac{2\, L\Pi(T_1 - T_o)}{\dfrac{1}{r_1 h_1} + \dfrac{\ln(r_2/r_1)}{k_1} + \dfrac{\ln(r_3/r_2)}{k_2} + \dfrac{1}{r_3 h_o}} \quad \dots (2)$$

and $U = \dfrac{1}{\dfrac{1}{h_1} + \dfrac{1}{k_1} + \dfrac{1}{k_2} + \dfrac{1}{h_o}}$ ....(3) <u>N.B.</u> Ignoring any scaling or fouling factor.

where, $\dfrac{dq}{dt}$ = rate of heat transfer Kcal h^{-1}

T_1 = steam temperature, ^{o}C

T_o = air temperature, outside cylinder, ^{o}C

K_1 = thermal conductivity of drum wall, Kcal.m^{-1}.h^{-1}.^{o}C^{-1}

K_2 = thermal conductivity of product film, Kcal.m^{-1}.h^{-1}.^{o}C^{-1}

r_1 = drum radius (internal), m.

r_2 = drum radius (external), m.

r_3 = product film radius, m.

L = drum length, m.

U = overall heat transfer coefficient Kcal.m^{-2}.h^{-1}.^{o}C^{-1}

h_1 = surface transfer coefficient (steam/drum surface) Kcal.m^{-2}.h^{-1}.^{o}C^{-1}

h_o = surface transfer coefficient (air/product) Kcal.m^{-2}.h^{-1}.^{o}C^{-1}

1.5. The product

1.5.1. Processing

Figure 1.2. Principal operations in the production
of typical dehydrated foodstuffs (6, 21).

Fruits and Vegetables
↓
Washing
↓
Sorting
↓
Peeling, slicing, pitting, coring
↓
Blanching
↓
Sulphiting
↓
Drying
↓
Packaging
↓
Storage
↓
Transport
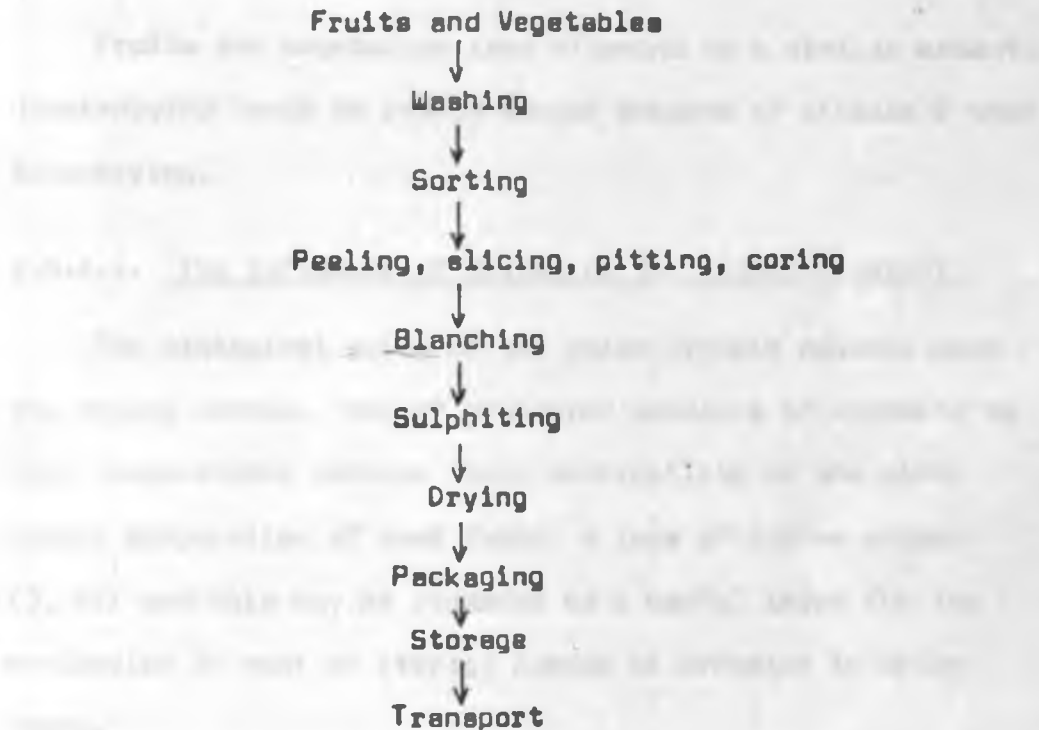
1.5.2. The influence of dehydration on the nutritive value of the foodstuff (2).

During dehydration, a foodstuff loses moisture content
and consequently causes a concentration of the nutrients in
the final product. Thus, proteins, fats and carbohydrates are
present in larger amounts per unit weight in the dried food
product than in the raw material.

However the dehydrated food product has a lower quality
than the original raw foodstuff. The loss in vitamin content

depends upon the method of preparation, dehydration and sto-
rage of the final dried product.

The loss in ascorbic acid and carotenes occurs mainly
through oxidation. Riboflavin is light-sensitive, while
thiamine is heat-sensitive.

Fruits and vegetables lose vitamins to a similar extent.
Quick-drying tends to retain larger amounts of vitamin C than
slow-drying.

1.5.2.1. The influence of drying on the protein content

The biological value of the dried protein depends upon
the drying method. Use of prolonged exposure of proteins to
high temperatures reduces their availability in the diet.
During dehydration of most foods, a loss of lysine occurs
(3, 22) and this may be regarded as a useful index for the
evaluation of heat or storage damage to proteins in dried
foods.

1.5.2.2. The influence of drying on fats

Oxidative rancidity is an important factor to be conside-
red for the keeping quality of dried foods. Higher tempera-
tures result in higher degrees of deterioration of the fat.
This deterioration can be avoided by the addition of antioxi-
dants.

1.5.2.3. The influence of drying on carbohydrates

Fruits and vegetables are rich in carbohydrates. During
dehydration processes a deterioration in fruit product is often

directly related to the carbohydrate content. A discolouration of the product is usually due to non-enzymatic browning or caramelisation reactions.

The addition of sulphur dioxide reduces both enzymatic and non-enzymatic browning because sulphur dioxide acts as an inhibitor of these reactions and also as an antioxidant.

Van Arsdel (6) claims critical moisture levels in browning as 1-30%. Consequently browning occurs at slow rates for moisture contents less than 1% and greater than 30% and that other reactions, such as rancidity become more important in the food deterioration during storage.

1.5.2.4. The influence of drying on food acceptance

The caramelisation, discolouration, loss in texture and physical form, loss of volatile flavours and poor rehydration characteristics are properties of dried foods which tend to discourage consumer acceptance.

Dehydration processes should, therefore, be designed to minimise these undesirable characteristics.

1.5.2.5. The influence of drying on toxic constituents (e.g. the cyanide ions).

The Horse beans as well as the Lima beans and cassava contain linamarin (23). This compound releases cyanide (a very toxic constituent) under autohydrolysis by the following mechanism:

$$\text{Glu} - \overset{\overset{\displaystyle CH_3}{|}}{\underset{\underset{\displaystyle CH_3}{|}}{C}} - CN \quad \xrightarrow{\text{HOH}} \quad \overset{\text{Glu} + CH_3}{\underset{\underset{\displaystyle CH_3}{|}}{\overset{|}{C} - O + HCN}}$$
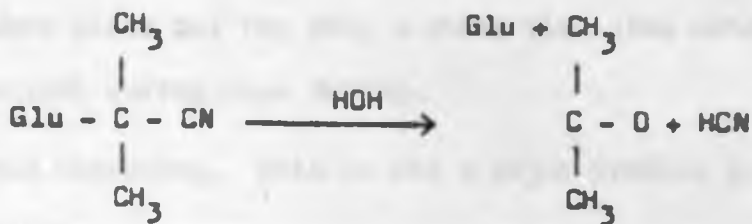
Linamarin

The spontaneous release of cyanide (HCN) from the plant
depends upon the presence of a specific glucosidase (enzyme)
and water. The consumption of the raw beans is, consequently,
fatal (23). Fortunately most of the cyanide ions present in
the raw product are lost in the washing and cooking processes
preceding dehydration.

1.5.3. Changes in the food during dehydration (6)

The following changes are noticed during dehydration prac-
tices:

(a) Browning reactions which depend on the bound water (24)
content of the food material in relation to its environ-
ment. This is a major problem during drum drier dehydra-
tion where high temperatures are applied.

(b) Shrinkage effects due to loss of 'turgor'. In thin film
dehydration this is not so evident.

(c) Bulk density: compared to the raw material, the bulk
density of the dehydrated product is very much lower.
Slow and fast drying may result in products of the same
moisture content but different bulk densities.

(d) Migration of soluble constituents within product. This

takes place but for only a short time (the constant rate period) during drum drying.

(e) Case hardening. This is not a major problem in drum drying.

(f) Irreversible loss of ability to rehydrate even when the temperature-hold time is not sufficient to produce browning or scorching.

(g) Loss of volatile constituents. This is an irreversible process and attempts to retain flavour components always prove difficult.

1.6. General conclusions from literature

A maximum drying rate can be obtained by using the following conditions:

(a) A uniform film thickness across the drum surface.

(b) A minimum retention time required to give the desired moisture content in the dried flakes.

(c) The maximum steam pressure for the given conditions and,

(d) A maximum puree solids content in the feed material.

A high moisture content in a drum dried product is due to the use of:

(a) low steam temperature

(b) a thick film

(c) a high total solids content

(d) fast speeds of drum rotation;

Heat damage (browning) and nutritive change in foods depend

on the physical and chemical characteristics of the food as
well as the drying temperature, retention time, moisture con-
tent and the storage conditions. The retention time required
for drying specific products depends upon properties of the
raw materials, including moisture content, composition, shape
and size of particles (film) to be dried, and also upon the
characteristics of the drier.

The capacity of the drum drier depends upon the follo-
wing:

(a)   the effective drum surface in contact with the feed stock

(b)   the drying characteristics of the feed material

(c)   the temperature of the process steam

(d)   the thickness of the drum wall

(e)   the solids content of the feed stock

(f)   the uniformity and thickness of the film of food material
      on the drum surface.

The film thickness depends on the drum speed, total solids
in puree, and the nip setting between the drum and feed rollers.

The overall rate of heat transfer as drum drying proceeds,
depends upon the following:

(a)   the solids content and physical properties of the film

(b)   the steam temperature

(c)   the film thickness of feed material

(d)   the drum-wall thickness and its thermal conductivity.

2. MATERIALS AND METHODS

2.1. Materials

(a) Fresh cassava (see section 3.1.4.1. for further details)

(b) Ripe bananas (see section 3.2.2. for further details)

(c) Dry horse beans (see section 3.3.2. for further details).

The materials were obtained from local markets or from the
fields. To make a batch of the raw puree, materials from various
sources were mixed up. A random variation was desired although
problems arose in supplies.

2.2. Reagents

Pure 'Analar' reagents were supplied by the Howse and Mac-
George, Nairobi.

2.3. Equipment

2.3.1. The Lips Kitchen Machines for cutting, pureeing, pul-
ping, screening and mixing. (Combirex IR8, Jakob Lips, 8902
Urdorf, Switzerland).

2.3.2. Steam pressure-cooker for pre-cooking ("Kelomat" Inter-
national A-1071 Vienna, Austria).

2.3.3. Single drum drier for drying (APV-Mitchell (Dryers)
Ltd., Carlisle, England).

2.3.3.1. The single drum drier (25)

Figure 2.1. <u>Vertical cross section along the diameter of the of the single drum drier.</u>
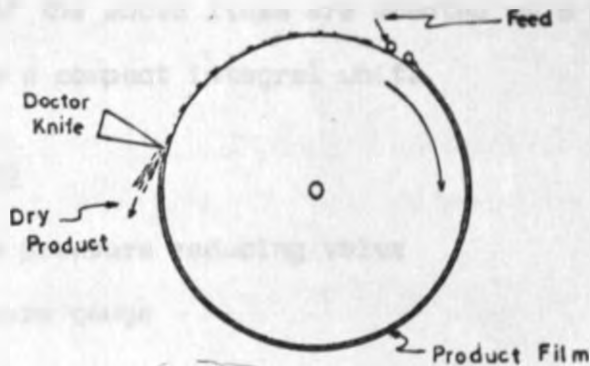
Diameter 12 in. (0.3048 m) Total surface area = 0.2797 m^2
Length 11.5 in. (0.2921 m) Effective drying surface = 79.3%
(0.2217 m^2). Chromium plated product contact parts with a
variable speed gear and a handwheel speed control.

The machine consists of one steam heated hollow cylinder,
the surface being very accurately ground. Wet material is fed
to the feed rollers and picked up on the surface of the cylin-
der which rotates and dries the material. After the drying
action has taken place the film is removed by a doctor or scra-
per knife, so located that the maximum surface area of the drum
is utilized, and collected in the tray provided.

The speed of the cylinder, the feed rate, and the pressure
of the doctor knife are all adjustable to give a finished pro-
duct of the desired moisture content. The drying cylinder is
driven from a size F10 Carter hydraulic variable speed gear
unit, transmitting power to a cast iron spur wheel fitted to
the drum trunnion all combined to give drying cylinder speeds

variable between 0 and 19 revolutions per minute. Thus the speed can be varied so that the drying time can be lengthened or shortened according to the material being handled.

All of the above items are mounted on a fabricated stand to provide a compact integral unit.

Accessories

(a) Steam pressure reducing valve

(b) Pressure gauge

(c) Safety valve

(d) Steam trap at condensate outlet, which gives efficient and economical operation of the equipment.

Figure 2.2. Vertical cross section view of the single drum drier along its length.
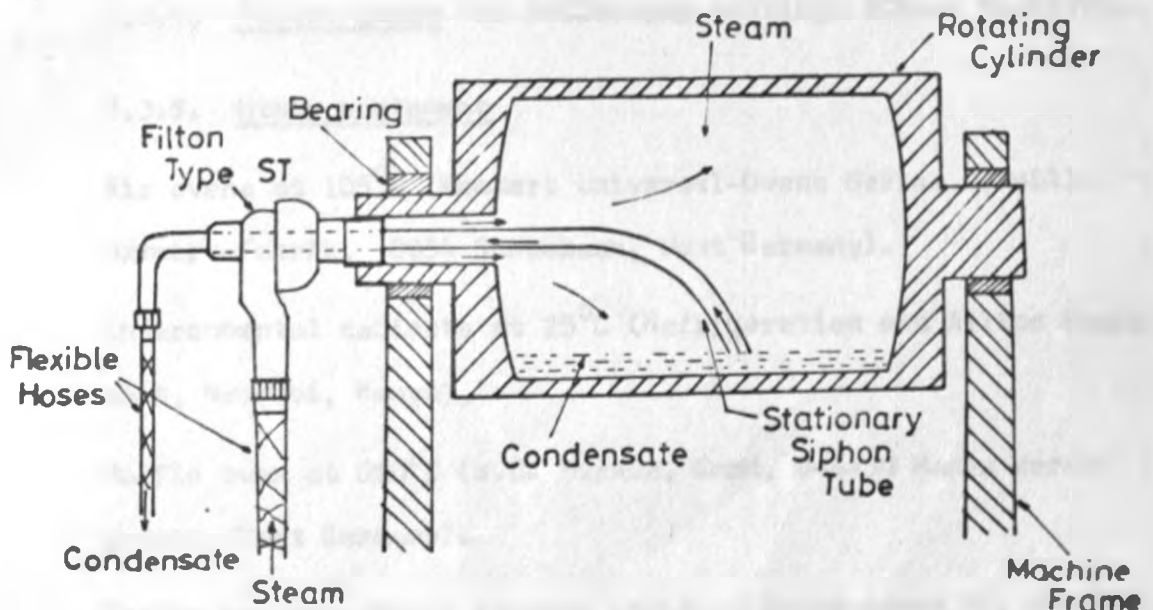
Source: Owners specification for the operation of an Experimental Drum Drier (25).

A.P.V. - Mitchell (Dryers) Ltd., Carlisle, England.

Note: Steam from the mains is at 7 kg.cm^{-2} gauge. It passes through a filter to remove impurities and 'pure' steam passes through two reducing valves which regulate the pressure entering the drum upto the maximum allowed of about 5.6 kg.cm^{-2} gauge (80 lbs. in.$^{-2}$ gauge) (25).

2.3.4. Rud. Fuchs single disc milling machine for milling the flakes into powder. (Basel, Switzerland).

2.3.5. 'Audion Elektro' manual-sealing jaws for sealing poly-thene bags.

2.3.6. 'Telemax' thermocouple and mercury-in-glass thermometer for temperature measurements. (West Germany).

2.3.7. Stop watch for time measurement.

2.3.8. Feeler gauge for roller-gap settings (Cimco No.4352).

2.3.9. Other equipment

Air ovens at 105°C (Memmert Universal-Ovens Series U, Willi-Memmert-Fabrik, D854 Schwabach, West Germany).

Environmental cabinets at 25°C (Refrigeration and Allied Equipment, Nairobi, Kenya).

Muffle oven at 600°C (W.C. Heraus, GmbH, D-6450 Hanau Werke-gruppe, West Germany).

Taring and analytical balance (Mettler Instrumente AG, CH-8606 Greifensee-Zurich, Switzerland).

Hand refractometer, 0 - 50° Brix("Kikuchi", Tokyo, Japan).

Laboratory vacuum evaporator ("Heidolph, West Germany).

2.4. Technical Measurements

2.4.1. Operational data for the drum drier (26)

The feed-rate G°(kg/h) and the dry product rate M°(kg/h) under equilibrium conditions, generally characterise the drum drier performance.

$$M^\circ = G^\circ \frac{100 - X_a}{100 - X_e}$$

Where X_a = water content of puree on dry weight basis

X_e = moisture content of product on dry weight basis.

$$W^\circ = G^\circ \frac{X_a - X_e}{100 - X_e} , \text{ is water evaporated}$$

Steam consumption D°

$$Q^\circ = D^\circ (i'' - i')$$

D° is the difference between loaded and empty drier steam consumption. i is the specific enthalpy of the steam (kcal/kg). (i'' refers to enthalpy of saturated vapour and i' to enthalpy of saturated liquid). Relating M°, G°, W°, Q° and D° to one another and to the effective drying surface A, thus:

Specific feed rate $P = G^\circ/A$ (kg/m^2.h)

Specific drying rate = $R = M^\circ/A$ (kg/m^2.h)

Specific steam consumption $d_m = D^\circ/W^\circ$ (kg/kg)

Specific drier performance $h_3 = W^\circ/A$ (kg/m^2.h)

2.4.2. The calculated film thickness

The apparent film thickness was determined as

$$L_f = \frac{m}{b.l.d} = \frac{m}{b.s.t.d.}$$

t = run time

d = puree density

s = π x D x rpm x 0.79 = effective drying circumference/
     minute.

b = drum width

m = weight of feed

2.4.3. Drying rate determination

The method suggested by Wadsworth et al (27) was closely
followed. Difficulties arising from design of the drier were
countered by scraping the film at various positions relative
to the feed rolls, and converting the distances into correspon-
ding time intervals. Then, the moisture content of the samples
obtained was determined and retention time - moisture content
curves plotted.

2.5. Problems Encountered in the Data Collection

2.5.1. Air humidity

The humidity of the air in the Pilot Plant changed from
time to time during the duration of the experiment. Little was
done to counter the problem because of drier design (atmosphe-
ric). A hood is normally included to collect vapours from the
surroundings while the problem is well solved in the vacuum
operated drum driers.

2.5.2. Temperature measurement

It was not possible to make good contact of the rotating drum-cylinder surface using either the mercury-in-glass thermometer or the 'Telemax' thermocouple. The latter read in degree centigrade. The soldered point-contact was not big enough. Adding pressure to contact with the fingers occasionally added resistance and hence error in readings. Many alternative methods have been suggested in order to counter this problem, some of them very expensive. Following the VDE/VDI standards (28) a surface-thermoelement Iron-Constant (Camille Baur, Basel) is often chosen for its much enlarged soldered-point contact which with only little pressure measures temperatures on the cylinder reliably.

Finally, temperature swings occurred during the cold feeding of raw material. There was no compensation on the temperature drops. It was therefore necessary to wait about five minutes in order to allow steady state conditions to be attained.

2.6. Steam Consumption Determination

In the determination of steam consumption and the heat of condensate the following methods were attempted:

2.6.1. Condensate weight determination

The condensate was cooled, collected and weighed corresponding to a known time interval. The condensate rate was then determined ($kg.h^{-1}$).

2.6.2. The calorimetric method

The condensing steam was collected over given weight of cold water at a known temperature. The resulting temperature of steam-water mixture and the total weight were determined. It was then possible to calculate the quantity of heat when the specific data for the collecting vessel were known and the initial temperature of steam calculated.

2.6.3. Condensate rates by calculation (29)

It is often impossible to obtain reliable figures of condensation rate on steam heated machines. In such cases the following approximate formula will be found helpful. It is of course, only approximate:

$$C = \frac{K(W-D) \times 540}{L} + \frac{W \times (T-t)}{L}$$

C = Kg. condensate per hour

W = Wet weight of material being dried per hour

D = Dry weight of material being dried per hour

L = Latent heat of steam at working pressure

T = Temperature of material leaving drier

t = Temperature of material entering drier

K = 1.0 for contact driers without steam heat rolls

     1.5 for contact driers with steam heated rolls

     2.0 for non-circulating air driers

2.7. Characterising the Product

2.7.1. General analytical methods

2.7.1.1. Water content

2.7.1.1.1. <u>Banana puree</u> Method M9d (30).

The method uses the Abbe Refractometer at 20°C. Refractive indices are converted into percentage total soluble solids (as sucrose) using given tables.

2.7.1.1.2. <u>Cassava</u>

Raw peeled cassava was peeled and sliced into thin segments. These were heated in an air oven (2.3.9) for 72 hours at 105°C.

2.7.1.1.3. <u>Beans</u> (raw)

The dry raw beans were powdered using a disc mill (2.3.4.). The sample was placed in an air oven (2.3.9.) for 4 hours, method Mdc (30) at 105°C.

2.7.1.1.4. <u>Raw cassava and bean purees</u>

Known weights of puree were mixed with a little washed sand and left to dry in air oven at 105°C for 4 hours. This was repeated until constant weight observed.

2.7.1.1.5. <u>Product flakes</u>

Flakes were powdered and dried in an air oven (2.3.9.) for 4 hours at 105°C method Mdc (30) till constant weight.

2.7.1.2. <u>Ash content</u> Method A17 (30)

The muffle furnace (2.3.10.) was operated at 600°C for 4 hours.

2.7.1.3. <u>Bulk density of flakes</u>

The mill (2.3.4.) was used for milling the flakes. A glass

measuring cylinder was filled with exactly 20g of powder and the volume read after tapping the cylinder 10 times on soft pads. Distance above the pads was about 20 cm.

2.7.1.4. Free starch (blue value) in flakes (31)

Blue value = Extinction coefficient x 452 + 5 at 660 nm.

2.7.1.5. Determination of sulphur dioxide

After the Monnier-Williams equivalent of AOAC method (32).

2.7.1.6. Determination of vitamin C

The method after Bakarat et al. (33) was selected.

2.7.1.7. Browning development and hydroxymethylfurfural determination (34, 35)

See also the Calibration curve for hydroxymethylfurfural (figure 2.3.).

2.7.1.8. Reducing sugar determination

The Luff Schorl method was followed (36).

2.7.1.9. Oil determination

The Soxhlet procedure was used.

2.7.1.10. Crude protein determination

The Kjehdahl procedure. The multiplying factor Nx6.25 was used.

2.7.1.11. Determination of the cyanide ions

The method of Epstein (37) was followed. See Calibration curve figure 2.4.

2.7.2. Storage Properties

2.7.2.1. Browning development. See section 2.7.1.7.

2.7.2.2. Equilibrium relative humidity

The approximate sulphuric acid method was followed and the experiment conducted in environmental cabinets (2.3.9.) on dessicators. (See table 2.1.). An alternative method using saturated chemical salt solutions (38) has been recommended.

Table 2.1. Constant humidity with sulphuric acid solutions (39).

% H_2SO_4	Relative humidity
1	100
8	97.5
15	93.9
21	88.8
28	80.5
34	70.4
40	58.3
45	47.2
50	37.1
60	18.8
69	8.5
78	3.2

2.7.2.3. Taste Panel: The Triangular Test (30).

The test gave an indication of product preference betweeen the cooked (or raw) and drum dried rehydrated products. Table 2.2. was used for 'significance level determination'. A total number of twenty non-trained panelists who, however, were familiar with the local products appeared in the taste panel. Three replications of the test were used. Usually, the product produced under optimum conditions of pressure, drum speeds and raw feed total solids was taken to make the reconstituted product. Three samples were presented for tasting. One was the raw product as normally consumed while the other was the reconstituted product. The third sample was either of the two mentioned. The task for the panelist was to pick out the 'odd' sample.

Table 2.2. Number of correct answers required for a
specified number of triangular tastings (40).

Number of tastings	Number of correct answers necessary to establish significant differentiation		
	$P \leq 0.05$	$P \leq 0.01$	$P \leq 0.001$
7	5	6	7
8	6	7	8
9	6	7	8
10	7	8	9
11	7	8	9
12	8	9	10
13	8	9	10
14	9	10	11
15	9	10	12
16	10	11	12
17	10	11	13
18	10	12	13
19	11	12	14
20	11	13	14
21	12	13	15
22	12	14	15
23	13	14	16
24	13	14	16
25	13	15	17

Note: P = Significance level, 1 in 20, 100 and 1000 presentation.

Figure 2.3. Standard calibration curve for Hydroxymethyl-
furfural.
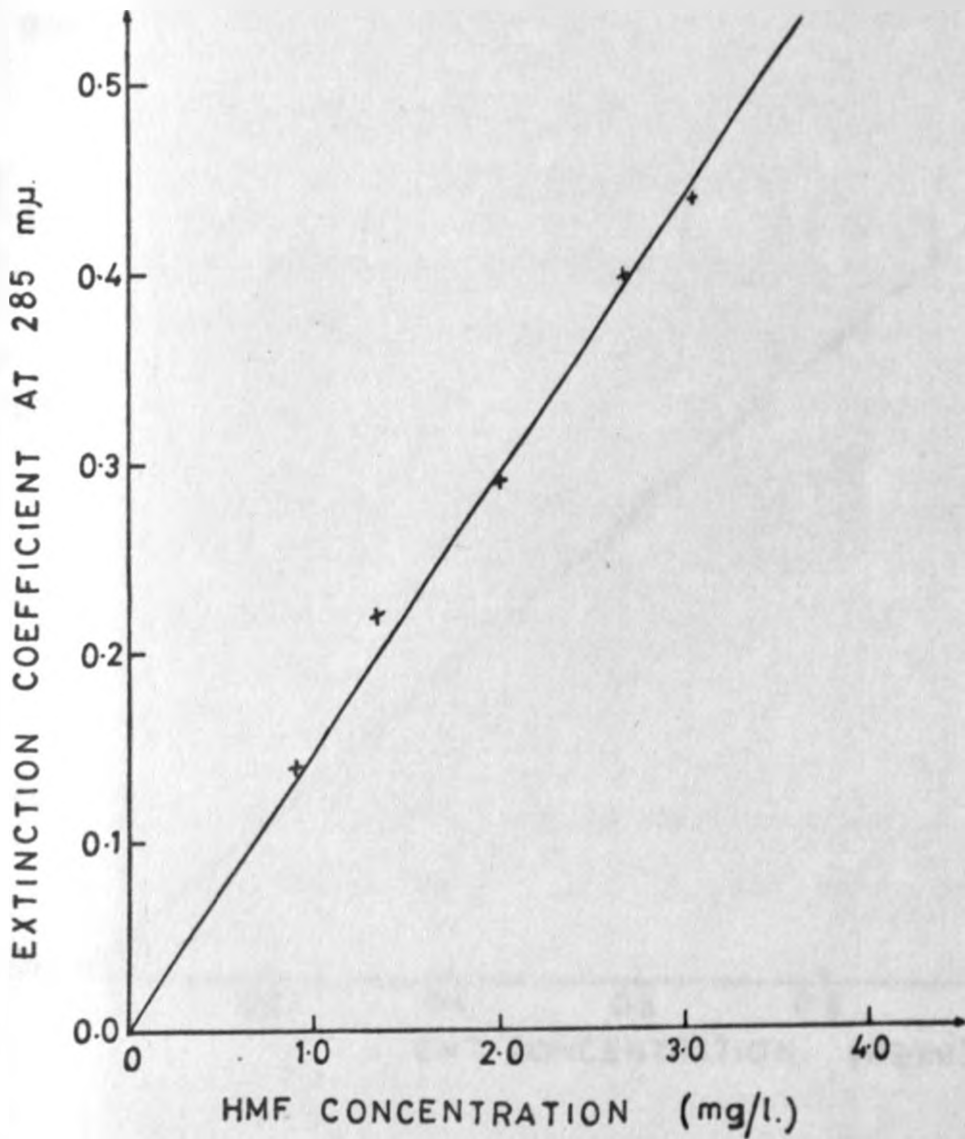
Figure 2.4. Calibration curve for cyanide ions
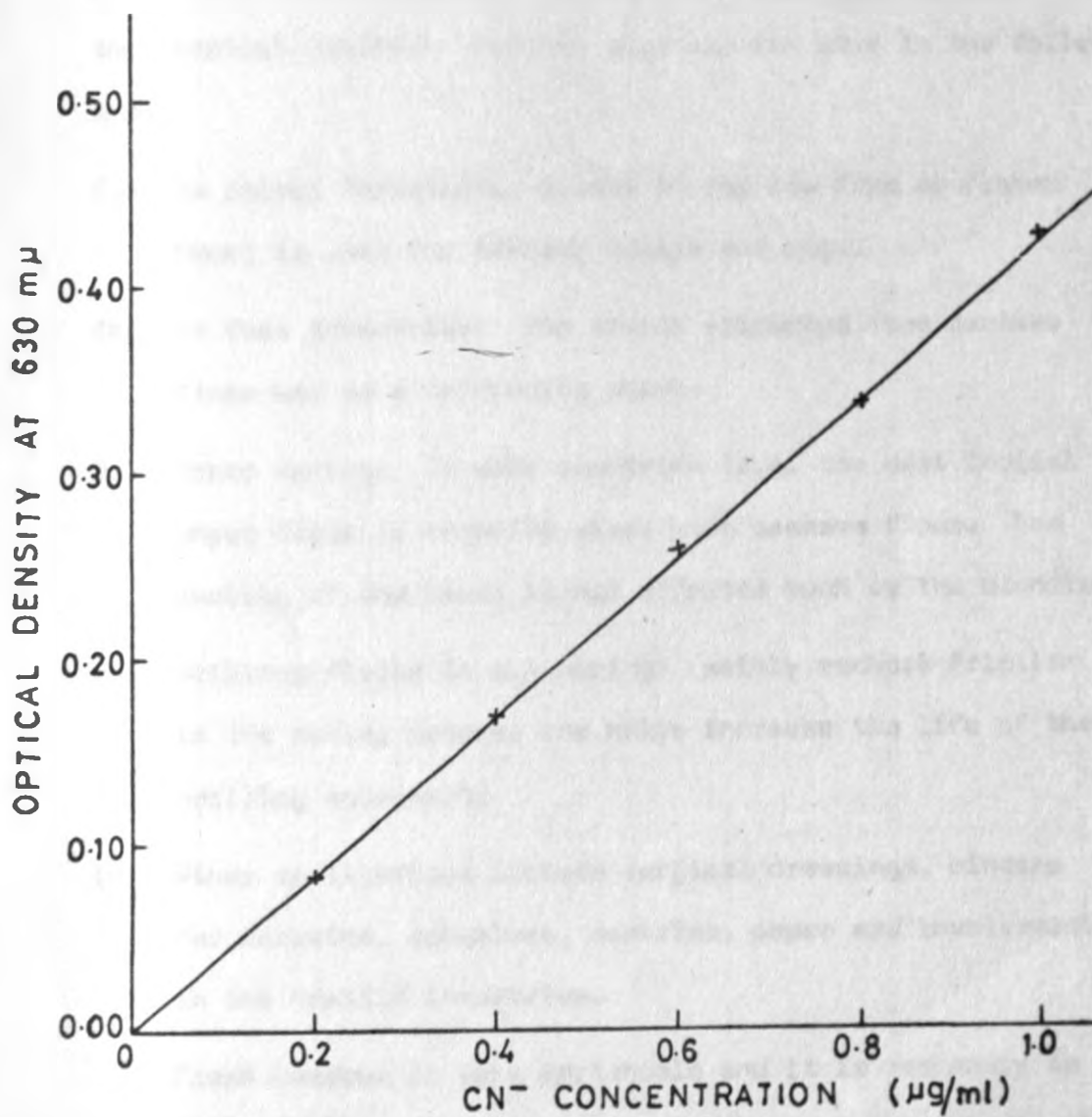
3. EXPERIMENTAL WORK, RESULTS AND DISCUSSIONS

3.1. CASSAVA (manihot; manioc)

3.1.1. Preliminary Investigations

3.1.2. Introduction

Fresh and processed cassava is the main staple food (i.e. a source of carbohydrates) for millions of people living in the tropical regions. Cassava also has its uses in the following:

(a) As animal feedstuffs, either in the raw form or flaked form; is used for feeding cattle and pigs.

(b) In food industries: The starch extracted from cassava finds use as a thickening agent.

(c) Bread making: In some countries (e.g. the West Indies) wheat flour is normally mixed with cassava flour. The quality of the bread is not affected much by the blending.

(d) Drilling fluids in oil boring: mainly reduces friction in the boring process and helps increase the life of the drilling equipment.

(e) Other applications include surgical dressings, binders for ceremics, adhesives, dextrins, paper and involvement in the textile industries.

Fresh cassava is very perishable and it is necessary to process the tubers into some form of dried product as soon as possible after harvesting (41).

There are variations between the standards for different cassava products and between different countries but the quality

criteria that are emphaised are moisture, fibre, ash and starch content plus a general cleanliness of the product.

Table 3.1.   Official standards for cassava flour (42)

Colour   White to light cream

            - free from rancidity, foreign matter and insect infes-
              tation.

            - contains no objectionable odours

     (N.B. High crude fibre, and ash reduce digestibility).

                                                  %
            Moisture   10 - 14
            Starch   70 - 82
            Total ash   1.8 - 3.0
            Crude fibre   1 - 6

3.1.3. Raw Product Data - Cassava composition

Table 3.2. Composition of the edible portion of cassava

Determination	Result
Water content (dry weight basis)	60 - 65%
Solids content	35 - 40%
Crude protein: (Nx6.25)	0.5 - 1.0%
Vitamin C: - raw cassava	25 - 30 mg/100g
- cooked cassava	20 - 25 mg/100g
Reducing sugars	0.05-0.10%
Fat content	less than 1.0%
Total ash	1.0%
Specific gravity	1.07 - 1.18
Estimated starch content	22.5%
Cyanide ion	9.8µg/g 0.96 " (cooked) 0.96 " (drum dried)

3.1.4. Major Studies

3.1.4.1. The manufacture of cassava flakes

(a) Preparation of puree for drum drying

The fresh mature root was cleaned by hand using flowing tap water, peeled by hand and finally trimmed. The peeled roots were sliced using the slicer/grater of the"Lips Kitchen Machine" (section 2.3.1.) to a thickness of about 0.5 cm. Approximately 300 ml of cooking water was added to 1kg of material; the mixture steamed in a pressure cooker (2.3.2.) for 7-8 minutes, and finally passed over a rotating screen with openings of 0.15 mm in diameter (see section 2.3.1.). The final mash free of the bulk of woody pith was mixed with known amounts of water to produce controlled values of total solids. The material was then passed on to the drum drier (section 2.3.3.1.), the mill (section 2.3.4.), and finally sealed (section 2.3.5.).

(b) The flow diagram for the manufacture of cassava flakes

Figure 3.1. Flow diagram for the manufacture of cassava
flakes
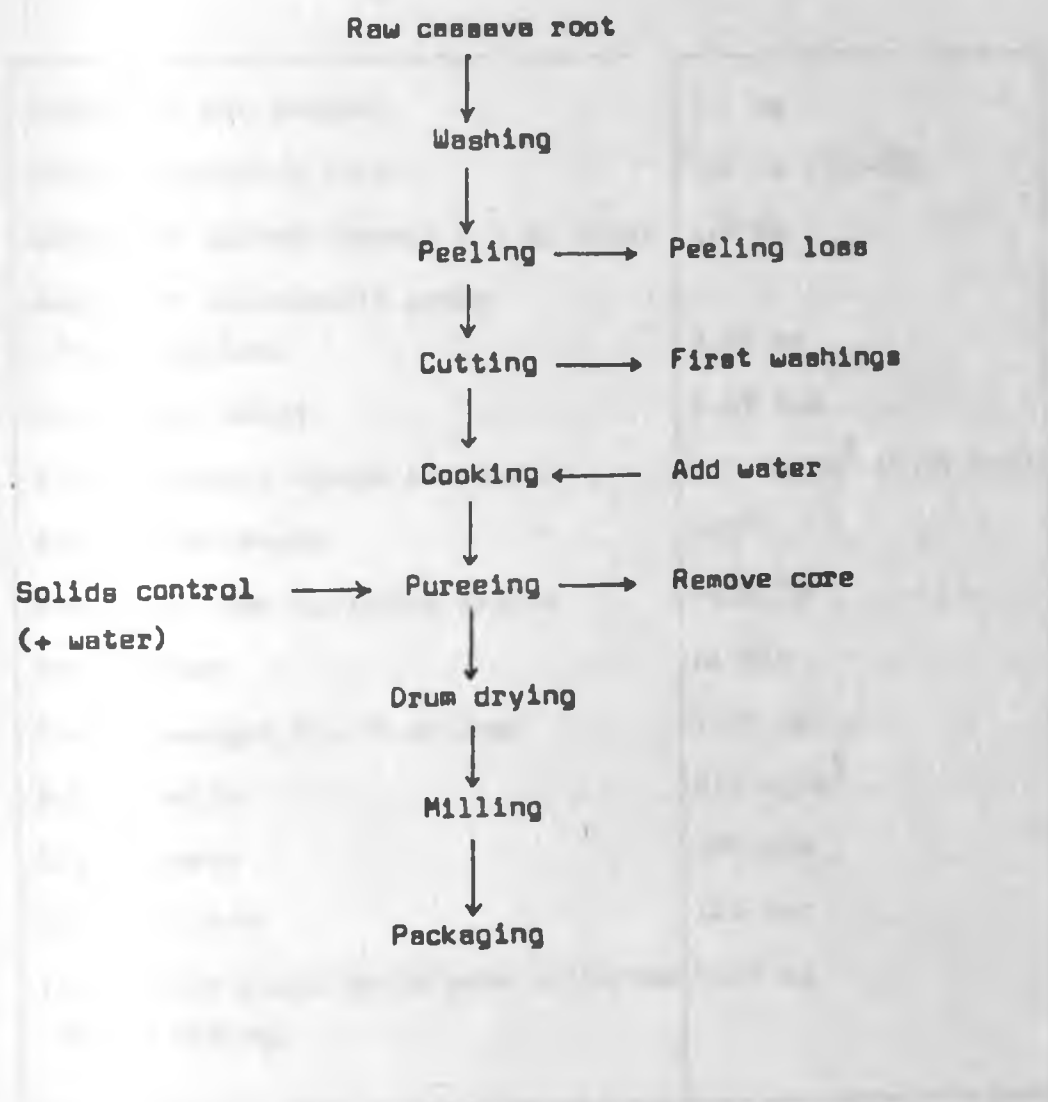
Table 3.3. Typical operational data on preparation of cassava flakes

Weight of raw cassava	3.7 kg
Peeling/trimming loss	0.6 kg (15-20%)
Weight of cooked cassava + 1 kg water	4.0 kg
Weight of recoverable puree (43.5% solids)	3.25 kg
Drum drier speed	1.43 rpm
Steam pressure (gauge pressure)	3.0 kg/cm^2 (2.94 bar)
Steam temperature	$142^{o}C$
Feed-gap: top satellite roller	4×10^{-4} m
Drying time	61 min
Product weight (95.2% solids)	1.00 kg
Bulk density	212 kg/m^3
SO_2 in puree	250 ppm
SO_2 in flakes	128 ppm
Total gross steam condensate collected during drying	4.65 kg

3.1.5. RESULTS AND DISCUSSION

3.1.5.1. Composition of cassava

The composition of the edible portion of cassava used to produce cassava flakes is shown in Table 3.2. The range indicated in the data is from duplicate determinations for each constituent of the cassava, obtained at different times and from different sources. Variations are small considering the various factors contributing to the product composition. The specific gravity and total solids are high. The high starch and low total reducing sugar content indicate that this material should be suitable for dehydration, as in the case of potatoes. However dehydration properties may be unpredictable due to differences in starch granules and cooking characteristics (43). For a root crop the ascorbic acid content is surprisingly high. Pressure cooking reduced the ascorbic acid content by about a quarter of its original value.

3.1.5.2. Dehydration of cassava

Table 3.3. shows some typical data obtained during the manufacture of cassava flakes. To partially counteract discolouration during storage of the product it was decided to peel, wash and leave the cleaned product to drip-dry before dipping the peeled product in sulphur dioxide (contents as high as 500 ppm SO_2 were used) bath. The same procedure was however, unsuccessful with the already discoloured product. It seems that the mechanism of discolouration is not the same as in potatoes or yams (44).

The peeling and trimming losses (about 20%) probably could not be reduced any further even in commercial practice. Using the final peeled and cooked root as a raw material, the yield of dried product approximated about 100%.

The raw root contains practically no free starch as indicated by results on blue value, table 3.4. Free starch increases slightly through cooking. Mashing, however, increased the content tremendously but this was not affected any further by dehydration.

Table 3.4. Changes in the blue index of cassava through processing.

Form of cassava	Blue value index
	(read as extinction coeffi- cient at 660 nm)
Raw root (38% solids)	2
Cooked root	23
Mashed root	210
Cassava flakes (95.2% solids)	215

3.1.5.3. General observations during the drum drying of cassava flakes.

The relationships between moisture content, drum speed, steam pressure and film thickness were examined together with their effect on drying rates, browning, bulk density and food quality.

Slow rotation of the drum resulted in browning, espe-
cially noticeable at higher steam pressures. It was difficult
to dry the film uniformly over the whole effective drying sur-
face. The film tended to peel off from the surface and as
such accounted for erroneous results in the final moisture
content and production rates. A combination of high drum
rotation speeds and high temperatures resulted in the forma-
tion of a "dust like" powder. High drum rotation speeds at
a constant, but low steam pressure resulted in the formation
of a product of high moisture content.

Dilution of the original puree resulted in low production
rates. Where possible, it was best to use the original puree
for dehydration on the drum drier.

Good product rehydration was obtained by the use of warm
water and warm milk and although accompanied by a characteris-
tic "pastiness" (according to the author and panelists) the
original cassava taste was retained.

Table 3.5. Effect of drum speed on moisture content

Drum speed in revolutions per minute (rpm)	Moisture content % dry weight basis (dwb)
0.73	3.3
1.36	3.5
3.00	3.8
4.60	4.5
6.00	4.9

Constant gauge pressure = 1 kg.cm^{-2} (approx. 1.7 bar absolute)

N.B. Assuming an atmospheric pressure of 0.85 bar for the
      Kabete area.

Higher moisture contents of the final product occurred as the drum speed was increased. Higher speeds correspond to shorter retention times and, a limit is reached where the high moisture content in the product becomes excessive and affects removal from drum and leads to a much shorter storage life.

Table 3.6. <u>The effect of retention time on moisture content, specific heats and thermal conductivities of product during drum drying of cassava.</u>

Retention time Sec	Moisture content (% dry weight basis)	Specific heats $kJ.kg.K^{-1}$	Thermal conductivities $W.m^{-1}.K^{-1}$
0	56.5	2.72	0.44
5	13.2	1.28	0.30
10	4.9	1.00	0.27
13	4.5	0.98	0.27
20	3.8	0.96	0.27
44.1	3.5	0.95	0.27
82.1	3.3	0.95	0.27

Table 3.6 relates the retention time to moisture content, specific heats and thermal conductivities of cassava puree during the drum drying process. The latter two have been calculated on the basis of moisture content (see Appendix 7) Earle, (45). As retention time increases the moisture content decreases rapidly (Figure 3.2.) until a moisture content

Figure 3.2   Graph of moisture content against retention time

Steam pressure = 1 kg cm^{-2}

Total solids of feed 40.5%

Gap setting = .40 mm.
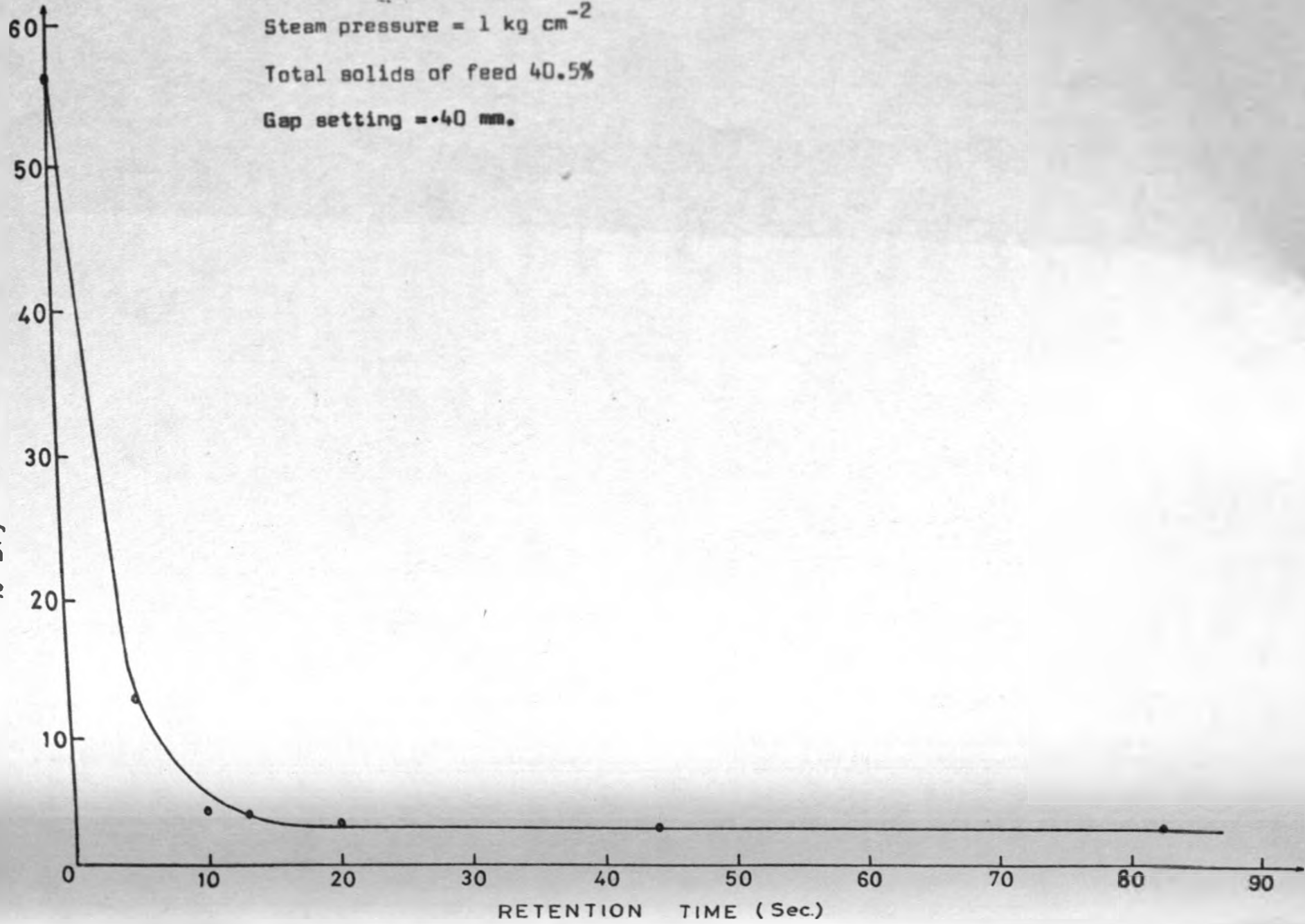
of about 5% is attained; below this value the decrease is small. Spadaro et al (46) has obtained a similar curve in sweet potato dehydration. (The sweet potato root is closely related in composition to cassava). The initial rate of water removal is high followed by a falling rate that sharply decreases during final stage of drying. Specific heats and thermal conductivities decrease following the moisture trend.

Table 3.7. <u>The relationship between overall heat transfer coefficient and drum speed with product on drum surface.</u>

Speed rpm	U $W.m^{-2}.{}^{o}K^{-1}$
0.73	177.7
1.36	209.4
3.00	340.0
4.60	497.8
6.00	538.6

Constant steam pressure (3.8 bar absolute)

<u>Note:</u> Atmospheric pressure approximates to 0.85 bar for the Kabete area. Also(1 kg.cm^{-2} = 0.981 bar).

Clearly the overall heat transfer coefficient depends on the drum speed. But at the same time the working equation (1) (page 12) and the production rate curves (Figure 3.3.) show the dependence on steam pressure (temperature), total

solids and moisture content. This dependence of the overall heat transfer coefficient on drum speed shows that the product film on the drum drier must vary as a function of drum speed (see table 3.11 and Charm, (17)). Furthermore, the speed of rotation also effects the thickness of the condensate film on the inside of the drum surface. A thinner condensate film results from the use of higher drum speeds. This implies less resistance to the heat transfer process and therefore higher values of U (see table 3.7.) and Earle page 103 (45)). This assumes no inert gases present on the inside of the drum.

Table 3.8. The effect of total solids on moisture content of cassava flakes.

Total solids %	Moisture content % dry weight basis
40.5	3.3
39.2	4.6
37.0	6.8
35.3	7.4

Absolute steam pressure = 3.7 bar

Drum speed   = 3 rpm

As the feed total solids content was reduced by dilution of the original puree the flake moisture content increased, for constant drum speed and steam pressure (table 3.8.).

Table 3.9. The relationship between drum speed and the
            production rate for cassava flakes

Drum speed rpm	Production rate per effective drum surface area $Kg.h^{-1}.m^{-2}$
0.72	1.6
1.36	1.9
3.00	3.1
4.60	4.6
6.00	5.0

As one would expect, with increasing drum speed so the
production rate increases (table 3.9.). Figure 3.3. indicates
that this is a curvilinear relationship dependent on total
solids content. However, very high speeds result in high
moisture levels in the product. The product is no longer
"free-flowing", and when added to water lumps form resulting
in a non-uniform cassava paste. At very low drum rotation
further limit is attained where, due to an increase in film
density, the drying film tended to fall away from the hot drum
surface (9).

Figure 3.3. Relationship between drum speed, production
rate and total solids of feed.
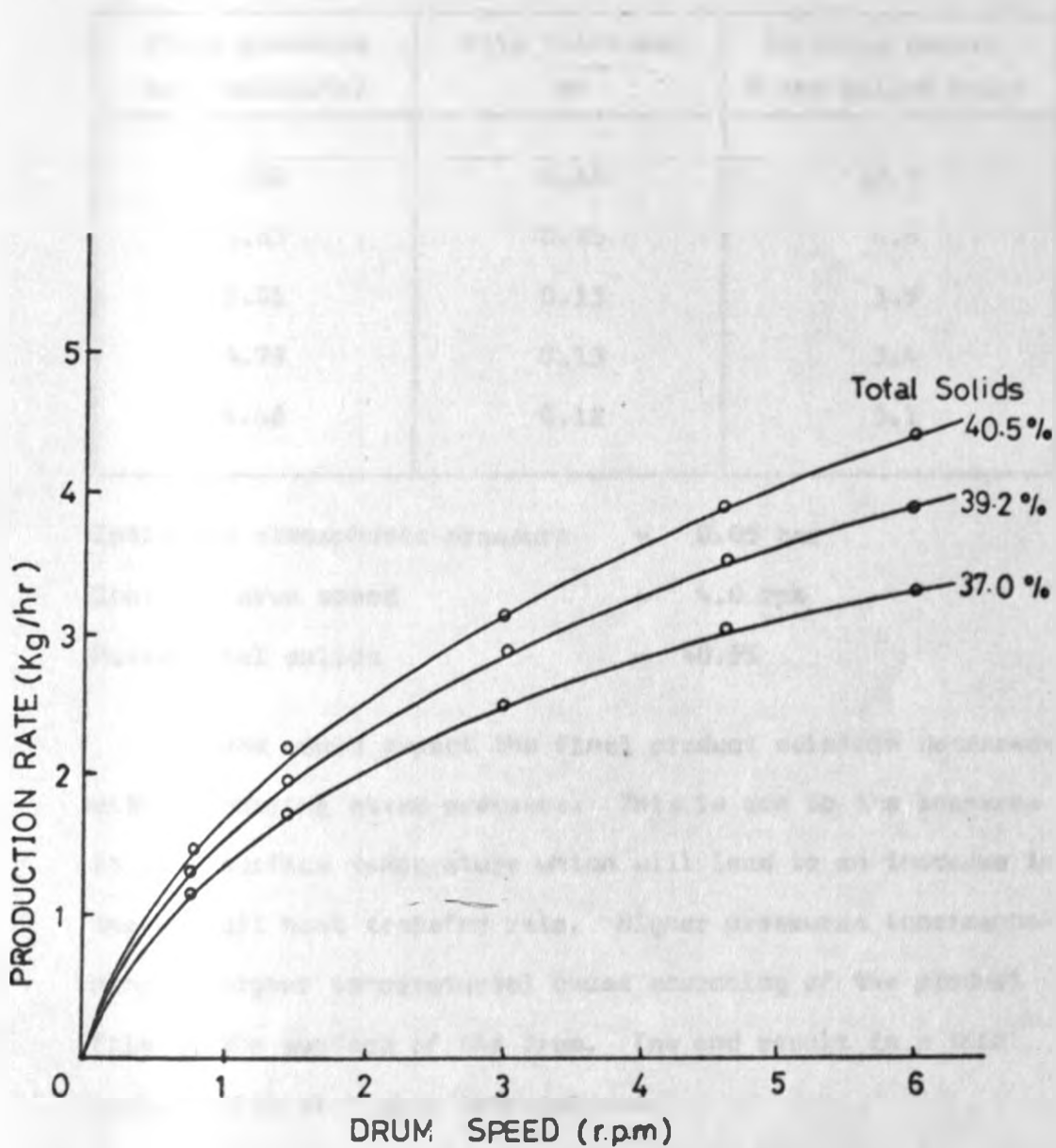
Table 3.10. The effect of steam pressure on the final cassava
flake moisture content and film thickness.

Steam pressure bar (absolute)	Film thickness mm	Moisture content % dry weight basis
1.34	0.16	12.7
1.83	0.15	4.8
2.81	0.13	3.9
3.79	0.13	3.4
4.48	0.12	3.1

Estimated atmospheric pressure   =   0.85 bar

Constant drum speed   =   4.6 rpm

Puree total solids   =   40.5%

As one would expect the final product moisture decreases
with increasing steam pressure. This is due to the increase
in drum surface temperature which will lead to an increase in
the overall heat transfer rate. Higher pressures (correspon-
ding to higher temperatures) cause scorching of the product
film on the surface of the drum. The end result is a thin
product film at higher temperatures.

Table 3.11. The influence of drum rotation on film thickness
and production rate of cassava flakes.

Drum speed rpm	Film thickness calculated mm	Production rate $Kg.h^{-1}.m^{-2}$
0.73	0.12	10.40
1.36	0.08	11.00
3.00	0.06	12.28
4.60	0.06	15.10
6.00	0.05	19.65

Steam pressure (absolute) 3.8 bar

Total solids 40.5%

The film thickness decreases with increasing drum speed as shown in table 3.11. But table 3.9. shows the production rate increasing as the drum rotation speed increases. This means that a higher production rate is achieved although the film layer becomes thinner with increasing drum speed.

The quantity of cassava puree deposited per unit area decreases at higher drum speeds, resulting in a decrease in final product bulk density (9). See also table 3.15.

Table 3.12. The effect of steam pressure on the production
rate and the cassava flake moisture content.

Absolute steam pressure bar	Production rate $Kg.h^{-1}.m^{-2}$	Flake moisture % dry weight basis
1.80	14.40	4.85
2.80	14.26	4.24
3.80	14.00	3.90
4.80	13.91	3.23

Drum rotational speed 3 rpm

Total solids 40.5%

Atmospheric pressure 0.85 bar (estimated)

Table 3.13. shows that the production rate of cassava
flakes varies little, while the final flake moisture content
decreases with increasing steam pressure. This is due to the
higher drum surface temperature which leads to an increase in
the overall heat transfer rate (46).

A higher total solids content gives rise to greater produc-
tion rate of cassava flakes (figure 3.3.). For the range of
rotation speeds used (upto 6 rpm) no noticeable maximum rate
of production was realised.

It was possible to obtain good quality flakes using undi-
luted cassava puree. Dilution was possible from about 40.5%
to 25% total solids requiring a feed gap variation from 0.20 mm
to about 0.70 mm, respectively.

Table 3.13. The influence of steam pressure on bulk density
(cassava).

Steam pressure Absolute pressure (bar)	Bulk density $kg.m^{-3}$
1.83	556
2.81	526
3.80	500
4.77	470

Estimated atmospheric pressure   =   0.85 bar

Constant drum speed   =   3 rpm

Total solids   =   40.5%

Bulk density decreases with increasing steam temperatures
table (3.13.). At high steam temperatures scorching of the
product film usually results in thin films of low moisture con-
tent and hence lower bulk density.

Table 3.14. The effect of drum speed on bulk density of
cassava flakes.

Drum speed rpm	Bulk density $kg.m^{-3}$
0.73	444
1.36	425
3.00	416
4.60	392
6.00	377

Constant absolute pressure   =   3.80 bar (atmospheric pressure
0.85 bar)

Total solids   =   40.5%

Table 3.15. The effect of puree concentration on flake
              film thickness.

Total solids of puree (%)	Film thickness (mm)
37.5	0.12
39.0	0.10
40.5	0.07
43.5	0.05

Feed gap   = 0.40 mm

Constant speed   = 0.73 rpm

Constant absolute pressure = 3.80 bar

Table 3.15. shows the relationship between puree total
solids and the product film thickness. A higher product con-
centration is related to a thinner film thickness which in
its turn will lead to a higher production rate (table 3.11.).
An increase in total solids of puree leads to a higher visco-
sity of the puree. Viscosity is analogous to fluid flow resis-
tance. The average flow rate of the puree at the nip increa-
ses with decreasing viscosity puree dilution. Spadaro et al,
(46) explain the dependence of film thickness on the total
puree solids by assuming that at constant drum rotation, the
resistance in flow of puree offered at the nip is essentially
constant for the various puree dilutions. The authors suggest
the only other variable as the film thickness. To maintain
constant mass flow through the nip a thicker film must result
at lower puree total solids.

Thus the major factors affecting the film thickness of cassava flakes appear to be drum velocity, steam pressure, and puree total solids (tables 3.10,,3.11 and 3.15). Table 3.16. refers to the relationship between drum speed and the following:

Production rate; evaporation rate; steam consumption; and overall heat transfer coefficient. The evaporation rate increases with increasing drum speeds as a result of an improvement in the rate of heat transfer. Evaporational rates up to 90 $kg.h^{-1}.m^{-2}$ (7) under favourable commercial conditions have been realised.

However, rates much lower than this value have also been obtained. This difference arises from uncertain factors of heat transfer rates and the effect of drum speeds and film thickness. It is this uncertainty that makes it necessary to make pilot scale tests in order to size a drum drier. The evaporation rate increases with increasing drum speed due to the combination of (a) the formation of a thin (less resistance to heat flow) condensate film on the inside of drum drier and (b) the increase in the convective heat transfer on the outside of the drum (45). A "forced convection" heat transfer is assumed in the latter consideration (45).

With a constant total solids content in the puree the evaporation rate, the condensate rate and the feed rate all tended to increase with increasing drum speed; similarly with increasing drum speed but did not vary much with steam pressure. This compares well with the results obtained by Spadaro et al, (46).

The overall heat transfer coefficient varies with the
drum speed and also the steam pressure. This depends on the
moisture content of the product as well as the drum surface
temperature. Clearly the overall heat transfer coefficient
depends on the film thickness, steam pressure and the drum
speed (tables 3.7, 3.10) which play a great role.

The steam consumption does not show a clear trend but it
tends to always lie between 1.0 and $\dfrac{2.0 \text{ kg. steam}}{\text{kg. water evaporated}}$
for changing drum speeds and pressures.

Table 3.16. The influence of drum speed on feed rate: production rate; evaporation rate;

steam consumption; and overall heat transfer coefficient.

Run 1

Drum speed rpm	Feed rate $kg.h^{-1}.m^{-2}$	Moisture content (% dry weight basis)	Production rate $kg.h^{-1}.m^{-2}$	Evaporation rate $kg.h^{-1}.m^{-2}$	Nett condensate rate $kg.h^{-1}.m^{-2}$	Steam consumption kg. steam/ $kg.H_2O$ evaporated	Overall heat transfer coefficient $W.m^{-2}.k^{-1}$
0.73	7.55	3.3	1.64	4.36	7.55	1.73	677
1.36	9.27	3.5	1.91	5.36	9.73	1.81	1087
3.00	14.41	3.8	3.05	8.36	14.73	1.76	1860
4.60	22.50	4.5	4.55	12.95	18.41	1.42	2496
6.00	25.91	4.9	5.00	14.86	23.18	1.56	2961

Absolute steam pressure   = 1.8 bar
Total solids   = 40.5%
Feed gap   = 0.60 mm
Estimated atmospheric pressure   = 0.85 bar)
Drum surface   = 0.22 m^2

Table 3.16. continued

Run 2

Drum speed rpm	Feed rate $kg.h^{-1}.m^{-2}$	Moisture content (% dry weight basis)	Production rate $kg.h^{-1}.m^{-2}$	Evaporation rate $kg.h^{-1}.m^{-2}$	Nett condensate rate $kg.h^{-1}.m^{-2}$	Steam consumption kg. steam/ $kg.H_2O$ evaporated	Overall heat transfer coefficient $W.m^{-2}.k^{-1}$
0.57	6.77	2.4	1.09	5.68	10.27	1.81	739
1.43	10.09	2.5	1.68	8.41	13.59	1.62	1060
3.00	14.00	2.8	2.27	11.73	15.59	1.33	1721
4.60	15.95	3.1	2.64	13.32	22.09	1.66	2294
6.00	16.59	4.0	2.82	13.77	22.18	1.61	3235

Absolute steam pressure = 2.8 bar

Total solids = 39.1%

Feed gap = 0.40 mm.

Drum surface = 0.22 m^2

Table 3.16. continued

Run 3

Drum speed rpm	Feed rate kg.h^{-1}.m^{-2}	Moisture content (% dry weight basis)	Production rate kg.h^{-1}.m^{-2}	Evaporation rate kg.h^{-1}.m^{-2}	Nett condensate rate kg.h^{-1}.m^{-2}	Steam consumption kg. steam/ kg.H$_2$O evaporated	Overall heat transfer coefficient W.m^{-2}.k^{-1}
0.59	9.50	1.4	1.41	5.73	8.09	1.41	1026
3.00	12.23	1.6	1.73	8.36	15.91	1.90	2017
4.60	15.86	2.1	2.41	11.95	20.45	1.71	2594
6.00	18.00	2.8	3.05	14.77	23.64	1.60	2996

Absolute steam pressure   =   3.8 bar

Total solids   =   39.1%

Feed gap   =   0.40 mm.

Drum surface   =   0.22 m^2

Table 3.16.   continued

Run 4

Drum speed rpm	Feed rate kg.h^{-1}.m^{-2}	Moisture content (% dry weight basis)	Production rate kg.h^{-1}.m^{-2}	Evaporation rate kg.h^{-1}.m^{-2}	Nett condensate rate kg.h^{-1}.m^{-2}	Steam consumption kg. steam/ kg.H$_2$O evaporated	Overall heat transfer coefficient W.m^{-2}.k^{-1}
0.58	11.05	1.3	1.18	9.14	10.55	1.15	1007
3.00	13.91	1.5	1.77	13.00	18.64	1.43	1779
4.60	17.45	1.9	2.23	14.64	22.95	1.57	3191
6.00	17.86	2.1	2.41	18.68	26.14	1.40	3494

Absolute steam pressure   =   4.8 bar

Total solids   =   39.1%

Feed gap   =   0.40 mm.

Drum surface   =   0.22 m^2

3.1.5.4. Quality changes during processing

Table 3.17. The influence of steam pressure on nutrients during cassava processing.

Absolute steam pressure (bar)	Vitamin C mg/100g	Protein % (Nx6.25)	Moisture content % dry weight basis
1.8	6.8	1.73	4.8
2.8	6.3	1.82	3.9
3.8	5.8	1.91	3.4
4.8	3.4	1.92	3.1

Drum speed 3 rpm

Solids content 40.5%

Original vitamin C content = 25 - 30 mg/100g

Table 3.17 shows the influence of increasing temperature on the nutrient content of cassava. As expected, the moisture content decreases with increasing steam pressure due to improved rates of heat transfer across the drum surface. Again, as one would expect, the protein content increases as the water content decreases. However, as noted earlier (section 1.5.2.1.) the protein may not all be as digestible as expected owing to denaturisation by heating.

Vitamin C on the other hand is always decreasing with increasing temperatures, the final content being about a fifth of the original amount.

Table 3.18. Observations on browning and hydroxymethylfurfural content for cassava during processing.

Absolute steam pressure (bar)	Drum speed rpm	HMF at 285 nm	Browning at 380 nm
2.81	6.00	0.09	0.010
2.81	4.62	0.10	0.010
2.81	3.00	0.12	0.020
2.81	1.43	0.13	0.025
2.81	0.57	0.15	0.030
1.83	4.62	0.12	0.020
2.80	0.57	0.11	0.010
3.80	1.46	0.13	0.020
4.77	4.6	0.13	0.025

Table 3.19. The effect of steam pressure on browning during processing.

Absolute steam pressure (bar)	Browning measured at 380 nm	
	with 500 ppm SO_2	without SO_2
1.8	0.010	0.020
2.8	0.014	0.022
3.8	0.018	0.023
4.8	0.020	0.025

Constant drum speed = 3.0 rpm

Total solids = 40.5%

Estimated atmospheric pressure = 0.85 bar

Table 3.19 shows the "heat damage" during processing at different steam pressures and constant drum speed. Higher processing temperatures produce lower final moisture contents for a given drying time but the effect of browning becomes more apparent. It is difficult to judge the relative browning of samples since the final values of extinction coefficient are small although the trend is clear. This is due to the very small content of reducing sugars in cassava. The addition of sulphur dioxide has, among others, two main advantages. On the one hand the browning is inhibited considerably, and on the other hand it is possible to use higher process temperatures without causing extensive browning.

Table 3.20 shows that lower drum speeds result in higher heat samage. This is simply because the contact time of the product film on the hot drum surface was longer at lower drum speeds.

Table 3.20. The effect of drum speed on browning

Drum speed rpm	Moisture content (dry weight basis)	Browning read at 380 nm	
		with 500 ppm SO_2	without SO_2
0.57	3.3	0.018	0.030
1.46	3.5	0.015	0.025
3.00	3.8	0.011	0.020
4.60	4.5	0.010	0.011
6.00	4.9	0.010	0.010

Absolute steam pressure = 3.8

Total puree solids = 40.5%

Estimated atmospheric pressure = 0.85 bar

3.1.5.5. Storage properties

The observations on browning (non-enzymatic) during storage, were taken for over three months. The product with a moisture level of 2.9% (dry weight basis) did not appear to change significantly during this storage period. The final product remained free-flowing, with an attractive white appearance and odourless.

It was difficult to distinguish between the reconstituted and fresh (according to the author's opinion). In this case the product had been stored in the dark at room temperature and sealed in plastic bags under normal atmospheric conditions. According to the panelists the results of the triangle test indicate there was not a great difference (P ≤ 0.05, table 2.2.) between the boiled (chunks or mashed) cassava and the reconstituted, drum dried product.

Loss of ascorbic acid (table 3.1.; 3.2.) during the processing of dried cassava flakes was prevalent during the mashing and dehydration stages. The storage time did not produce any further drastic changes in the ascorbic acid content. As in the case of dehydrated yams (Onayemi and Potter, (44) it may be possible to supplement the cassava with ascorbic acid after dehydration, especially as there would be very little decrease in ascorbic acid content during storage. Unfortunately, this would produce a rise in the production costs of dried cassava and as such, would not be bought by the lower income groups in Kenya. This rise in cost would have to be balanced against the improved nutritional value of the final product.

Table 3.21 shows that the sulphur dioxide content of the dried and packed cassava decreases with storage time.

Table 3.21.   The influence of storage time on product quality

	30 days	60 days	120 days
Moisture content % dry weight basis	2.9	3.2	3.3
Vitamin C mg/100g	4.8	3.9	3.8
Browning extinction coefficient at 380	0.018	0.019	0.019
SO_2 ppm	125	93	62

Original sulphur dioxide content directly after dehydration was found to be 128 ppm. The samples were prepared at 3 kg.cm^{-2} steam gauge pressure (3.8 bar absolute) and a constant rotation of 3 rpm. They were then sealed (section 2.3.5) in plastic bags and stored in the dark at room temperature (range found 15°C - 25°C). No special precautions were taken with regards to controlling variations in temperature and relative humidity of the store room atmosphere.

For more satisfactory results future experiments should be repeated in conditions of controlled atmosphere during drying and better methods of packaging, either in inert gas or vacuum, would be preferable.

Figure 3.4. The adsorption isotherm for the cassava flakes.

Sample produced at 3rpm and 3.8 bar absolute

pressure.
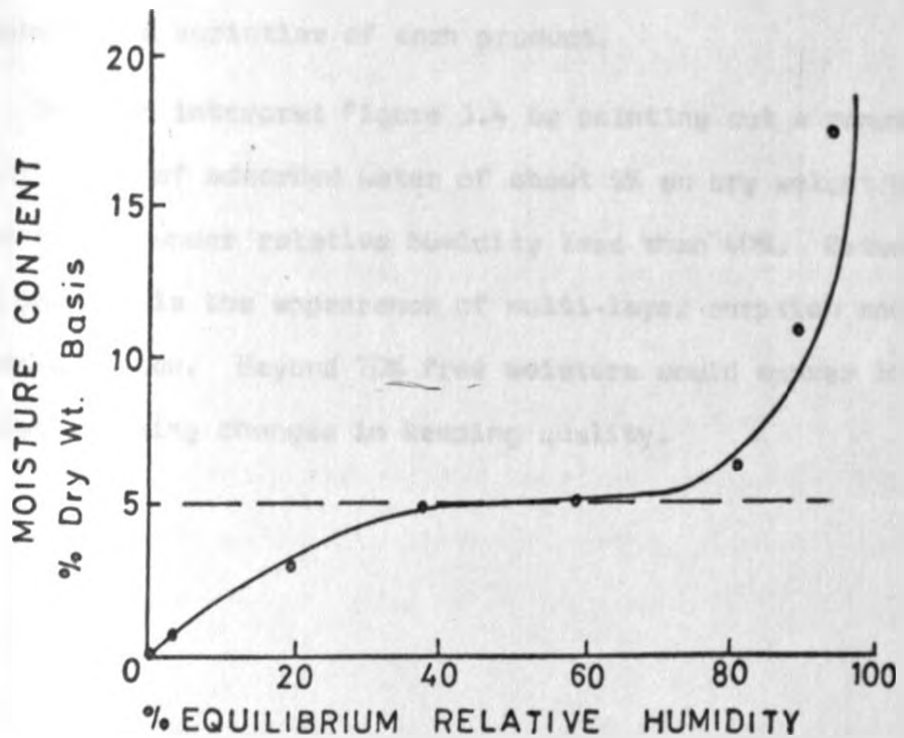
From figure 3.4. it can be inferred that cassava flakes are not

a very hygroscopic product.

3.1.5.5.1. The adsorption isotherm

Interpretation of the hysteresis in moisture sorption may be difficult although extensively studied (47). Results vary widely in the moisture determination although a method has already been established for measurement of relative humidity in a dew-point apparatus (Ayerst, 1963). The accuracy of measurement of the isotherms has been determined, including a standardisation procedure, by Pixton and Warburton (48). A complication exists in tropical products due to the great numbers of products and varieties of each product.

One can interpret Figure 3.4 by pointing out a monomolecular layer of adsorbed water of about 5% on dry weight basis that exists under relative humidity less than 40%. Between 40% and 70% is the appearance of multi-layer sorption and chemo-sorption. Beyond 70% free moisture would appear in the product causing changes in keeping quality.

3.1.5.6. Optimising the final quality of drum dried cassava flakes

In order to obtain drum dried cassava flakes of the best quality, there are a number of precautions that one must observe during the whole process.

(a) Choice of raw materials

Only the "sweet" cassava should be used for human consumption. The root should not be bruised. The "bitter" cassava should not be used for human consumption. These are precautions against cyanide (HCN) poisoning (23). The root for processing should be mature and, if possible, freshly harvested.

(b) Preparation for dehydration

(i) Washing: To remove soil and other surface contaminants.

(ii) Peeling: To remove the cortex layer which is richer in HCN than the rest of the sweet cassava root. This should be followed by thorough washing of the peeled root under a stream or spray of running water. Finally the peeled root should either (a) be drip-dried and stored in this form without discolouration or (b) be processed immediately.

(iii) Depithing and trimming
The woody core is not edible and may be removed either before or after cooking by splitting the root length-wise and using a knife, or by hand when pre-cooked. The woody ends are also removed by hand or machine cutting.

The author found that the above process was much simpli-
fied when using the "Lips Kitchen Machine" (2.3.1.).
The core in this case was not removed before cooking,
but all the woody tissue was screened-out during the
washing process.

(iv) Cooking: Boiling the root in water takes about
thirty minutes whereas steaming in a pressure cooker
(approx. 1.8 bar, (absolute)) takes approximately five
minutes and claims a smaller nutrient loss, Harris et al
(49). These authors also recommend cooking of the whole
root to prevent higher vitamin C losses usually accompa-
nied by cutting and slicing of the root. A more uniform
cooking was evident however, by slicing root to pieces
about 0.5 cm in thickness than when cooked whole. Be-
sides, the pressure cooker holding capacity was higher
in the latter operation.

The cooking water should then be drained off to further
reduce the quantity of HCN. A longer cooking led to
production of pre-gelatinized (less sticky) product and,
according to experimental experience, more acceptable for
consumption.

(v) Mashing: The kitchen machine used for mashing the
cooked cassava was previously cleaned with steam to reduce
enzymatic contamination. To extend the storage or shelf-
life sulphur dioxide (500 ppm as maximum content) was
added in solution form during mashing. SO_2 also helps
to reduce non-enzymatic browning when processing at higher

temperatures as well as inhibit enzymatic browning.

(vi) Control of solids content

Clean hot water can be added to vary the total solids
content. During this work purees of cassava were not
used with a total solids content of less than 30%.

(c) Dehydration conditions

Table 3.22. Optimum conditions for cassava flake manufacture

Steam pressure	2-4 kg.cm^{-2} gauge
	(2.8 - 4.8 bar) absolute
Feed solids	30 - 40.5%
Feed gap	0.4 - 0.6 mm
Drum speed	1.5 - 4.5 rpm
Flake moisture (dry weight basis)	3.0 - 4.5%
Browning (extinction coefficient at 380 nm	0.010 - 0.025
Production rate (dry product)	2.3 - 4.5 kg.h^{-1}.m^{-2}

Note: Drying surface area = 0.22 m^2

Experiments with potatoes, (50) suggest ways of improving
the bulk density of the flakes. The higher density flakes
showed a greater consumer preference. In the cassava a high
bulk density was obtained by a combination of low steam pressures
and lower drum speeds.

For the processing conditions mentioned above, the range of
browning experienced was not large and the product can be

described as white.

Drum dried cassava flakes could be produced under a wide
range of process conditions without noticeably impairing the
final product quality.

(d) Storage: Product after milling should be stored in water-
proof bags, in cans under vacuum or in inert gas such as Nit-
rogen. Room temperatures and absence of strong light would be
satisfactory for storage.

(e) Consumption: A tasty product was obtained with a paste
of as few as 30% solids in warm water or milk (50-60°C) and
salt (to taste). Sticky lumps, usually difficult to break by
stirring, formed which made rehydration times difficult to
record.

3.2. BANANA FLAKES

3.2.1. Introduction

Drum dried banana flakes and other forms of dehydrated
banana products serve as an outlet for fresh banana rejected
for export due to minor quality faults at the packing stage,
and as a diversion for surplus production which cannot be sold
on the fresh fruit market (51). In Kenya dehydration of ripe
bananas is not practised.

Trade in this type of dried product for indirect consump-
tion has been on a very small scale because they compare unfa-
vourably in appearance, taste, and even convenience with fresh
bananas.

Sales only prosper where fresh bananas are not readily available or good keepability is required (51).

Banana flakes find a use in flavouring of other food products, as part of a breakfast cereal, or in baby food but other than this, the demand is limited at present. This type of product is very susceptible to flavour deterioration on storage. It is also necessary to pack this product in moisture-proof containers because it is very hygroscopic. It has less commercial importance, only a small amount going to the international markets (52). The powder is used as flavouring and as food in ice-cream, milk shakes, baby foods, pie fillings and puddings (53).

The drying of bananas (high sugar content) to obtain a suitably dry product without impairment of flavour is a difficult task. Efficient removal of such large quantities of water would require the use of high temperatures and/or lengthy contact times between the product and the heating surface. But, non-impairment of flavour requires relatively low temperatures and a short contact time, or vacuum dehydration. The following circumstances have tended to work against the drum drying of bananas (54):

(1)   The use of high temperatures for rapid drying and high capacity tends to cause colour and flavour damage.

(ii   The banana flake as a dry product is a high-density flake which reconstitutes poorly, in terms of both time and soluble solids, in water.

(iii)   A plastic film of product can build up at the doctor
        knife and so lead to a product of uneven film thickness,
        and poor flakes.

    Some of the problems mentioned above concerning the banana
flakes can be overcome by:

(i)   Stretching the film at doctor knife.

(ii)   Using an air blast at point of contact of knife and drum
        surface. The relative humidity of air set at less than
        45% and a dry bulb temperature less than 20°C.

    Likewise problems concerned with the impairment of flavour
can be overcome to a certain degree by:

(i)   Minimising the contact temperature at the feeding-nip
        by use of "false puddles". In this case actual contact
        between product and drum surface is avoided.

(ii)   Removing humid air (vapours) from the product surrounds.

    Heat damage (the Maillard browning) of the banana flakes
can be reduced by the use of sulphur dioxide (22).

3.2.2. Processing methods employed

Figure 3.5. Flow diagram for the manufacture of banana flakes

```
                    Ripe bananas
                         │
                         ▼
                     Weighing
                         │
                         ▼
      Peeling ──────────────→ Peeling waste
                         │
                         ▼
                     Pureeing
                         │
                         ▼
     Screening ─────────────→ Screening waste
                         │
                         ▼
                    Sulphiting
                         │
                         ▼
                Single drum drier
                         │
                         ▼
                    Packaging
```
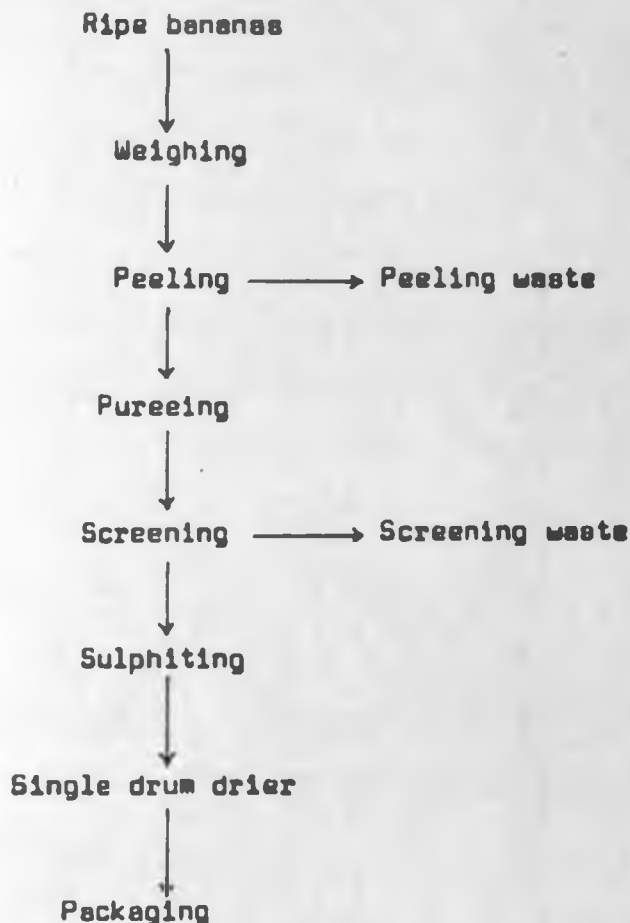
Figure 3.5 shows the important steps in the experimental manufacture of drum dried banana flakes. Peeling was done by hand while mashing was done using the "Lips Kitchen Machine" (section 2.3.1.). A screen with hole diameter of 0.15 mm was finally used to remove seedy particles in the fruit pulp. Addition of sulphur dioxide in the form of solution (500 ppm) was a necessary step to inhibit product discolouration.

Various drum speeds and steam pressures were applied and the resulting product examined for quality changes.

The product was packed and heat sealed into polythene bags
in the presence of air.

3.2.3. RESULTS AND DISCUSSIONS

3.2.3.1. General observations during the manufacture of banana flakes

As one would expect, a product of high moisture content (about 10% or more) was obtained when using low steam pressures and high drum speeds. The resulting product had a light yellow colour with an absence of any detectable flavour, from the author's point of view, which was indicative of very little heat damage. The collection of such a product at the doctor knife was not possible without use of cooled compressed air. This compressed air helped to reduce the plastic nature of the drum dried banana film.

Scorching and heavy browning resulted at high drum temperatures, this was especially so at lower drum speeds. A strong caramel flavour was detected by the author when tasting the rehydrated flakes.

At intermediate drum drying pressures golden yellow flakes were produced, but on standing the browning continued to develop until brown flakes were produced. The product was, under these conditions very hygroscopic and there was a minimum of delay between drying and packing. According to the author the flavour of the rehydrated flakes was much like the original raw bananas but the texture and colour were distinctly different. When no additives were used this resulted in the production of very poor and unattractive dried banana flakes.

Homogenisation of banana puree prior to dehydration

(followed or preceded by pasteurisation) has been recommended
as a compulsory and very favourable step to enhance the final
quality of the drum dried banana flakes (53, 54).

Table 3.23.   Composition of ripe banana puree prior to
             dehydration

Component	Composition content
Water	70 - 73%
Proteins	1.1%
Carbohydrates	25 - 28%
Vitamin C	9 mg/100g
Fat	0.2%
Ash	0.9%

The composition of the edible portion of ripe bananas
shows a high water content as well as a high sugar content
(table 3.23.   The latter is useful in the technological assess-
ment of the browning reactions during the heat treatment of
the product.   It is possible that both caramelisation of sugars
and the Maillard reactions appear simultaneously during drum
drying of bananas.   The change in Vitamin C content is a use-
ful indicator of the effect of the heat treatment on the final
nutritional value of the product during the drying process.
Fortunately, for the banana flakes, there was no pre-cooking
step, and so the first destruction of Vitamin C occurred during
the pureeing stage.   This was then followed by the major loss

of Vitamin C during the dehydration stage.

3.2.3.2. Dehydration of bananas

Table 3.24 is a presentation of the typical drum drying data obtained for banana flakes. The enzymatic discolouration of the raw puree may be minimised by the sole addition of sulphur dioxide (500 ppm SO_2), in the form of solution or by a combination of a steam blanching and the addition of a smaller amount of sulphur dioxide.

Other than peeling loss no other losses occurred in the yield of banana flakes and consequently a 100% recovery was possible from the peeled product.

Table 3.24. Banana flakes

Typical production data

Weight of raw ripe bananas	6.7 kg
Weight of peeled bananas	4.6 kg
Peeling loss	2.1 kg
Weight after mashing and screening (water content = 69% dry weight basis)	4.4 kg
Feed	3.9 kg
Weight of flakes (5.4% moisture dry weight basis)	1.1 kg
Steam pressure (absolute)	2.8 bar
Steam temperature	$131.0^{o}C$
Feed gap (top roller)	0.20 mm
Drum time	30 min.
Specific gravity	1.07
Bulk density, flakes	870 kg m^{-3}
Apparent film thickness	0.09 mm
Steam consumption	1.37 $\frac{kg\ steam}{kg.H_2O}$ evaporated

For the total solids content of original banana puree used during drum drying process the feed gap at the top feed roller was restricted to a maximum of 0.2 mm. A smaller gap resulted in very low flake production rates while with greater gaps the puree passed through without the formation of a uniform film.

Unlike cassava and beans, the dehydration conditions with banana puree covered a narrower range of steam pressure and drum speeds. Consequently, steam pressure of 2.8 - 3.8 bar absolute were used. Using lower steam pressures than this resulted in the production of a film of very high moisture content; even when using compressed air, drying was incomplete.

Long retention time led to a considerable reduction in the capacity of the drum drier. Higher temperatures, on the other hand, resulted in a very heavy browning of the product. Under such conditions of pressure and drum speed the hygroscopic nature of the final product was much less than normal but unfortunately, the product quality was poor due to browning.

Table 3.25. The effect of retention time on the moisture content, specific heat and thermal conductivity of drum dried banana flakes.

Retention time (sec)	Moisture content (% dry weight basis	Specific heat $kJ.kg^{-1}.k^{-1}$	Thermal conductivity $W.m^{-1}.k^{-1}$
0	70.0	3.18	0.47
5.0	12.0	1.24	0.29
8.0	5.8	1.02	0.27
13.0	4.7	1.00	0.27
23.0	2.9	0.93	0.26
32.0	2.0	0.90	0.26
74.0	1.3	0.88	0.26

Solids content of the original puree = 27%

Absolute steam pressure 2.8 bar

Feed gap   =   0.20 mm.

Figure 3.6. Retention time against moisture content of banana flakes.

Steam pressure 3 kg.cm^{-2} gauge

Solids content of feed = 27%

Feed gap = 0.20 mm.
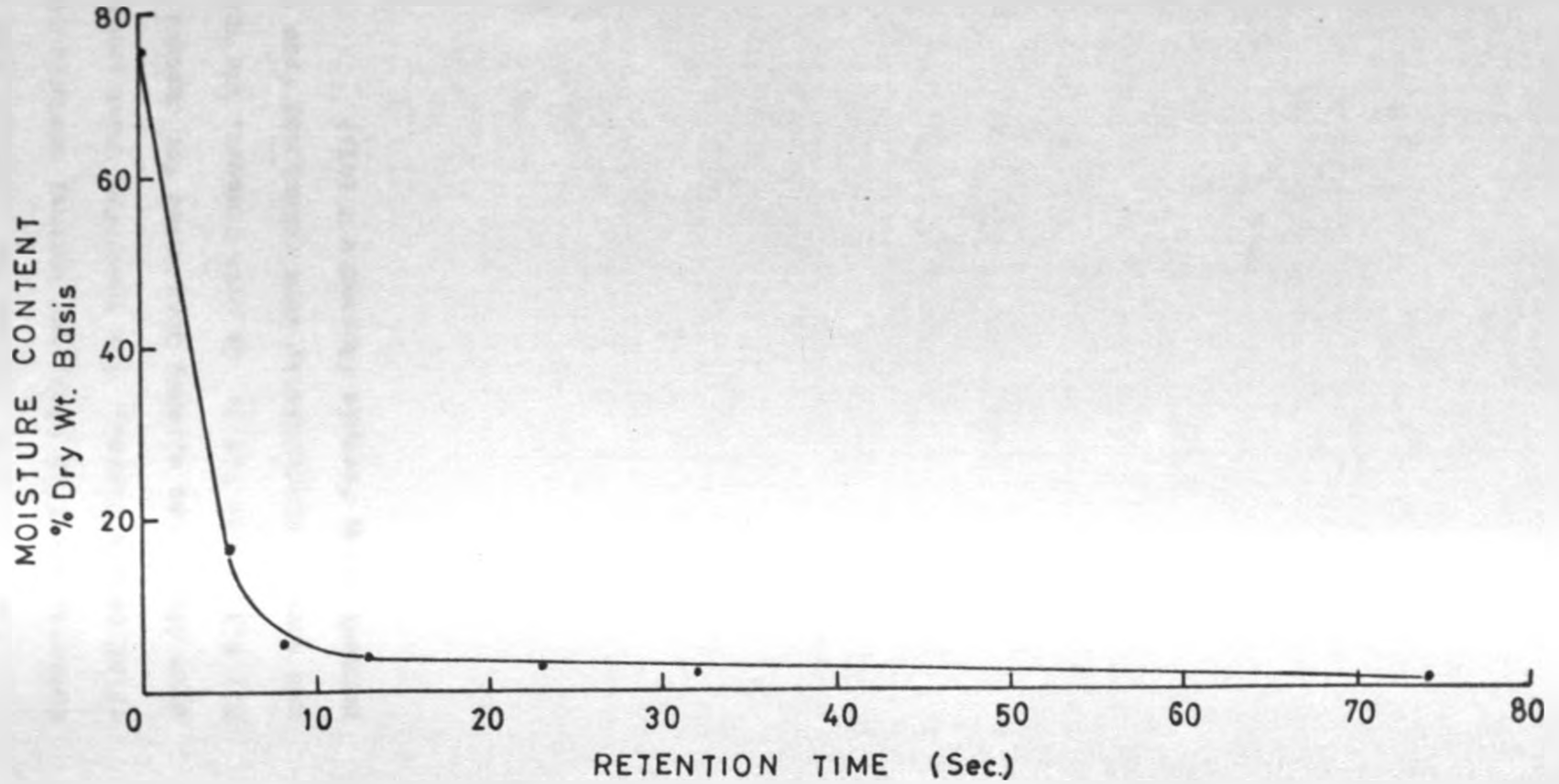
The table 3.25 relates the retention time to moisture
content, specific heat, and thermal conductivity of drum
dried banana flakes. The trend for these properties during
drum drying has already been noted for cassava (section
3.1.5.3, table 3.6.). As with cassava, the specific heat
and thermal conductivity were calculated from the moisture
content using formula (Appendix 7 (45)).

Table 3.26.   The relationship between steam pressure, drum

speed, production rate and moisture content of

final banana flakes

(a)

Steam pressure (bar absolute)	Feed rate kg.h^{-1}	Normalised feed rate	Production kg product kg feed	Moisture content % dry weight basis
1.8	2.65	1.410	0.611	7.58
2.8	2.02	1.074	0.568	1.79
3.8	1.88	1.000	0.578	1.33
4.8	1.97	1.048	0.588	0.58

Drum speed   =   0.81 rpm

Total solids content of original puree =   26%

Feed gap   =   0.20 mm

(b)

Drum speed (rpm)	Feed rate kg.h^{-1}	Product rate kg Product kg feed	Moisture content (% dry weight basis)
1.88	3.41	0.314	2.02
2.61	5.50	0.318	2.94
4.62	6.84	0.316	4.71
7.50	7.17	0.332	5.81

Steam pressure   = 3.8 bar absolute

Total solids content of original puree = 26%

Feed gap   0.20 mm

Table 3.26 shows little variation in the production rate
for a large variation in the steam pressure. Moisture content
as one would expect decreases with increasing steam pressure
due to the improved rates of heat transfer at higher steam
pressures.

Increasing the drum speed led to an increase in the feed
and production rates as well as the moisture content of the
final banana flakes. Consequently, at a drum speed of over
7.5 rpm and a steam pressure of 3.8 bar absolute very wet
flakes were produced which had unfavourable storage life.
On the other hand, a very slow drum speed (e.g. 0.81 rpm)
resulted in a product exhibiting heavy browning.

On the basis of product quality alone, a drum speed bet-
ween 2.5 and 5 rpm would appear to be more suitable for the
drying of banana flakes when using a steam pressure of 3 $kg.cm^{-2}$
gauge (3.8 bar absolute). At very low drum speeds and high
steam pressures of the order of 4.7 bar absolute heavy brow-
ning of the product occurred.

An alternative way of minimising product heat damage is
to use low steam pressures and slow drum speeds. However,
the author found that for drum dried banana flakes this combi-
nation did not reduce the final moisture content to a low
enough value (of the order of 3% on a dry weight basis) for
favourable storage. Consequently, steam pressures 1 $kg.cm^{-2}$
gauge (1.8 bar absolute) are not recommended for the drum
drying of bananas.

Table 3.27. The effect of steam pressure on the bulk
density of drum dried banana flakes.

Steam pressure (bar absolute	Bulk density kg.m^{-3}
1.8	833
2.8	784
3.8	714
4.8	690

Improved heat transfer rates at the drying surface exp-
lains why, for similar retention times, increased steam
pressures produce drum dried flakes of decreasing bulk den-
sity (table 3.27 (similar to cassava table 3.13)). Scorching
of the product film usually results when high steam pressures
are applied in the drum. The product has a low moisture con-
tent (and usually dusty) and consequently the bulk density
decreases with increasing steam pressures.

Figure 3.7. Effect of Drum Speed on Apparent Film Thickness of drum-dried bananas.
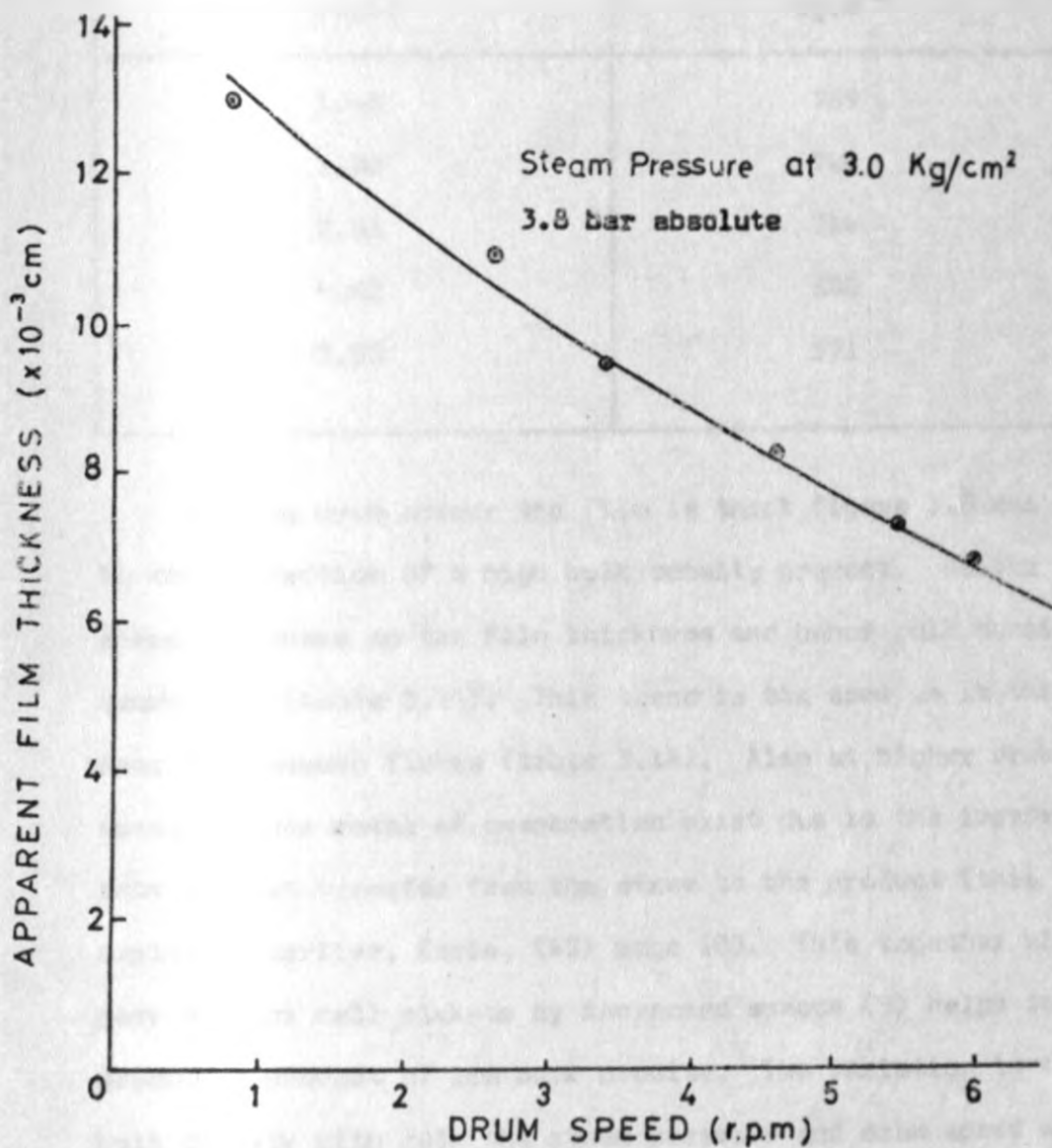
Constant steam pressure = 3.8 bar absolute

Table 3.28.   The effect of drum speed on the bulk density of
drum dried banana flakes

Drum speed (rpm)	Bulk density kg.m^{-3}
1.42	769
1.88	740
2.61	714
4.62	606
7.50	571

At slow drum speeds the film is thick figure 3.8 and leads
to the production of a high bulk density product. As the drum
speed increases so the film thickness and hence bulk density
decreases (table 3.28). This trend is the same as in the
case for cassava flakes (table 3.14). Also at higher drum
speeds higher rates of evaporation exist due to the improved
rate of heat transfer from the steam to the product (this was
explained earlier, Earle, (45) page 103. This together with
poor product cell pick-up by increased speeds (9) helps to
produce a product of low bulk density. The variation in the
bulk density with both the steam pressure and drum speed would
be very undesirable from the point of view of packaging the
final drum-dried product.

A third factor affecting the bulk density is the angle at
which the doctor knife touches the drum surface (55). Wadsworth
et al. (55) have shown that for sugar-rich products which ruffle

at the doctor knife during the scraping process, the degree
of ruffling (hence film thickness variation) depends on the
resistance at the doctor knife. The bulk density varies with
film thickness. The resistance varies with the angle of con-
tact. Thus the bulk density can be controlled by varying the
doctor knife angle of contact with the drum.

3.2.3.3. Quality changes during the processing of drum dried bananas.

The amount of heat damage exhibited by the drum dried
bananas during processing was assessed by measuring the so-
luble browning content (section 2.7.1.7), hydroxymethylfur-
fural content (section 2.7.1.7) and nutrient content (Vitamin
C, section 2.7.1.6; protein, section 2.7.1.10 and fat, section
2.7.1.9).

Table 3.29. Quality changes during the dehydration of drum-
dried bananas.

Drum speed (rpm)	Steam pressure bar absolute	Protein %	Carbohyd-rates %	Vit. C mg/100g	Fat %	SO_2 (ppm)
1.46	2.8	4.4	88.0	4	0.8	375
2.61	3.8	4.3	88.0	3	0.8	300
6.00	4.8	4.4	88.1	2	0.7	270

Final moisture content of banana flakes 3% dry weight basis

Solids content of the original feed   = 27%

Sulphur dioxide content in the original feed = 500 ppm

The concentration effect on the nutrients is shown in data for protein, fat and carbohydrates when compared with the data for the original feed (table 3.24, section 3.2.2.1.). The quality of the protein is likely to have been greatly affected by heat denaturisation; this could well result in poor digestibility and problems with reconstitution of the final product. Problems could also arise concerning the increased fat content since rancidity may now reduce the product storage life and consumer appeal.

Vitamin C is, on the other hand, destroyed by increased temperatures. This is apparent from the data comparing original and final product (section 3.2.2.1., table 3.24). The SO_2 content remaining depends greatly upon the steam pressures applied; but helps to reduce further product deterioration during storage.

Table 3.30. Observations on the browning and hydroxymethyl-furfural in the final drum dried banana flakes.

Steam pressure bar absolute	Drum speed rpm	HMF at 285 nm	Browning at 380 nm
1.8	0.81	0.280	0.09
2.8	0.81	0.410	0.13
3.8	0.81	0.605	0.14
4.8	0.81	0.780	0.15
3.8	1.88	0.380	0.13
3.8	2.61	0.350	0.12
3.8	4.62	0.240	0.11
3.8	7.50	0.200	0.10

HMF values may not have a great meaning now that the re-
action in which it is formed terminates in final polymerisa-
tion with the creation of dark-coloured pigments, the melanoi-
dine (22). However, the trend follows that for browning as
shown in table 3.31. This agrees with the findings on apple
sauce (34).

3.2.3.4. Optimisation of the processing and storage conditions to produce drum dried banana flakes of an acceptable quality.

Bananas used in the manufacture of drum dried flakes will
generally be the surplus from the fresh banana market, the
bruised and the undersize fruit (52). However it is, since
the final product quality will depend on the condition of the
feed material, important to consider the quality of the initial
raw material as well as the process conditions used in order
to improve the final quality of flakes.

(a) Choice of raw material

The bananas used in the manufacture of drum dried flakes
should all be at a similar stage of ripeness. Where possible,
bruised portions should be removed.

(b) Preparation of banana puree for dehydration

(i) Peeling: This could be done by hand and is necessary
in order to expose the clean edible flesh.

(ii) Mashing: This was done using the "Lips Kitchen
Machine" in this project.

(iii) Precautions necessary to avoid discolouration:
Sulphur dioxide should be added in the form of solution
(500 ppm maximum content) during the pureeeing/mashing
stage of the process.

(iv) Screening: This would be necessary in order to
remove the black seedy particles from the central pith
of the fruit.

(v) Homogenisation and pasteurisation: This has been
suggested as a necessary step to ensure the formation
of a continuous film (i.e. without holes) on the drum
surface (53).

(vi) Control of the solids content of the initial feed
material: The original banana puree was used in the un-
diluted form in this project. However, to improve the
drum drier's capacity it would be advisable to preconcent-
rate under vacuum to prevent heat damage.

(c) Dehydration conditions

Steam pressure	2.5 - 3.5 bar absolute
Feed solids	26% weight to weight basis
Feed gap setting	0.20 mm
Drum speeds	2.5 - 5 rpm
Production rate	7 - 12 $kg.h^{-1}.m^{-2}$
Browning (extinction coefficient) at 380 nm	0.10 - 0.13

(d) .Storage

The product should be stored in moisture-proof containers

preferably sealed in vacuum or with an inert gas. Storage
should then be in the dark at low temperatures. The above
are precautions against chemical and photo-chemical reactions
leading to deterioration of the product during storage.

3.3. HORSE BEAN POWDER

2.3.1. Introduction

According to the author, the bean powder could be used
in making bean soup. It is a good alternative to meat protein
and consequently, could be used in food mixes where other ing-
redients are protein-poor (49). The quantities used would vary
much depend on the required final composition of a 'balanced'
human diet. This would require a knowledge of the composition
of all the other ingredients in the food mix. The protein
from plant sources has been classified as B type as compared
to type A from animal sources. One needs greater quantities
of B type protein than A type to meet the dietary demands for
protein.

Unlike cassava and bananas, the storage of mature-dry-
beans (after harvest) is not critical. Under controlled sto-
rage (moisture, insect infestation, temperatures, etc.), dried
beans could last for a number of years. The bean powder would
mainly be used as a convenience food, for effective utilisation
of storage space, and to reduce distribution costs.

Beans are not usually eaten raw, but once cooked the stora-
ge even at low temperatures is unfavourable. The breakdown of
fat and protein occurs resulting in the formation of rancid
and off-flavours such that the product would no longer be suitable

for human consumption. Consequently, dehydration could provide
a useful means of preserving the cooked-bean slurry so that
after a period of storage the product would still be fit for
human consumption.

3.3.2. The production of drum dried horse bean

Figure 3.8. Flow diagram for production of drum dried, horse bean powder.

Raw dry beans

↓

Sorting and Weighing

↓

Soaking + washing

↓

Pressure cooking ←——— Fresh water

↓

Pureeing ←——— Water

↓

Drum drying

↓

Milling

↓

Packaging
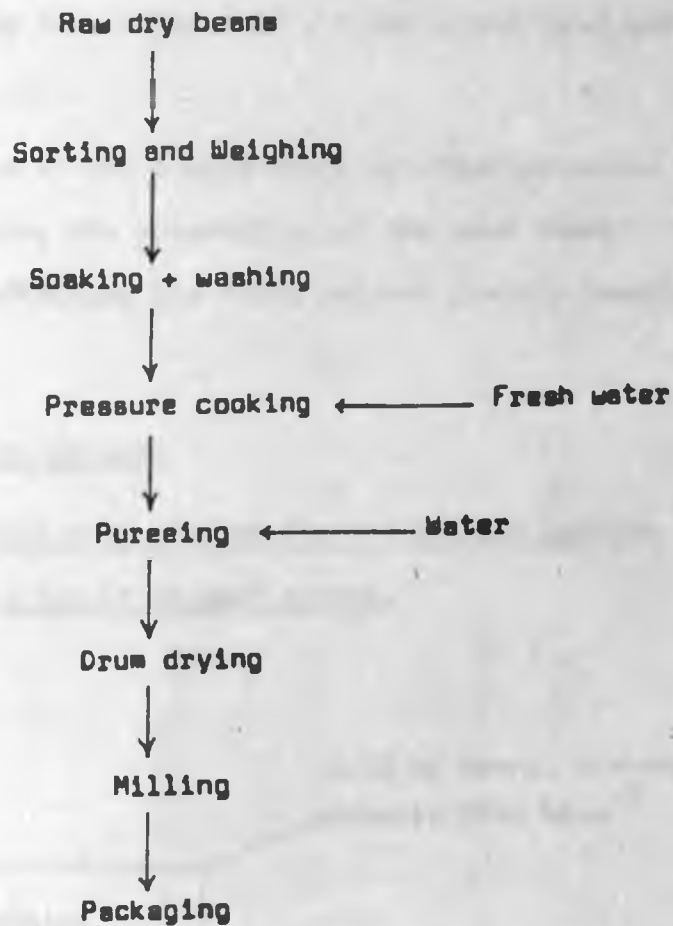
Figure 3.8. shows the various steps followed to obtain drum dried, horse bean powder on a batch basis.

In the mashing stage, a screen with apertures 0.15 mm in diameter was used to remove foreign solid particles and also the cortex material from the slurry. The control of the total solids content is a necessary step before any drying process. This was effected by the addition of a known quantity of warm (50°C) water.

It was possible to use a wide range of steam pressures and drum speeds during the dehydration of the bean slurry without adversely effecting the final product quality (section 3.3.3.).

3.3.2.1. The soaking process

Figure 3.9. A typical mass balance for the soaking process carried out in an open vessel.

1 kg dry beans (density = 1140 kg.m⁻³)   Soaking 24 hours   2.20 kg beans, drained density 1040 kg.m⁻³

14 kg water   12.65 kg water

Evaporational loss = 0.15 kg water
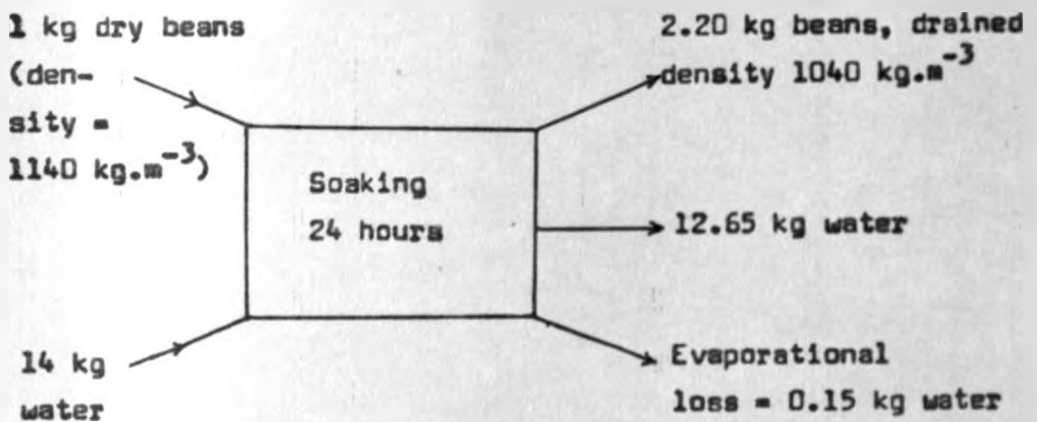
Soaked dry beans were capable of absorbing more than double their own weight of water and resulted in changing the density from 1140 to 1040 kg.m⁻³ for dry and wet beans, respectively. Soaking is a necessary process practised in the canning of baked beans (author's experience). The process helps in the

cleaning of the raw material by (a) dissolving soil; (b)
removing bad odours appearing during the initial storage of
the raw material; (a) removing bulk microorganisms contami-
nating the surface of the raw materials; (d) softening the
outer tissue; and lastly (e) helping in the control of the
final fill-weight and drained-weight of a canned product. (e)
is obviously not applicable to dried beans.

3.3.3. RESULTS AND DISCUSSIONS

3.3.3.1. General observations during the drum drying of horse beans.

Without solids control (i.e. with very high solids content), application of the bean slurry to the drum feed rollers resulted in a very poor "pick-up" of product on the drum surface. By lowering the total solids content of the raw feed material a more uniform film of material formed on the drum surface.

As with cassava, the non-enzymic browning of horse bean slurry was not particularly noticeable to the eye; a cream-coloured product being obtained at the end of the drying process.

A combination of high steam pressure (over 4 bar absolute) and high drum speeds (over 5 rpm), resulted in the formation of a dusty product (thin film) which led to a reduction in the capacity of the drum drier. Low drum speed led to the formation of a thick film which tended to peel off before reaching the doctor knife. The phenomenon was noted for both cassava and banana flakes (section 3.1.5 and 3.2.3., respectively).

Additives such as sulphur dioxide were not necessary when drum drying beans.

3.3.3.2. Composition of dry horse beans

From the composition data given in table 3.31, it would seem that horse beans are very suitable for drying because of their low sugar content. However as far as the Maillard reaction

is concerned, at high temperatures, a high protein content plus water, even in the presence of a low sugar content may still contribute to the browning of the final drum dried product.

Of primary concern during storage, besides non-enzymatic browning reactions, would be the development of rancid off-flavours and by-products from the oil content of the beans. To reduce this storage rancidity, precautions would have to be taken during storage, such as the removal of trace metals and impurities that would catalyse the development of peroxides; also the removal of oxygen from the package. It may also be useful to extract the oil during the preparation stage before dehydration.

The Vitamin C content of the raw material is on the low side and is not detectable by the method of analysis used (section 2.7.1.6) once cooking, slurring and dehydration has taken place.

Table 3.31. Composition of mature, dry, horse beans

Determination	Result % weight
Moisture content	13.3 (dry weight basis)
Crude proteins (Nx 6.25)	22.3
Carbohydrates	57.8
Oil	2.0
Vitamin C	3 mg/100g
Ash content	4.5
Cyanide ion concentration	21.8 μg/g
	3.2 μg/g (cooked)
	3.2 μg/g (dried)
Density	1140 kg m^{-3}

For methods of analysis used see section 2.7

The data shown in table 3.31 agrees closely with those values expressed in the literature (56, 57).

Table 3.32. The effect of the retention time on the moisture content, thermal conductivity and specific heat of the drum dried product (beans).

Retention time (sec)	Moisture content (% dry weight basis)	Thermal conductivity $(W.m^{-1}.k^{-1})$	Specific heat $(kJ.kg^{-1}.k^{-1})$
0	75.70	0.48	3.37
5	22.50	0.32	1.59
10	6.75	0.28	1.06
13	6.50	0.27	1.05
20	4.95	0.27	1.00
41	3.65	0.27	0.96
78	3.25	0.26	0.95

Total solids of the initial raw feed material = 24.3%

Steam pressure = 1.8 bar absolute

Feed gap setting = 0.60 mm.

Table 3.32 shows the effect of the retention time on the final moisture content, the specific heat and thermal conductivity during the drum drying of horse beans. The rate of drying falls considerably after a moisture content of 7% is attained (Fig. 3.10). With the longest retention time of 78 seconds the corresponding moisture content is high compared to similar observations with both cassava (Figure 3.2.) and bananas (Figure 3.5). The differences in the porosities of cassava, beans and bananas may probably account for the observed differences.

MOISTURE
% Dry W

50 — 60 — 70 — 80 —
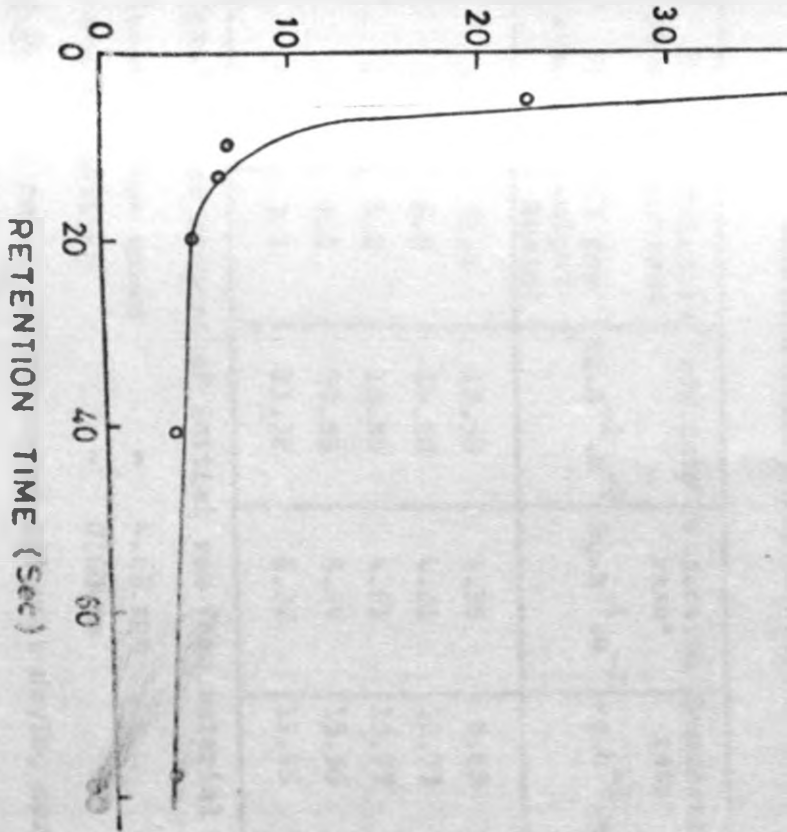
Figure 3.13. The relationship between moisture content and Retention time during the drum drying of horse beans.

Steam pressure = 3 kg cm^{-2} gauge

Gap setting = 0.60 mm

Solids content = 26.3%

Thus suggesting that the rates of diffusion of moisture during drum drying will vary from material to material under similar conditions (pressure, retention time, etc.) of drum drying.

The specific heat and thermal conductivity of the drum dried product are related to the moisture content as shown by Earle, Appendix 7, (45) and noted earlier for cassava (section 3.1.5.) and bananas (section 3.2.2.). The final drum dried product exhibits a much lower moisture content than the product possesses during the early stages of drum drying (table 3.32); this also helps to explain the lower and almost constant values obtained for thermal conductivities and specific heats of the final product.

Table 3.33. The effect of steam pressure on the final product moisture content, feed rate, production rate, evaporation rate and condensate rate.

Steam pressure (bar absolute)	Moisture content (% dry weight basis)	Feed rate* kg.h^{-1}.m^{-2}	Production rate* kg.h^{-1}.m^{-2}	Evaporation rate* kg.h^{-1}.m^{-2}	Condensate rate* kg.h^{-1}.m^{-2}
1.3	31.4	13.50	4.55	8.68	15.18
1.8	6.5	14.50	4.81	10.73	18.09
2.8	5.2	18.55	4.91	13.77	20.23
3.8	4.1	20.59	5.64	15.36	21.73
4.8	3.1	23.32	6.32	17.45	23.00

Total solids content of initial raw feed material = 24.3% dry weight basis.

Constant drum speed   =   4.62 rpm

Feed gap setting   =   0.60 mm

N.B. * All rates are expressed per unit drying surface area (= 0.22 m^2).

A very unsatisfactory product of high moisture content
was obtained at very low steam pressures (below 1.8 bar abso-
lute). Above 2.0 bar absolute pressure the moisture content
falls rapidly from about 30% to 7% (dry weight basis) and then
more slowly with higher pressures (figure 3.11). The feed
rate increases readily with increasing steam pressures. This
is most likely because the rate of evaporation increases (table
3.33) with increased steam pressures (this in turn because of
the higher values of the rate of heat transfer at higher steam
pressures).

Production rate does certainly fall with increased steam
pressures (table 3.34). This is probably caused by a loss of
product through scorching.

Table 3.34. Normalised data of feed and production rate
during the drying of beans.

Steam pressure (bar absolute)	Normalised feed rate	Production rate kg product / kg feed
1.3	1.00	4.55
1.8	1.07	4.50
2.8	1.37	3.58
3.8	1.53	3.69
4.8	1.73	3.65

Figure 3.11.   Steam pressure against moisture content

Drum speed 3 rpm

Gap setting 0.60 mm

Feed solids content 24.3%

Atmospheric pressure 0.85 bar
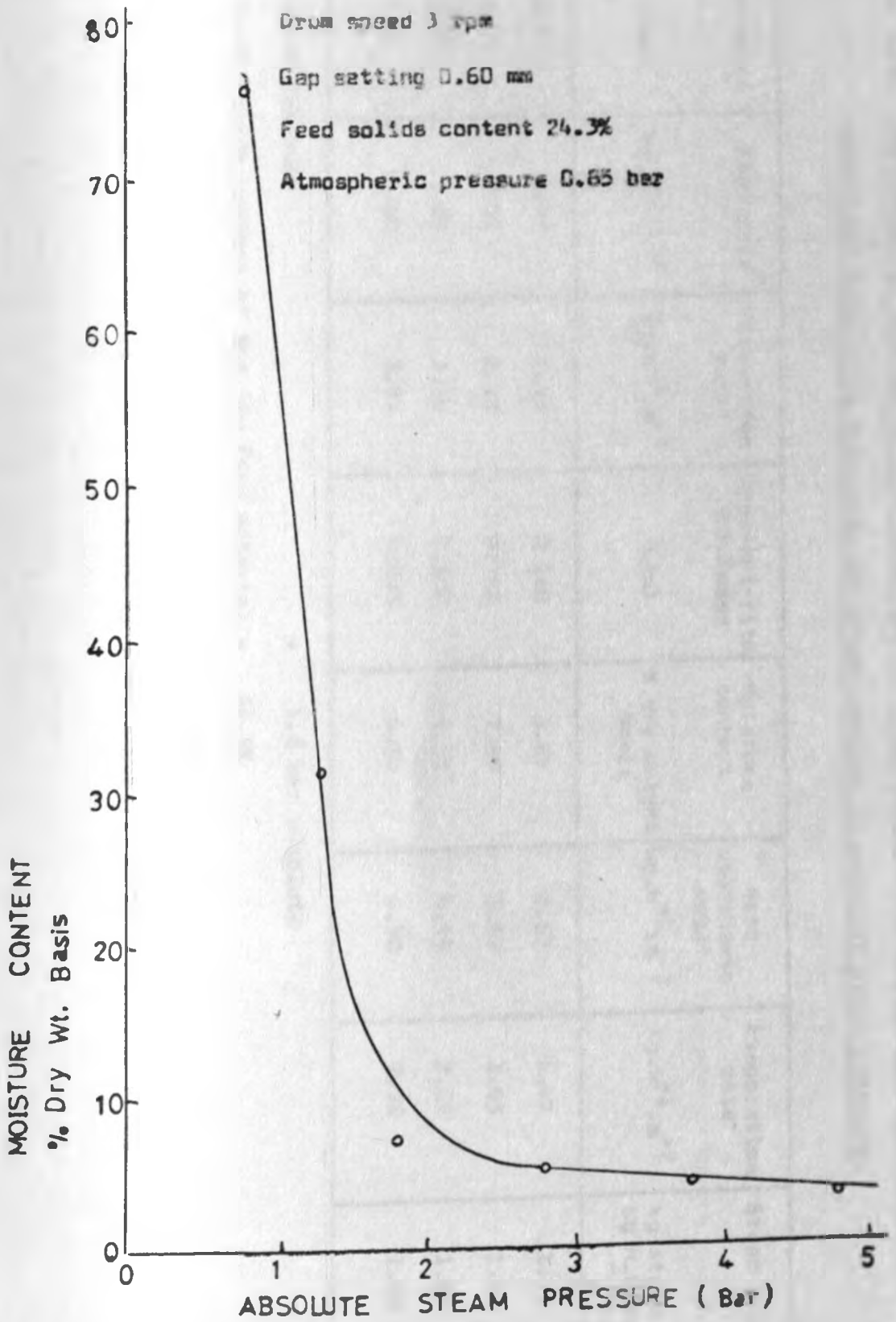
Table 3.35. The effect of changes in drum speed on the final product moisture content, feed rate, production rate, film thickness and steam economy at constant steam pressure.

Drum speed (rpm)	Feed rate* $kg.h^{-1}.m^{-2}$	Production rate* $kg.h^{-1}.m^{-2}$	Apparent film thickness (mm)	Moisture content % dry weight basis	Nett condensate rate* $kg.h^{-1}.m^{-2}$	Evaporation rate* $kg.h^{-1}.m^{-2}$	Steam economy kg steam per kg H_2O evaporated
0.77	6.77	1.45	0.160	3.25	2.63	1.47	1.79
1.46	9.09	2.18	0.140	3.65	3.59	1.95	1.84
3.00	13.05	3.14	0.100	4.95	4.95	2.66	1.86
4.62	14.50	3.91	0.095	6.50	4.58	2.76	1.66

Steam pressure   =   1.8 bar absolute

Total solids content of the raw feed material =   24.3%

Feed gap setting   =   0.60 mm

N.B. * Rates above are expressed per unit drying surface area (= 0.22 m^2).

Table 3.35 shows very clearly that as one increases the drum speed one increases the final product moisture content together with an increase in feed rate, production rate and evaporation rate. The moisture content increases because of the much reduced retention time of product on the drum surface; the increase in the feed rate because of the greater drying surface available per unit time at higher drum speeds (explains also the increase in production rate); higher evaporation rates are due to higher rates of heat transfer through the food film on the drum surface. The formation of a thin film of condensed vapours on the inside of the drum and the "forced convection" effect on the outside of the drum improve the rate of heat transfer from steam to the food film.

The steam economy trend shows no definite pattern but values fall in the range 1.6 - 1.9 $\frac{kg. \text{ steam}}{kg. \text{ of } H_2O \text{ evaporated}}$

Higher drum speeds produce thinner product films, which correspond to higher production rates (see cassava table 3.11.).

Table 3.36. The effect of changes in total solids content
of raw feed on the production rate, apparent
film thickness and the final product moisture
content.

Total solids % weight weight	Moisture content % dry weight basis	Production rate kg.h^{-1}.m^{-2}	Apparent film thickness (mm)
24.3	3.5	5.64	0.095
22.1	4.1	5.05	0.100
20.0	5.3	3.95	0.110

Pressure   =   3.8 bar absolute

Drum speed   =   4.62 rpm

Feed gap setting   =   0.60 mm

From table 3.36 ut can be seen that as one increases the
total solids content of the feed material the film thickness
and the moisture content of the final flakes tend to decrease
whereas the production rate increases. These observations
are similar to those seen in the sweet potato production (46,
58) and also for cassava (table 3.15.).

Table 3.37. <u>The influence of steam pressure on bulk density</u>
 <u>(beans)</u>.

Steam pressure bar absolute	Bulk density $kg.m^{-3}$
1.8	412
2.8	380
3.8	345
4.8	330

Total solids content of raw feed material = 24.3% weight
 for weight basis

Drum speed   =   4.62 rpm

Feed gap setting   =   0.60 mm

Table 3.38. <u>The effect of drum speed on final product bulk</u>
 <u>density</u>.

Drum speed rpm	Bulk density $kg.m^{-3}$
0.77	351
1.46	345
3.00	340
4.62	335
6.00	331

Feed gap setting   = 0.60 mm

Steam pressure   = 3.8 bar absolute

Total solids content of the raw feed
material   = 24.3% (weight to weight)

The table 3.37 shows the effect of steam pressure on the product bulk density. Increasing the steam pressure produces a decrease in the final product bulk density. The product scorching produced at high temperatures corresponds to the production of a thinner film; one could assume that the same explanation applies as for cassava and bananas (sections 3.1.5. and 3.2.3. and tables 3.13 and 3.28, respectively).

Referring to table 3.38 it can be seen that increasing the drum speed also produces a decrease in final product bulk density. This trend is again similar to cassava and banana drum drying (tables 3.14, 3.29).

3.3.3.3. Changes observed in the quality of beans after drum drying.

The heat damage on the product was assessed through measurements of soluble browning and hydroxymethylfurfural content (see section 2.7.1.7. for methods used) the results of which are shown in table 3.39. The effect of dehydration on the nutrient content of the foodstuff has also been recorded in table 3.40 (also refer table 3.32 for comparison).

The trend of values for hydroxymethylfurfural and the soluble browning shows an increase in both for an increase in steam pressure and also with longer retention times (slow drum speeds). This has also been noted for cassava and bananas (sections 3.1.5, 3.2.3. and tables 3.18, 3.31 respectively).

Table 3.39. <u>Observations on browning and hydroxymethyl-</u>
<u>furfural content at the end of drum drying</u>
<u>(beans).</u>

Steam pressure (bar absolute)	Drum speed (rpm)	HMF at 285 nm	Browning at 380 nm
1.8	0.77	0.520	0.120
1.8	1.46	0.400	0.080
1.8	3.00	0.380	0.070
1.8	4.62	0.345	0.045
1.8	6.00	0.325	0.040
1.8	4.60	0.400	0.070
2.8	4.60	0.408	0.070
3.8	4.60	0.415	0.080
4.8	4.60	0.425	0.090

Table 3.40. <u>Observations on the composition of nutrients of</u>
<u>the beans powder dried at constant drum speed</u>
<u>and at different steam pressures.</u>

Steam pressure (bar absolute)	Ash %	Moisture content %	Carbohyd-rates %	Protein %	Oil %	Vitamin C mg/100g
1.8	4.5	6.7	62	24	2.5	0
2.8	4.6	5.6	61	25	2.4	0
3.8	4.6	4.2	62	24	2.3	0
4.8	4.5	3.1	62	24	2.4	0

<u>Note:</u> Composition on 'dry weight' basis

Total solids of the raw feed material = 24.3% weight to weight

Drum speed   = 4.62 rpm

Table 3.40 shows that the moisture content is decreased from 6.7 to 3.1% dry weight basis for a three-fold increase in steam pressure. The individual constituents showed very little difference from the original data of the raw product (table 3.32). This was to be expected because the raw product contained low water content (table 3.32). As in the case of cassava and bananas the effect of heat on protein may be accompanied by a decrease in digestibility (22). No Vitamin C was detected by methods used for Vitamin C determination (section 2.7.1.6.).

3.3.4. Optimisation of the preparation and processing conditions to produce drum dried horse bean powder of an acceptable quality.

3.3.4.1. Introduction

The drum drying conditions used for horse beans are very similar to those used in the production of drum dried cassava flakes.

The final moisture content is not critical from the point of view of storing the drum dried product, since the original beans, in a mature and dry condition, would normally be stored at a moisture content of about 10% (dry weight basis). Spoilage in storage may, however, occur through oxidation of the oil or breakdown of the protein to produce rancid and putrefactive flavours, respectively. This would necessitate packing the drum dried product under vacuum or inert gas.

3.3.4.2. Production of the horse bean powder

(a) Choice of the raw product

Uniformly mature, dry beans, free from insect infesta-
tion, and other foreign bodies (sand, soil, plant and animal
remains, rotten seeds, etc.) should be selected for dehydra-
tion. One should not use slurries with solids content less
than 20% because this will lead to poor production rates and
problems with the product pick-up.

(b) Sorting and washing

All the foreign materials should be removed by screening,
or by hand. A final washing with fresh water removes soil,
bad odours, and the greater bulk of microorganisms.

(c) Soaking (see section 3.3.1.1.)

(d) Cooking

The beans are steamed in a pressure cooker for about 10
minutes in a little water (½ kg of water to 1 kg of beans).
The cooking water should be discarded to remove most of the
cyanide poison from the food material.

(e) Mashing, decortication and total solids control

The cooked product was mashed and screened in the "fruit
pulper" of the 'Lips Kitchen Machine'. This process effec-
tively removed the cortex material. The solids control was
done using the elliptical mixer of the "Lips Kitchen Machine",
with additions of measured amounts of fresh tap water.

(f)   Drum drying conditions

Steam pressure	1.8 - 4.8 bar absolute
Feed gap setting	0.60 mm
Total solids content of raw feed material	approximately 24% dry weight basis
Drum speeds	1.5 - 5.0 rpm
Production rate	2.27 - 6.36 (kg.h^{-1}.m^{-2})
Final moisture content	3 - 6.5% dry weight basis

(g)   Grinding

The bean flakes were ground to powder using a disc attrition mill (section 2.3.4.).

(h)   Storage

The product should preferably be stored in moisture-proof bags sealed under vacuum or with inert gas, such as nitrogen. Where possible, packets should be stored at low temperatures and away from the light.

(i)   Consumption

The horse bean powder may be used to form a spread in dry form on   a ready dish.   It could also be used in the manufacture of a bean-soup.

3.4. Preliminary Studies into the Application of Drum Drying for Other Local Food Products.

3.4.1. Fruits (one example)

3.4.1.1. Drum dried pawpaw (papaya) flakes

Tasty pawpaw flakes were obtained by drum drying pawpaw puree. The puree was made by either (a) pre-concentrating the raw pulp to about 15° Brix in open steam jacketed vessel, (b) evaporating in a batch evaporator (steam-jacketed pan) under vacuum or (c) by the addition of measured amounts of corn starch to the raw pulp. The latter method also reduced the hygroscopic nature of the final drum dried flakes.

According to the author's experience with pawpaw flakes, the retention of the original pawpaw flavour was poor even with additions of sulphur dioxide (500 ppm), citric acid (1000 ppm) and ascorbic acid (1000 ppm).

3.4.2. Vegetables (one example)

3.4.2.1. Drum dried pumpkin

Pumpkin powder has about one-seventh the weight and one-quarter the volume of regular puree (59). Blended with spices the powder is used for making excellent pies. The flow sheet of the manufacture of pumpkin powder includes pre-concentration to about 20% solids with addition of sulphur dioxide (3600 ppm) equivalent of sodium sulphite and sodium bisulphite to inhibit product darkening. Packaging in inert gas is recommended.

3.4.3. Cereals (one example)

3.4.3.1. Drum dried wheat flakes for baby food formulation

A baby food base was prepared from wheat flour. The flour-water mix was in the ratio 40:60 of flour to water, respectively.

The product was heated in an open pan and stirred continuously in order to avoid burning (this step would best be carried out in a   scraped surface heat exchanger, e.g. the votator, etc., for a short hold time (of the order of 10 - 15 seconds) and high temperatures (of the order of 150 - 160°C.)). The gelatinised mass was inelastic and was ready for drum drying.

4. GENERAL DISCUSSION AND SUMMARY OF CONCLUSIONS

4.1. Discussion

The single drum drier is useful for drying many diffe-
rent types of food products. However, in order to obtain a
product of high quality, the fresh, raw material must also
be of high quality. Finally, the processing temperatures,
drum rotation speeds and raw feed total solids should be ba-
lanced so that one obtains a dried product of optimum quality.

The composition of the raw food material is useful in
helping to predict the extent of heat damage likely (i.e. the
Maillard reaction and caramelisation of sugars) as well as
indicating the more sensitive components (e.g. Vitamin C) and
the possibility of retaining sufficient of these nutrients du-
ring drum drying. Vitamin C may therefore be used as indica-
tor of heat damage in a drum drying operation. The effect of
the processing conditions on the toxic constituents will greatly
determine the suitability of the final dried product for human
consumption. Fortunately, for the drum drying operation, these
toxic constituents are almost completely removed during the
preliminary processes of raw-product washing and cooking, which
precede drum drying.

It may be necessary to control the raw feed total solids;
(a) by the addition of measured quantities of water (i.e. where
the raw feed solids are high as with beans and cassava); (b)
by the addition of foreign materials such as fibre, starch or
sugar; or (c) by performing a preconcentration step (i.e. where
raw feed solids are low as in the case of pawpaw puree). The

above treatments not only adjust the feed total solids, but
in the light of this work it has been shown that they can
also modify the feed pick up at the drum surface which will,
in turn, affect the final product quality and yield.

The maximum steam pressure gauge allowed for use with
the pilot drum drier is 5.6 kg./sq.cm. (5.5 bar). The maxi-
mum drum rotation is 19 revs. per minute. At first it might
seem that by using high steam pressures and fast drum rota-
tion speeds it would be possible to obtain a maximum produc-
tion rate. However, it can be seen from this work that at high
steam pressures corresponding to very high steam temperatures
and rates of heat transfer many food products would be liable
to scorching. Although the resulting product film would be
thin and have a low bulk density, the accompanying heat damage
involved could mean a final dried product of low quality. On
the other hand, very low steam pressures (below 2.5 bar abso-
lute produce very little heat damage, but when combined with
high drum rotation speeds the moisture content of the final
dried product is usually high and unfavourable for both rehyd-
ration and storage/shelf life.

Low drum rotation speeds (below 3 rpm) usually result in
the formation of a thick product film of high bulk density.
Unfortunately, the production rate is low at low drum speeds
which tends to make the operation uneconomical when conside-
ring large-scale drum drying processes.

Increasing the total solids content of the feed material
(maintaining the steam pressure and drum speed constant) leads

to the formation of a thin, low moisture content product film as opposed to a thick, high moisture content film with low solids content of feed material. Similarly, a higher solids feed content leads to a higher production rate when compared with that for feed material of lower solids content.

Heat damage was inhibited to a great extent by the use of sulphur dioxide. This additive is effective for both enzymatic (for the raw product) and non-enzymatic (during the drum drying) browning. The observed browning was much lower when the additive was applied to the raw feed material rather than when no no additive was used. Any sulphur dioxide additive remaining after drum drying is useful in promoting a prolonged shelf life and hence good storage time.

The final drum dried product has many uses, some of which could be involved in the formulation of baby foods, soups, drinks, and breakfast cereals, etc. Drum drying, however, is not the cheapest method of preservation by dehydration. It is unfortunate that a processed food obtained by expensive methods of production must, in the absence of subsidies be sold at an expensive price. Consequently, the low-income groups (in Kenya and other developing countries) who would otherwise benefit from the use of some of the drum dried product mentioned in this thesis, may not, in the end, be able to afford to purchase such items. This argument has to be balanced against the fact that it is preferable to have abundant supplies of relatively expensive feed commodity rather than no food at all. The latter must also be viewed in the light of the fact that dehydrated

foods in general, in this case drum dried foods, offer much
longer storage lives and easier and cheaper distribution,
even to the most remote locations.

4.2.   Summary

The relationship between film thickness, steam pressure, mash solids, retention time and drum speed, together with their effect on drying rate, the final moisture content, the nutritive value, browning and some thermal data (specific heats, thermal conductivities and overall heat transfer co-efficients) were examined.

High steam pressure and long retention times resulted in excessive product browning. The bulk density of the final product decreased with increased drum speed. A decrease in film thickness, at constant retention time, corresponds to higher overall drying rate and lower moisture content of the dried flakes. Higher total solids in the raw product puree resulted in a thinner film and a higher production rate.

The effect of adding SO_2 was determined during the processing as well as the storage of the final product.

The conditions leading to maximum drying rate were:

(1)   Minimum film thickness uniform across the surface of the drum.

(2)   Minimum retention time required to give the desired moisture content in the dried flakes.

(3)   Maximum steam pressure possible with regards to heat damage.

(4)   Maximum puree solids content which form a uniform film on the drum.

A product with optimum qualitites is possible to manufacture by balancing steam pressure, drum speed and puree total

solids. An economical operation, however, would require higher production rates which could affect the product quality.

The Vitamin C was greatly destroyed by heat during processing. Addition of SO_2 helped minimise the browning effect. The possible danger of cyanide poisoning in cassava and horse beans was satisfactorily reduced in the cooking step.

5. SUGGESTIONS FOR FUTURE WORK

1. Preparation of a stable foam as in foam-mat drying and application of such a layer of foam to the heated drum (17).

2. Dissolution of a soluble gas in the feed material. The film on the rolls is frothy as it is heated and dried. This would certainly have an influence on the rate of drying as well as the quality of the final product (17).

3. Rapid exhaustion of steam from space above the rolls; introduction of air of controlled relative humidity and temperature (17).

4. Storage life of product in flexible packages impervious to oxygen, moisture and light e.g. 3-ply laminates such as polyolefin-foil-mylar (21).

5. Determination of the effect of processing on HCN contents of cassava and beans and the control on amounts in final product.

6. Product fortification

   e.g. protein enrichment of cassava

      fish powder + cassava

   - a soya - banana powder (Steinberg 1972)

7. Formulation for a baby food using one of the dehydrated products or a combination of them as base material.

8. Means of improving the drum dried product shelf life and the stability of product quality during storage.

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