FOOD RESEARCH INSTITUTE,
ACCRA, GHANA

PROJECT TITLE

ASSESSMENT OF MEAT DRYING IN HOT HUMID CLIMATES USING NATURAL CONVECTION, CLOSED-TYPE SOLAR DRYERS AND INVESTIGATION OF PRACTICABLE MEAT DRYING PARAMETERS.

PHASE II (FINAL REPORT)

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CONTENTS

Page No.

LIST OF TABLES AND ILLUSTRATIONS

ABBREVIATIONS

AB 1x1 cm	Brined meat strips, 1x1cm. (width x breadth) Ambient dried
AR 1x1 cm	Raw meat strips, 1x1 cm (width x breadth) Ambient dried
AB 2x2 cm	Brined meat strips, 2x2 cm (width x breadth) Ambient dried
AR 2x2 cm	Raw meat strips, 2x2 cm (width x breadth) Ambient dried
R 1x1 cm	Raw meat strips, 1x1 cm (width x breadth)
R 2x2 cm	Raw meat strips, 2x2 cm (width x breadth)
B 1x1 cm	Brined meat strips 1x1 cm (width x breadth)
B 2x2 cm	Brined meat strips 2x2 cm (width x breadth)
R 0.5x2 cm	Raw meat strips 0.5x2 cm (width x breadth)
B 0.5x2 cm	Brined meat strips 0.5x2 cm (width x breadth)

TSD	:	Tent Solar Dryer
CSD	:	Cabinet Solar Dryer
Expt	:	Experiment
Unmod	:	Unmodified
mod.	:	modified
LDPE	:	Low density polyethylene

ABSTRACT

Two natural convection, closed-type solar dryers (Cabinet and Tent), were constructed and evaluated in comparison with ambient drying method for their drying performance on different meat strip sizes in the hot humid climatic zone of West Africa, viz Accra, Ghana.

Results from the studies indicated the following:

Ambient drying method and the modified TSD (in Experiment 3)showed the desired functions for the initial drying stages of meat strips.

The CSD showed the desired functions for later drying stages of meat strips.

The effect of increased ventilation to the drying chamber of the TSD was to increase the rate of moisture removal from drying meat strips in the initial drying period. The increased ventilation however, led to lowered temperature increases in the drying chamber and consequently lowered drying performance of the TSD during later drying period of meat strips.

1x1 cm raw meat strips dried and stored better than 1x1 cm. brined and 2x2 cm. raw and brined dried meat strips, when stored at room temperature in aerobically sealed plain LDPE bags during a 6 week storage period.

Consequently, 1 cm thick meat strip seemed to be the critical meat size to dry under the present conditions of study.

Brine, (containing 3,5 or 10% salt) infusion of meat strips for short or long periods prior to drying, adversely affected moisture removal from drying meat strips and subsequently shortened the storage life of the dried product.

Gelatine coated (10% gelatine solution preparation at 40°C) and hot smoked (ca. 50°C for 30 minutes) solar dried meat strips, aerobically sealed in plain LDPE bags and stored at room temperature had greatly extended shelf life during a 6 month storage period.

All dried meat strip sizes studied rehydrated to more than half their original weight during a 6 hour rehydration period in water at room temperature.

Sensory evaluation on dried meat strips cooked in a traditional soup indicated better meat flavour and acceptability than when cooked in ordinary water.

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1. INTRODUCTION

Sun-drying of meat under the natural conditions of temperature, humidity and air flow, is one of the oldest methods of preserving meat.

Warm, dry air of a low humidity of about 30 per cent and relatively small temperature differences between day and night are optimal conditions for meat drying (FAO, 1990).

The drying process implies the removal of moisture from the meat, accomplished by vaporizing the moisture that is contained in the meat. To achieve this, the latent heat of vaporization must be supplied. The two important controlling factors in the unit operation of drying are: The transfer of heat to provide the necessary latent heat of vaporization, and the movement of moisture or water vapour through the meat tissue and then away from it to effect the separation of moisture from the meat (Earle, 1983).

During the initial stages of drying, there is relatively high evaporation of loosely held moisture on meat surfaces away from the meat. This process may be accomplished in the presence of abundant flow of relatively dry air over meat surfaces, with the minimum amount of heat necessary to supply the latent heat of vaporization of water.

In the later stages of drying, when most of the surface moisture on meat has been evaporated, the important process control is the heat necessary to agitate moisture from within deeper meat tissues to move by capillary action towards the periphery of the meat to be evaporated.

Meat to be dried is best prepared when cut into uniform strips and hanging, in order to expose maximum surface area for the evaporation of moisture.

There must be a balance between the process controlling factors in the initial and later stages of drying in order to acheive uniform and complete drying. An imbalance for instance, due to too high meat surface temperature, may lead to case hardening of meat which will inhibit further evaporation of moisture from within deeper meat tissue. The non uniformly dried meat will therefore stand the risk of microbial deterioration during storage.

Under this circumstance, meat size (thickness) becomes critical. It has been found in the present study that 2cm. or more meat thickness gave undesirable results with respect to dried meat quality and storage life.

The problem associated with drying meat under natural conditions in hot humid climates is the relatively large differences in environmental parameters between day and night. The presence of high relative humidites for example, inhibit the capacity of air to pick up and evaporate moisture during the drying process.

Effective drying can normally take place during the day when temperature is relatively high and relative humidity low. However, during late evenings throughout to early mornings, temperature drops gradually and relative humidity rises. These conditions are unfavourable for the effective evaporation of moisture from meat, therefore as a consequence, the drying process slows down to virtually a standstill during this period.

In order to avoid the risk of spoilage of drying meat during the intial drying period (first day of drying), some critical amount of moisture must be removed from the meat (between 10 to 20 percent, depending on meat strip size) during this period. This may be achieved with the provision of good, relative dry air circulation over drying meat in the presence of the minimum amount of heat necessary to provide the latent heat of vaporization of water.

When this protection is afforded to the drying meat strips during the first day of drying, the meat strips then stand a better chance of drying completely when the necessary heat required to move and evaporate moisture from within meat tissues is provided, during the later drying period.

The objective of the present study is to assess all parameters associated with the development and application of closed-type, natural convection solar dryers for the drying of meat in hot humid tropical climates.

In this study, two closed-type, natural convection solar dryers (Cabinet and Tent) were constructed and evaluated in comparison with ambient drying method for their drying performances on different meat strip sizes. Storage life, product quality and sensory characteristics of the dried meat strips were also studied.

Results obtained in the study and recommendations proposed which would lead to improved efficiency of solar drying of meat strips under the conditions studied have been given in the forgoing report (Phase II, Final Report).

2. MATERIALS AND METHODS

2.1 Meat selection and preparation

Fresh, relatively lean beef (from same day slaughtered animals), were purchased from the Meat Marketing Board, Accra, early in the morning. Meat cuts purchased ranged from clod, sticking and hind-quarter cuts.

Before meat preparation, the meat was washed under running tap water and placed on a meat cutting table previously cleaned and rinsed with 5% hypochlorite solution, (knives and containers to hold prepared meat were similarly cleaned).

The meat was trimmed of fat, gristle, connective tissue and bones were removed. Muscles were separated and membranes removed. The muscles were then cut along their fibre lengths into long strips. These were further subdivided to obtain the required meat dimensions of 1x1 cm and 2x2 cm. (width x breadth). Meat strip lengths were however variable (ranging between 10-15cm.)

In another experiment (Experiment 6), one isolated meat muscle, separated from fresh hind-quarter meat was prepared as described above into 1x1 cm and 0.5x2cm (width x breadth) meat strips.

It was desired to load solar dryers with meat strips very early in the morning so as to take advantage of a longer drying period during the day. Unfortunately, this was not possible because, meat preparation and weighing activities took much of the early hours of the day. Prepared meat strips were therefore kept refrigerated (ca. 5°C) overnight, well covered with plain LDPE sheeting to prevent dessication. Meat strips were then weighed and loaded into solar dryers for drying first thing the following morning.

2.1.1. Brining of meat strips

Three different brining treatments were applied to meat strips in this study.

In Experiment 1, half of the prepared raw meat strips were soaked in 3% (w/v) brine at an infusion rate of 1:2 (meat to brine) for two hours at room temperature, before draining meat for solar drying.

In Experiment 5, half of the prepared raw meat strips were soaked in 5% (w/v) hot brine (ca. 80°C) for 30 minutes at the same infusion rate as for meat strips in Experiment 1. Brined meat strips were subsequently drained and solar dried.

In Experiment 6, half of the prepared isolated meat muscle strips were soaked in 10% (w/v) cold brine overnight at room temperature, at 1:2 (meat to brine) infusion ratio. Meat strips were subsequently drained and solar dried.

2.2 Solar drying methods

Two types of solar dryers (Tent and Cabinet) were used for the drying of meat strips. The description of solar dryers, dimensions and characteristics have been given in detail in the Phase I Report of this study. Solar dryers were positioned north to south direction, and spaced in an open barb-wired compound to avoid shade casing of one on the other.

Meat strips to be dried were hung on an aluminium rod (about 112cm. long) with hooks tacked along its length. The rod with hooks and meat strips were then weighed together. Having tagged and preweighed the empty rod with hooks, the intial weight of meat strips on each loaded rod was established by difference.

Rods with hanging meat strips were then loaded into the solar dryers, being supported on wooden braces within the drying chambers. The doors of the solar dryers were then kept closed.

During the initial stages of drying, the lower sliding ventilation doors of the TSD (unmodified) were kept open to allow for increased ventilation into the drying chamber. These doors were however, kept closed from the second day of drying onwards, to allow for increased heat retention within the drying chamber.

The CSD had no such sliding ventilation doors. This dryer had one top vent (chimney) through which exhausted air flowed out of the drying chamber and collector air duct entrance through which air entered the drying chamber via the collector.

The drying process in this study was a continuous one hence, meat strips were not removed from the drying chambers throughout the whole drying period (between 3-4 days), except during weighing for mass changes and sampling for chemical analysis, moisture content and water activity determinations. Samples meant for these determinations were placed on separately labelled aluminium rods with hooks in the drying chambers.

Aluminium rod with hooks and hanging meat strips were weighed at least three times each day during the whole drying period, first in the morning, second in the afternoon and third late in the afternoon. Samples for analysis were also taken at the same time as for meat weighing. Meat strips were judged dried when more or less constant weights were established.

2.2.1. Sun drying method

Ambient (open-air sun drying) method of drying meat strips was also carried out at the same time as for solar drying methods for comparative studies as control samples, (mass changes of meat strips were recorded during meat drying). Meat strips for the sun drying method were hung out on a line fixed between two poles on the same compound where the solar dryers were placed. Meat strips hung approximately 1.35 meters from ground level on the line.

This method of drying does not afford any protection of the meat strips against pests, flies, dust and wetting by rains.

In the first experiment for instance, sun drying method meat strips vanished from the line overnight. In subseqent experiments, meat samples for this method of drying were therefore removed for safe keeping every evening.

All dried meat strips were packed in plain LDPE bags aerobically sealed and kept on wooden shelves under room storage conditions.

Dried meat samples were subjected to visual checks from time to time. The following analysis were also carried out on all meat samples: Raw and dried meat strips were subjected to proximate composition and microbiological analysis.

Solar dried meat strips were also subjected to sensory evaluation, water rehydration capacity analysis and water activity determination.

2.3 Measurement of environmental parameters during meat drying

The following environmental parameters were monitored during solar drying of meat strips:

Temperature, Relative Humidity, Air speed, and Solar Intensity (Insolation). Equipment used, description, correction factors and calculations associated with values obtained have been described in detail in the Phase I Report of this project.

All measurements were taken at 30 minutes interval continuously over the whole drying period for each experiment.

2.3.1. Temperature

Temperature (dry-bulb) was measured using the Grant Squirrel Data Logger connected with temperature probes, for Experiments 1 to 5.

(a) For the CSD, temperature at the following positions were measured:

(i) Entrance to collector air-duct from outside

(ii) Entrance to drying chamber from collector

(iii) Exit vent (chimney) from drying chamber

(iv) Mid-point of drying chamber, and

(b) For the TSD, the following positions were monitored:

(i) Entrance to drying chamber from lower vent

(ii) Mid-point of drying chamber, and

(iii) Upper vent exit point

(c) Ambient temperature was also measured.

In Experient 6, temperature measurements within solar dryers were taken with wet and dry bulb thermometers. Ambient temperatures (wet and dry bulb) were measured with the Whirling Hygrometer (refer to Phase I Report).

2.3.2 Relative humidity

Relative humidity was recorded for Experiments 1 to 5 using the Grant Squirrel Data Logger connected with a humidity sensor at the following positions: ambient air and mid-point of drying chambers of solar dryers (TSD-modified and unmodified, and CSD).

In Experiment 6, relative humidity within solar drying chambers were obtained using data from wet and dry bulb thermometers recorded. Ambient relative humidity was measured using the Whirling Hygrometer. In all cases, the relative humidity value was read from psychrometric charts (refer to Phase I Report).

2.3.3 Air Speed

Air speed was recorded with the Grant Squirrel Data Logger connected with a cup-type anemometer at the following positions:- ambient air; at about 30cm above ground level in Experiment 5, and at approximately 1.8 meters above ground level in Experiment 1; within drying chambers of solar dryers (TSD - unmodified, modified and CSD)
In Experiment 6, ambient air speed was recorded using a vane-type mechanical anemometer, positioned approximately 30cm. from ground level and the anemometer vanes facing right angles to the direction of air flow

(refer to Phase I Report). Measurements were taken three times daily, in the morning, afternoon and late afternoon.

Air speed within solar dryers was negligible.

2.3.4 Insolation

Solar intensity was measured for Experiments 1 to 5, using a dome-type solarimenter connected to the Grant Squirrel Data Logger. The solarimeter was mounted on a horizontal axis at approximately 1.8 meters above ground level away from any shading in the open air.

No insolation measurements were taken in Experiment 6.

2.4 Drying Experiments carried out

Six drying experiments were carried out in this study as follows:

2.4.1 Experiment 1

This was carried out using the TSD (unmodified) versus the CSD.

Ten kilograms of hind-quarter fresh beef was purchased for this experiment. Prepared boneless meat was then cut into 1x1 cm. and 2x2 cm. meat sizes. Half of each meat size was soaked in 3% brine for 2 hours at room temperature while the other half remained raw.

Meat samples were then shared among the experiemental treatments i.e for the two solar dryers and the sun drying method.

2.4.2 Experiment 2

This was carried out using the TSD (unmodified) from experiment 1 versus the TSD (modified). Modification in the latter TSD involved replacing the clear plastic sheeting on both triangular sides of the dryer with a fine aluminium mesh. This modification was done to investigate the effect of increased ventilation of the drying chamber on drying performance. Twenty kilograms of clod and sticking beef, prepared into 1x1 cm. and 2x2 cm. all raw beef strips were used for the experiment.

2.4.3 Experiment 3

This experiment was conducted using the TSD (unmodified) from experiment 1 versus the TSD (modified) from Experiment 2 with additional modification. This modification involved replacing the clear plastic sheeting on both rectangular sides of the TSD (from the base of the drying chamber floor to the first horizontal batton position), with a fine aluminium mesh. This modification was done for comparison and to investigate the effect of further increasing ventilation on drying performance of the solar dryer.

Twenty kilograms of sticking beef cut was prepared into 1x1 cm. and 2x2 cm. all raw beef strips for the experiment.

2.4.4 Experiment 4

This experiment was carried out using the TSD (modified) from Experiment 3 versus the CSD from Experiment 1, for comparative studies.

Twenty kilograms of hind-quarter beef was prepared into 1x1 cm. all raw beef strips for the experiment.

2.4.5 Experiment 5

This was carried out using the same solar dryers from Experiment 1, the TSD (unmodified) versus the CSD. This experiment was to confirm results obtained from Experiment 1.

Twenty kilograms of hind-quarter beef was prepared into 1x1 cm. and 2x2 cm. beef strips. Half of the sample size was soaked in hot (ca. 80^{o}C.) brine (5%salt) for 30 munites then drained. Raw and brined meat strips were then used for the drying experiment.

2.4.6 Experiment 6

This experiment was aimed at finding the effect of using an isolated meat muscle on the drying characteristics of meat strips with the smaller versions of the TSD (unmodified) and the CSD (refer to Phase I Report).

Ambient, (open air) sun drying of meat strips was also conducted for comparison.

It is known that different meat muscles from the same meat cut may behave differently under the same conditions of drying.

Moisture content was determined at intervals throughout the drying period for meat strips in solar dryers. Initial and final moisture contents (ie. for raw and dried meat strips respectively) were also determined for ambient dried meat strips in this experiment.

2.5 Preparation of gelatine solution for coating dried meat strips

In this study, dried meat strips from Experiment 6 were coated with gelatine solution preparations by dipping and subsequent surface drying. The study was aimed at investigating the effect of gelating coating on the storage life of dried meat strips.

10% (w/v) gelatine solution was prepared as follows:

One part dried gelatine powder was dissolved in nine parts distilled water by first soaking one-third of the gelatine powder in cold water for 20 minutes, then adding the rest of the water hot (Ca. 80-85°c).

Two different temperatures of 10% gelatine solution preparations were made at 40°C and 80°C respectively. Dried meat strips were dipped separately in these solutions and the meat strips subsequently dried in an open tray in the sun until gelatine coating was completely dried on meat strip surfaces. Gelatine coated dried meat strips were then packed and aerobically sealed in plain LDPE bags for storage under room conditions.

2.6. Hot smoke treatment of dried meat strips

Dried meat strips from Experiment 6 were subjected to hot smoke treatment to investigate the effect of that treatment on the storage life of dried meat strips. Dried meat strips were placed horizontally on a grill in a locally constructed smoking oven, pre-warmed to about 70°C from charcoal fire. Oven temperature was manually regulated by sprinkling small quantities of water to dampen fire until temperature was around 50°C. Small quantities of hardwood sawdust was placed at the fireplace to generate smoke. The oven door was shut and dried meat strips were smoked for 30 minutes while maintaining oven temperature at around 50°C.

Smoked dried meat strips were then cooled, packed and aerobically sealed in plain LDPE bags for room storage.

2.7 Analysis of meat samples

The following analysis were carried out on meat samples:

(i) Brined and raw fresh meat strips: Moisture content, crude protein, ash, salt, fat, pH and microbial counts.

(ii) Brined and raw dried meat strips: Moisture content, crude protein, ash, salt, fat, microbial counts, water rehydration capacity, water activity and sensory evaluation.

2.7.1 Moisture content determination

Total moisture content (wet weight basis) was determined according to AOAC (14th Ed.) procedures. Per cent moisture was calculated as follows:

$$\text{Moisture (\%)} = \frac{100\,(B-C)}{A}$$

Where A = initial sample weight

B = weight of dish + sample prior to drying.

C = weight of dish + sample after drying.

2.7.2. Crude protein analysis (Micro Kjeldahl method)

The modified AOAC (14th Ed.) method was used for the above analysis as follows:

(i) Sample digestion

Approximately 2g. of the ground sample was weighed by difference into a nitrogen-free filter paper, folded and transferred into a 500cm^3 Kjeldahl flask. Digestion catalysts made up of 96% sodium sulphate (anhydrous), 3.5% copper sulphate and 0.5% selenium dioxide, and then 25 cm^3 of concentrated sulphuric acid was added to the flask. The sample was digested until solution was clear and digestion completed.

(ii) Distillation

The digestion flask containing digested sample was cooled at room temperature and then 250 cm^3 of distilled water carefully added and mixed by swirling. The flask was allowed to cool and then connected to the distillation apparatus.

To a 250 cm^3 Erlenmeyer flask, 25 cm^3 of 2% boric acid solution containing screened methyl red indicator (0.01% methyl red and 0.08% bromocresol green indicators in alcohol), was added by pipette and the flask connected to the delivery tube, the latter dipping below the surface of the indicator solution. Anti-bumping stones (or zinc powder) was added to the sample digest, and 75 cm^3 of 50% sodium hydroxide solution was gently poured down the side of the Kjeldahl flask into the digested sample solution. The tap funnel was fixed and the flask heated to collect between 150 - 200 cm^3 distillate.

(iii) Titration

The distillate was titrated against 0.1 N Standard sulphuric acid until the appearance of a pink colour end-point. Crude protein (%) was calculated as follows:

$$\% \text{ crude protein} = \frac{(T-B) \times 1.4\ (N) \times 6.25}{\text{Sample weight}}$$

Where :
- T = volume of acid required to titrate sample
- B = volume of acid required to titrate blank.
- 1.4 = Milliequivalent weight of nitrogen including a factor of 100 for percentage.
- N = normality of acid
- 6.25 = factor for converting from nitrogen to protein.

2.7.3 Ash

About 2g. of ground sample was weighed into previously dried and weighed crucible. The sample was charred over a bunsen flame in a fume cupboard until all organic matter was completely charred. The charred sample was then ashed in a furnace at Ca. 500°C until completely ashed. Crucible containing ashed sample was cooled in a dessicator and reweighed.
Ash (%) was calculated as follows:

$$\text{Ash (\%)} = \frac{B \times 100}{A}$$

where :

A = Initial sample weight
B = Weight of ash.

2.7.4. Salt

(i) Sample preparation

About 2g. of sample was macerated in small quantities of distilled water for about two minutes. The macerated extract was filtered into a 250 cm^3 volumetric flask with the addition of small quantities of distilled water to wash macerated residue. The filtrate in the volumetric flask was then made up to the mark with additional distilled water.

(ii) Titration

25 cm^3 aliquots of the filtrate was then titrated against 0.1 M silver nitrate solution using few drops of 1% (w/v) potassium chromate indicator solution, until end-point (from yellow to brick red) colour was reached.

Per cent salt in sample was calculated as follows:

$$\% \text{ salt} = \frac{V \times 0.1 \times 58}{W}$$

where :

V = volume of titre used (less blank titre)
0.1 = molarity of silver nitrate
58 = molecular weight of salt (NaCl)
W = sample weight taken.

2.7.5 Total fat

Total fat (Soxhlet extraction) was carried out according to AOAC (14th Ed.) procedures. Fat content (%) was calculated as follows:

$$\% \text{ fat} = \frac{100 \times (B - C)}{A}$$

Where:

A = sample weight
B = weight of flask after extraction and evaporation of solvent
C = weight of empty dry flask before extraction

2.7.6 pH

pH of meat samples was determined using the Jenway 3020 pH Meter as follows:

Approximately 10g. of the ground sample was weighed into a 200 cm^3 beaker and 90 cm^3 of carbon dioxide free distilled water was added and thoroughly mixed. A fluted filter paper was placed part way down into the slurry and allowed to set for about 5 minutes. The pH electrode was then immersed into the filtered solution inside the fluted filter paper and the pH reading recorded. The pH meter in all cases was precalibrated using standard buffer solutions of pH 4.0 and 7.0 respectively.

2.7.7. Water rehydration capacity

Water rehydration capacity for Experiment 1 dried meat strips was determined as follows:

About 1.0 to 5.0 g weight of dried meat strips were cut and placed into 100 cm^3 beakers. About 30 to 50 cm^3 distilled water was added to completely cover the meat strips and then allowed to rehydrate at room temperature conditions. Rehydrating meat strips were removed from the beakers after every one hour, meat surfaces dabbed with a tissue to remove surface water and then reweighed. The weighing process was continued for at least 6 hours.

Per cent weight gain (or per cent rehydration) of the meat strip was calculated as follows:

$$\% \text{ rehydration} = \frac{\text{weight gained}}{\text{Initial weight}} \times 100$$

2.7.8 Water activity

Water activity of meat strips was determined using the (Decagon, model Cx1) water activity meter as follows:

a representative piece of meat strip was chopped into small bits and thoroughly mixed together. Small amounts of the prepared meat sample was placed in a dish which was then placed in the water activity meter chamber and the latter closed. The meter automatically displayed the water activity value and temperature at which recorded after some few minutes of equilibration, by giving a sound.

2.7.9 Microbial counts

2.7.9.1 Sample preparation

All meat samples presented for microbial analysis were asceptically collected using sterile blade and forceps, and sealed in sterile plain LDPE bags well labelled. 10g of the sample was asceptically taken and placed in a sterilized blender machine. 90 cm^3 of a quarter strength Ringer's solution was added and the mixture macerated at low speed for one to two minutes. Serial dilutions of the slurry obtained after maceration were made by transferring 1 cm^3 each of solution serially up to 10^{-6} dilution.

2.7.9.2 Yeast and mould counts

For the enumeration of yeast and mould, a low-acid medium was prepared by sterilizing 250 cm^3 of PDA (Potato Dextrose Agar) with 7.5 cm^3 of acid. Using the pour plate technique, 1cm^3 each of the serial dilutions were pipetted into duplicate sterile glass petri dishes. The dilutions were then overlaid in the petri dishes with the acidified PDA media prepared. The mixture was carefully rotated (clockwise and anticlockwise) to mix and the plates then incubated at 30°C for 24 hours.

2.7.9.3 Bacteria counts

Into duplicate sterile glass petri dishes were pipetted from 10^{-1} to 10^{-6} serial dilutions of prepared meat sample. These dilutions were overlaid with prepared PCA (Plate Count Agar) and similarly mixed as above. The plates were incubated at 30°c for 72 hours.

2.8 Sensory evaluation

Sensory analysis on representative samples of solar dried meat strips were carried out to investigate the acceptability of the dried meats based on their quality attributes. Ten taste panelists, all members of the Food Research Institute staff and experienced in sensory evaluation were used. Dried meat samples were offered to panelists in a traditional soup prepared as follows:

garden eggs, pepper and tomatoes were boiled and blended together in addition to onions. The mixture was then diluted with water to a semi-light consistency and then boiled. Dried meat strips which had been cut into short pieces and reconstituted in water overnight in a refrigerator were then cooked in the soup until fairly tender with the addition of salt to taste. The soup was served hot in small glass dishes to panelists. Water was provided for mouth rinsing between different sample evaluation.

In another sensory evaluation on dried meat strips, representative meat samples were reconstituted in water overnight in a refrigerator and then the meat cooked in ordinary water until tender, with the addition of salt to taste. This method was selected to remove any effect on sensory attributes due to the presence of soup or spices.

The sensory attributes evaluated were colour, tenderness, flavour, juiceness, off flavour and overall acceptability. A 5-point product rating scale was used, and attributes scored for were rated between, 1 for undersirable attribute to 5 for desirable attribute (see Appendix 18) for the taste panel score sheet used.

3. RESULTS AND DISCUSSIONS

3.1 Effect of meat cut selected on the recovery of boneless prepared meat

Results of Table 1 (see below) indicated a clear relationship between type of meat cut used and the percentage of boneless prepared meat recovered. Meat cuts used in Experiments 2 and 3 were from the fore-quarter, with their associated lower percentage recovery of boneless prepared meat. Meat cut obtained from hind-quarter meat had higher recovery rates for the boneless prepared meat.

Fore-quarter meat cuts used in the study were more difficult to prepare into suitable boneless portions. Muscles isolated were shorter and irregularly shaped, hence presented difficulty when uniform meat strips were cut from them.

On the other hand, hind-quarter meat cuts used were easier to prepare into suitable boneless portions. The muscles were longer and more regularly shaped. Cutting of uniform meat strips was easily done. Generally, hind-quarter meat cuts are premium cuts over fore-quarter meat cuts, in muscle type, tenderness and eating quality.

pH of fresh meat cuts as purchased were on the higher side especially for Experiments 4 and 5 meat samples. It was established that animals were poorly handled before slaughter and so was the meat. Meat purchased was not refrigerated and was kept under poor hygienic conditions. Higher ultimate pH values may be attributed to these conditions.

TABLE 1: SELECTION OF MEAT CUTS USED AND PERCENTAGE BONELESS MEAT RECOVERED AFTER MEAT PREPARATION

Experiment Number	Meat cut as purchased (Beef)	Meat Weight (initial)	Prepared boneless meat recovered (weight)	Prepared boneless meat recovered (%)	pH of fresh meat purchased (Ca.25°C)
1.	Hind quarter meat: (Topside and Silverside)	10.102kg	7.26kg	71.9	5.5
2.	Clod, sticking and chuck and blade	20kg	8.39kg	41.95	5.72
3.	Clod, and sticking	20kg	5.688kg	28.44	5.8
4.	Hind-quarter meat: (Thick flank, Topside and Silverside)	20kg	13.98kg	69.9	6.67
5.	Hind-quarter meat: (Toprump, Topside and Siverside).	20kg	14kg	70.0	6.3

3.2 Summary of results on environmental parameters monitored during meat drying.

Summary of results on the above are presented in Tables 2 and 3 below.

3.2.1 Air flow rate

Ambient air flow rate was recorded in three experiments in this study (see Table 2 below). Experiments 1 and 5 results were obtained using the Squirrel Data logger attached with anemometer. Experiment 6 results were obtained using a vane-type manual anemometer (refer to Phase I Report).

Apart from differences in airflow rate that may have occured due to the use of different equipment, the height from ground level at which measurements were taken might also have affected differences in results. Experiment 1 air flow rate was measured at a height approximately 1.8 meters from ground level, while Experiments 5 and 6 measurements were taken at approximately 30cm. above ground level, in the same direction for all the experiments.

Convectional air flow rate and direction were variable and difficult to predict at any particular time. Air flow rate within the TSD (unmodified) and CSD were negligible (Table 3). Air flow rate within the TSD (modified) increased with the level of modification. In Experiment 2, plain polythene sheeting covering the two opposite triangular sides of the TSD were replaced with fine aluminium mesh to increase ventilation within the TSD. In Experiment 3, further ventilation was provided to the TSD by replacing the plain polythene sheeting on the opposite rectangular sides from the base of the drying chamber floor to the end of the first batton. This increased ventilation accounted for the higher air flow rate within the TSD (modified) in Experiments 3 and 4.

TABLE 2: LOGSHEET OF RESULTS ON AMBIENT DRYING CONDITIONS

PARAMETERS MONITORED	EXPT.1	EXPT.2	EXPT.3	EXPT.4	EXPT.5	EXPT.6
1. Start of drying (Date/time)	25/01/91 (13.40 GMT)	5/02/91 (09.44 GMT)	12/02/91 (10.21 GMT)	19/02/91 (08.50 GMT)	23/02/91 (07.50 GMT)	16/04/91 (09.30 GMT)
2. End of drying (Date/time)	28/01/91 (09.40 GMT)	8/02/91 (10.44 GMT)	15/02/91 (14.21 GMT)	21/02/91 (14.20 GMT)	26/02/91 (13.50 GMT)	19/04/91 (15.00 GMT)
3. Air flow rate (ms^{-1})						
(i) Maximum	1.69	-	-	-	0.79	0.17
(ii) Minimum	0.65	-	-	-	0.0	0.13
(iii) Mean	1.29	-	-	-	0.27	0.15
4. Air temp. (°C)						
(i) Maximum	35.5	33.5	33.5	34.5	33.5	35.0
(ii) Minimum	24.5	24.0	23.0	24.5	23.5	26.3
(iii) Mean	27.2	27.5	26.9	27.6	27.3	31.6
5. Relative Humidity(%)						
(i) Maximum	100.0	-	-	-	-	81.0
(ii) Minimum	30.0	-	-	-	-	62.0
(iii) Mean	75.6	-	-	-	-	73.9
6. Insolation (Wm^{-2})						
(i) Maximum	817.2	820.9	923.6	908.6	919.8	-
(ii) Minimum	3.7	1.87	1.78	5.59	3.73	-
(iii) Mean	171.1	439.7	404.9	425.4	233.2	-
(iv) Total	21942.16	32406.72	32820.6	25250.0	36621.27	-

TABLE 3 : LOGSHEET OF RESULTS ON SOLAR DRYING CONDITIONS

PARAMETERS MONITORED	EXPT 1		EXPT 2		EXPT 3		EXPT 4		EXPT 5		EXPT 6	
	TSD (unmod.)	CSD	TSD (unmod)	TSD (mod)	TSD (unmod)	TSD (mod)	TSD (mod.)	CSD	TSD (unmod.)	CSD	TSD (unmod.)	CSD
1.Start of drying (Date/time)	25/01/91 (13.40 GMT)		5/02/91 (09.44 GMT)		12/02/91 (10.21 GMT)		19/02/91 (08.50 GMT)		23/02/91 (07.50 GMT)		16/04/91 (09.30 GMT)	
2.End of drying (Date/time)	28/01/91 (09.40 GMT)		8/02/91 (10.44 GMT)		15/02/91 (14.21 GMT)		21/02/91 (14.20 GMT)		26/02/91 (13.50 GMT)		19/04/91 (15.00 GMT)	
3.Air flow rate (ms^{-1}) (within solar dryer chamber)												
(i) Maximum	-	-	-	0.51	-	1.29	1.91	-	-	-	-	-
(ii) Minimum	-	-	-	0.002	-	0.013	0.32	-	-	-	-	-
(iii) Mean	-	-	-	0.48	-	0.54	0.69	-	-	-	-	-
4.Solar dryer chamber mid-point temperature (°C)												
(i) Maximum	45.5	47.5	39.0	37.1	39.0	35.3	34.8	45.5	43.0	51.9	49.5	49.0
(ii) Minimum	25.1	23.5	23.5	25.2	22.0	24.2	26.1	24.5	22.5	23.9	33.0	33.3
(iii) Mean	32.1	30.2	29.5	29.5	28.8	28.6	29.1	30.9	30.4	33.8	44.7	44.2
5.Relative Humidity (%)												
(i) Maximum	-	-	-	100.0	-	100.0	99.4	-	-	99.0	74.0	92.0
(ii) Minimum	-	-	-	45.8	-	52.3	61.6	-	-	28.5	46.0	55.0
(iii) Mean	-	-	-	81.89	-	82.9	87.4	-	-	72.3	55.1	70.6
6.Total moisture content in meat batch (kg)												
(i) Start	2.18	1.2	3.24	3.24	2.3	2.3	2.097	2.097	2.18	2.097	-	-
(ii) End	0.18	0.122	0.23	0.26	0.137	0.172	0.171	0.118	0.196	0.19	-	-
(iii) Moisture evaporated	2.0	1.078	3.01	2.98	2.163	1.128	1.926	1.95	1.984	1.907	-	-
7.System Drying Efficiency (%)	2.6	1.8	2.69	2.66	1.91	1.87	2.21	2.86	1.57	1.93	-	-

3.2.2 Temperature

Ambient temperature results indicated a more or less similar temperature recordings throughout the experimental period (see Table 2 above.)

Mid-point of drying chamber temperatures recorded (see Table 3 above), were higher than ambient temperatures recorded throughout the experimental period, and this was expected. The collector floor of the CSD and the drying chamber floors of the TSD and CSD were painted glossy black, and in addition to the plain polythene sheeting covering the solar dryers, a closed system was created capable of concentrating solar energy to warm up air within the drying chamber.

The CSD on the whole registed higher mid-point of drying chamber temperatures than the TSD.

Mid-point of drying chamber temperature of the TSD was lowered as more ventilation was provided to the dryer through modification from Experiments 2 to 3.

The CSD had two collector and absorber surfaces, viz, the collector floor surface and the floor of drying chamber surface (total floor surface area amounting to 3.453 m^2). The TSD had only one collector and absorber surface, viz, the floor surface of the drying chamber (total surface area amounting to 4.47 m^2), (Refer to Phase I Report). The effect ot increasing collector and absorber surfaces is to increase solar energy concentration leading to higher increases in temperature within the drying chamber. This was not exactly so in this study.

The lower mid-point of drying chamber temperatures recorded for the TSD could be attributed to other factors. The unmodified TSD had two adjustible lower ventilation doors on both triangular sides, apart from the two upper vents. The CSD on the other hand, had only one entrance for ventilation into drying chamber (the collector air duct), and one top vent (chimney) for expelled air from the drying chamber. Clearly, the TSD (unmodified) was slightly more ventilated that the CSD. This fact may have accounted for the lower mid-point of drying chamber temperatures recorded in the TSD despite the presence of a larger collector-absorber floor surface area.

The effect of increasing ventilation on the TSD was again to lower temperature increases within the drying chamber as occured in Experiments 2,3 and 4. (see Table 3 above.)

3.2.3 Relative humidity

Relative humidity results indicated high maximum values (near Saturation Point) and high mean values (see Tables 2 and 3 above), for both ambient and within solar drying chambers during the period monitored.

Similar values were obtained for ambient and within solar drying chambers in earlier experiments (Tettey et. al. 1991, Phase I Report).

The lowest relative humidity values usually occured during the day when temperatures were high.

From late afternoon throughout the night to early mornings, relative humidity values increased and approached saturation point around mid-night to early morning, when temperatures were usually low.

3.2.4 Insolation measurements

Maximum insolation value recorded during the day ranged between 800 to 1000 Wm^{-2} in all the experiments carried out (Table 2). The total insolation recorded may be related to the amount of sunshine received during the day, the collector surface area and the ability of the dryer to retain the heat increases obtained. The latter may be related to the level and nature of insulation of the collector and the level of reduction of heat loses on the drying chamber.

3.3 Comparisons between drying performance of solar dryers and ambient drying for meat strips dried.

The results and discussions on the above are presented below for Experiments 1 to 6 (Figures 1 to 15). Drying curves for the various meat strips dried using the TSD, CSD and ambient drying method have also been shown in Appendices 1 to 9.

3.3.1 Experiment 1

Results on per cent average of original mass (percent weight loss), indicated that the TSD performed better than the CSD for the drying of different meat strips (see Figs. 1,2, and 4). The CSD on the other hand was slightly better for the drying of B1x1 cm. meat strips (Fig 3).

Results on per cent moisture content indicated again the TSD to perform better than the CSD for the drying of raw and brined 2x2cm. meat strips (Figs 1 and 2). The CSD was slightly better in performance for the final moisture content attained by R1x1cm. meat strips (Fig.4).

In the initial drying of meat strips, the important step is the removal of loosely held surface moisture which can be achieved by a higher air flow rate over the drying meat surfaces. During the latter stages of drying however, temperature becomes more important to agitate moisture trapped within meat tissues to be carried to meat surfaces by capillary action for evaporation.

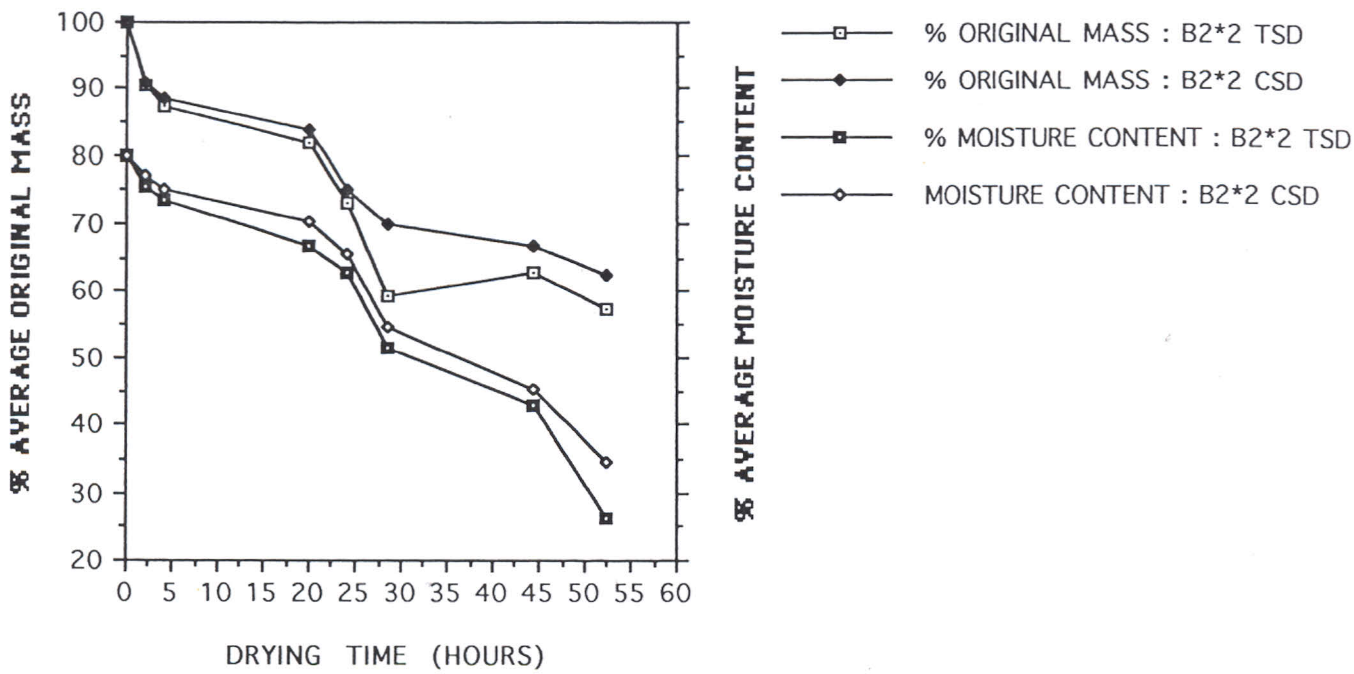
It will be recalled that the TSD (unmodified) was said to be slightly more ventilated than the CSD. The better performance of the TSD in this experiment was attributed to its better ventilation than the CSD.

This fact led to the modification of the TSD in Experiment 2 to increase ventilation within its drying chamber and to compare with the unmodified TSD to prove or disprove Experiment 1 results.

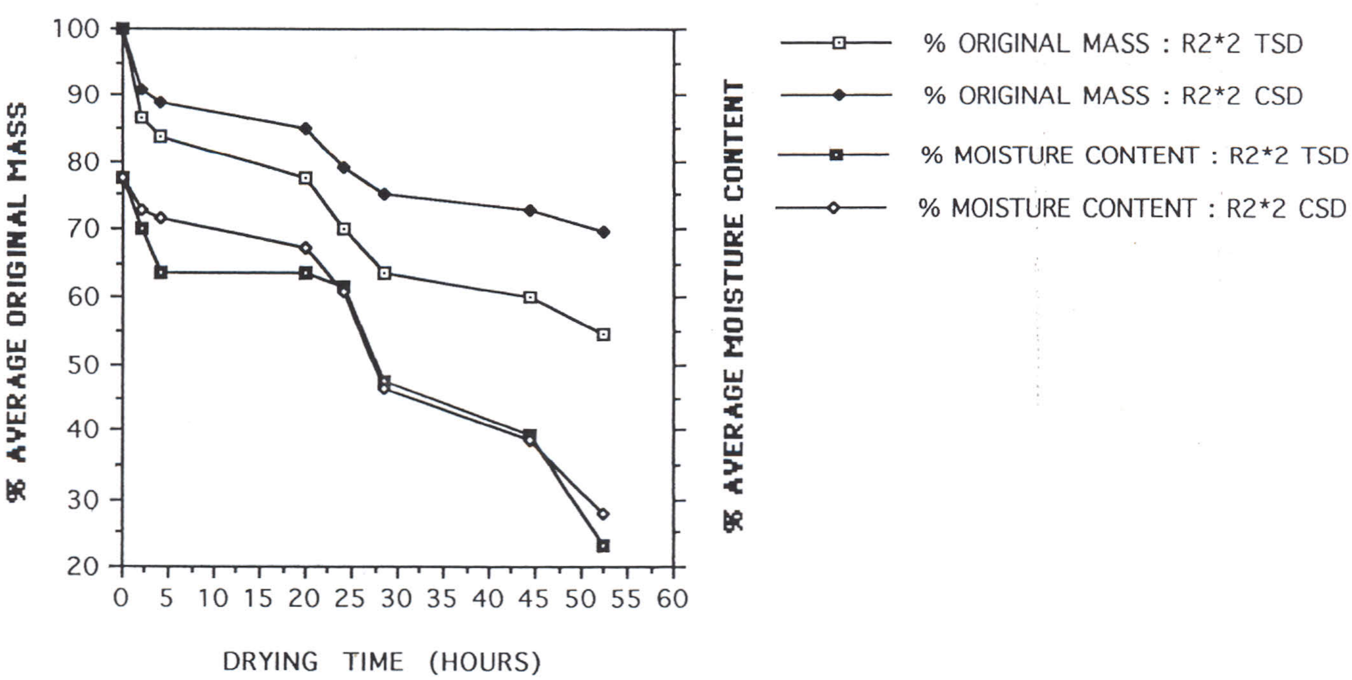
3.3.2 Experiment 2

Based on per cent weight loss results, ambient drying showed a slightly better performance than that of solar dryers (Figs 5 and 6). The TSD (unmodified) and TSD (modified) showed a rather similar performance for the drying of R1x1 cm and R2x2 cm. meat strips based on weight loss, moisture content and water activity results (Figs 5 and 6). R1x1cm meat strips however, on the whole, attained a lower final moisture content than R2x2cm meat strips irrespective of the dryer used.

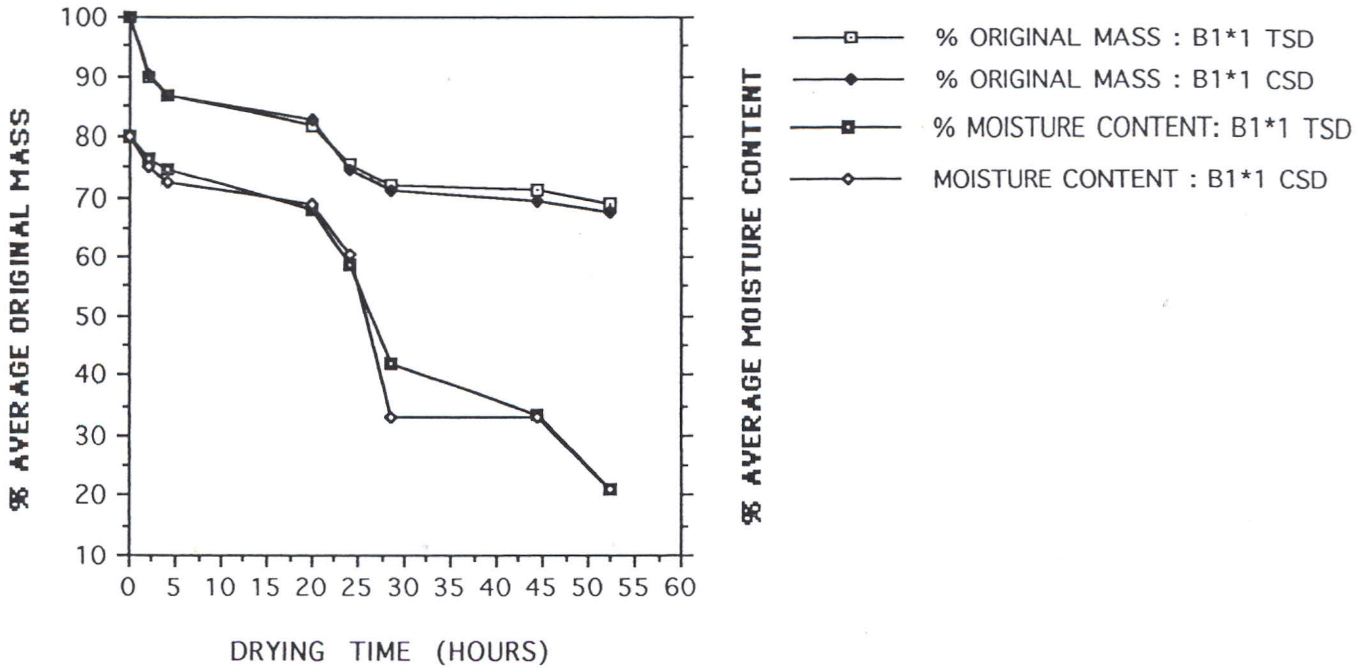
EXPT. 1 (FIG. 1) : COMPARISON BETWEEN TSD (unmodified) AND CSD ON THEIR DRYING PERFORMANCE WITH BRINED (3% SALT) 2*2 MEAT STRIPS



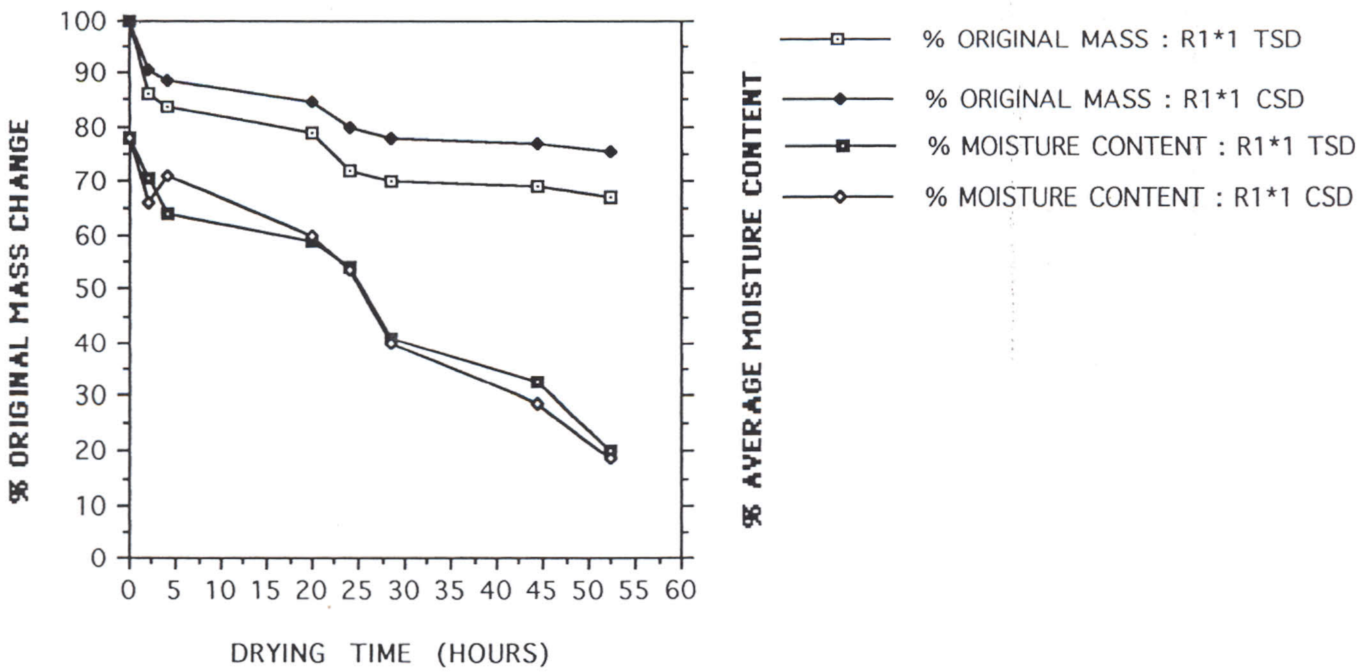
EXPT. 1 (FIG. 2) : COMPARISON BETWEEN TSD (unmodified) AND CSD ON THEIR DRYING PERFORMANCE WITH RAW 2 * 2 MEAT STRIPS



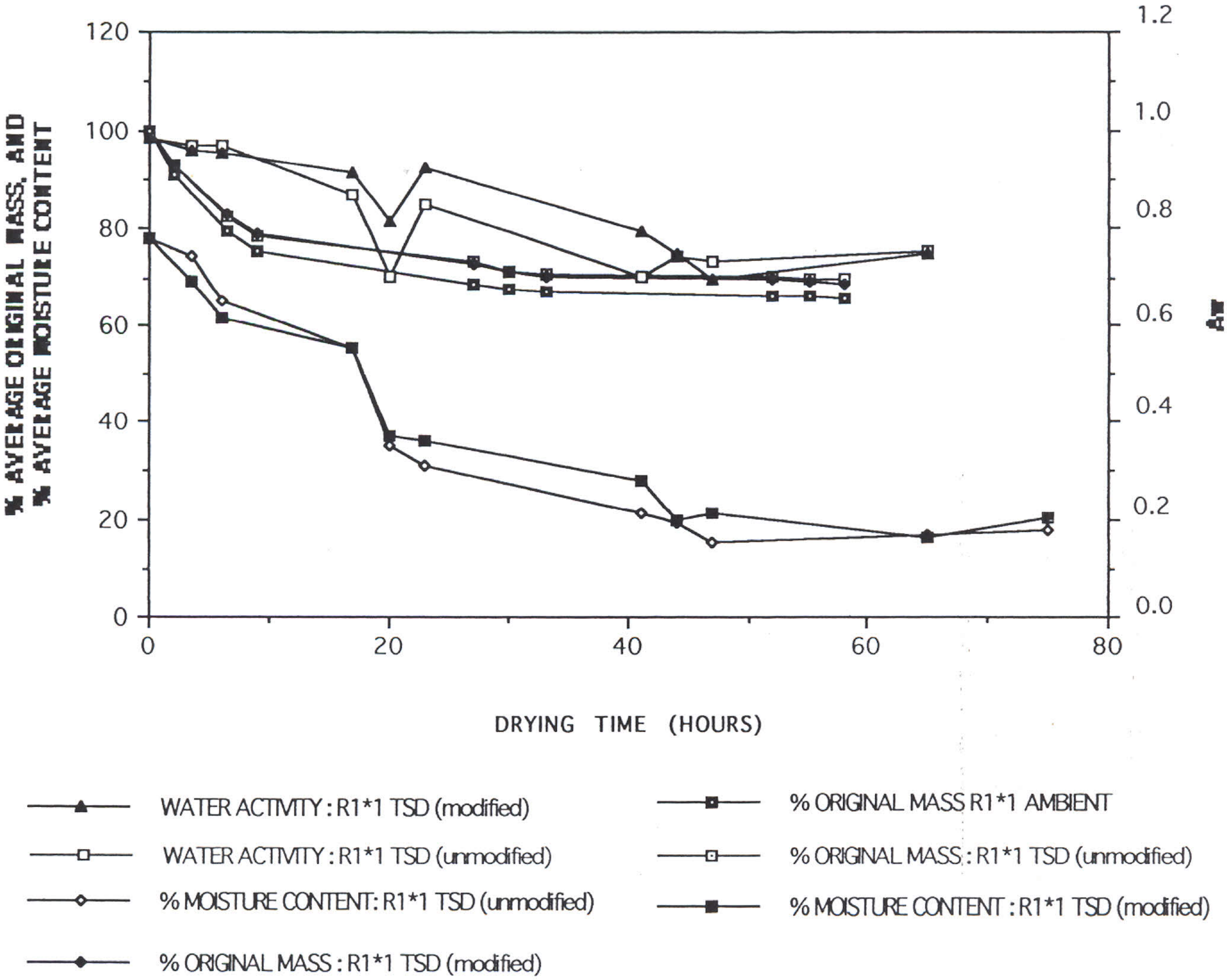
EXPT. 1 (FIG. 3) : COMPARISON BETWEEN TSD (unmodified) AND CSD ON THEIR DRYING PERFORMANCE WITH BRINED (3% SALT) 1*1 MEAT STRIPS



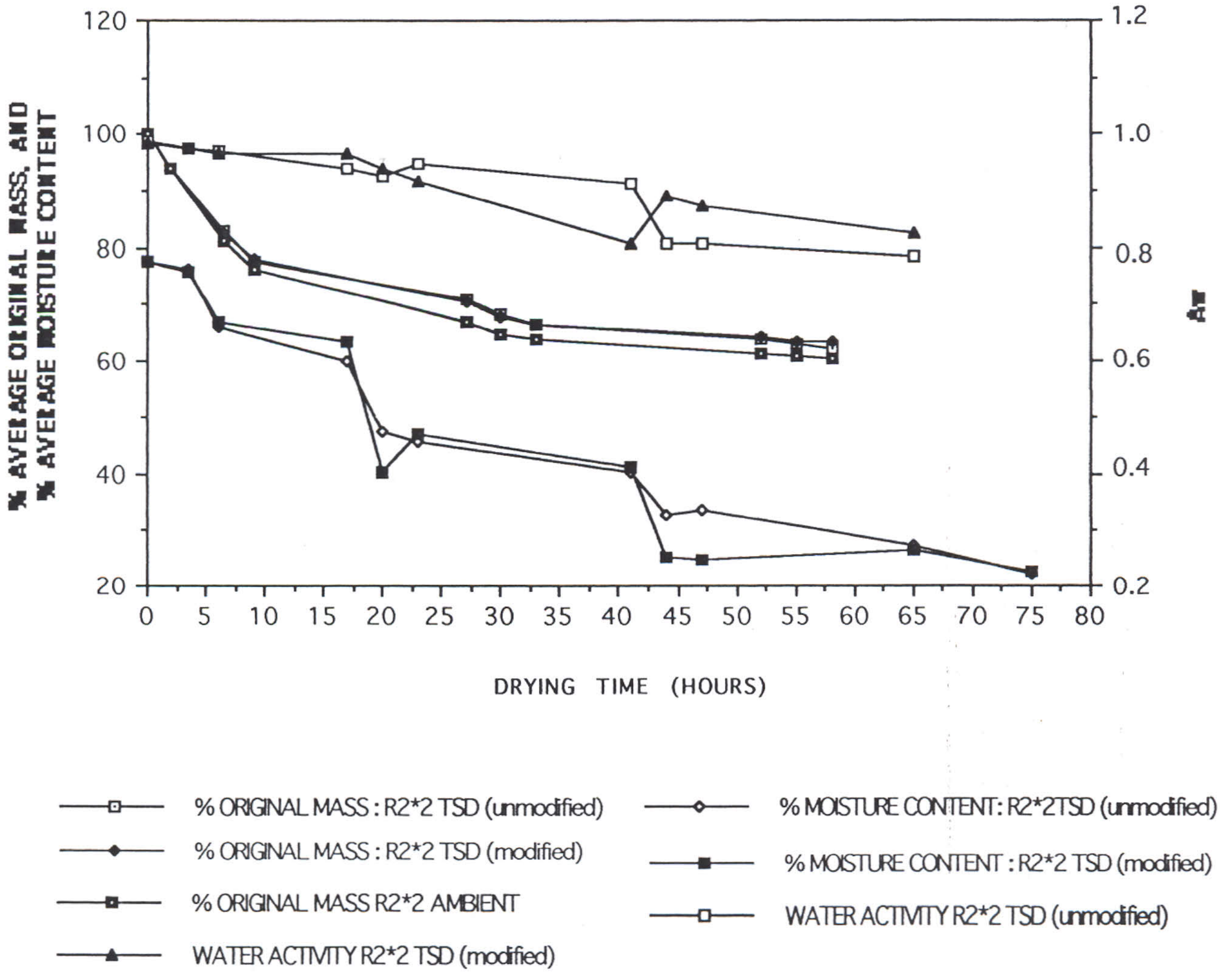
EXPT. 1 (FIG. 4) : COMPARISON BETWEEN TSD (unmodified) AND CSD ON THEIR DRYING PERFORMANCE WITH RAW 1*1 MEAT STRIPS



EXPT. 2 (FIG. 5) : COMPARISON BETWEEN TSD (unmodified), TSD (modified) AND AMBIENT ON THEIR DRYING PERFORMANCE WITH RAW 1*1 MEAT STRIPS.



EXPT. 2 (FIG. 6) : COMPARISON BETWEEN TSD (modified) AND AMBIENT ON THEIR DRYING PERFORMANCE WITH RAW 2 * 2 MEAT STRIPS



The final water activity of R2x2cm meat strips was slightly lower for the TSD (unmodified) than for the TSD (modified).

Results of Experiment 2 indicated that, increasing ventilation of the TSD drying chamber by modification, did not improve its drying performance over the unmodified TSD at least based on moisture content and water activity results (see Figs 5 and 6). However, based on weight losses, it seemed that increased ventilation seems to improve drying rate of meat strips, as evidenced by ambient drying results (see Figs 5 and 6).

This assumption led to further modification of the TSD in Experiment 3 to further increase ventilation of the drying chamber to approach ambient conditions, and then to investigate effect of this further modification on drying performance compared with the unmodified TSD.

3.3.3 Experiment 3

Results on weight losses for R1x1cm meat strips (Fig. 7) indicated that the TSD (modified) and ambient drying method performed similarly and better than the TSD (unmodified)

Moisture content and water activity results however, (Fig 7) indicated a clearly better performance for the TSD (unmodified) than for the TSD (modified) for the drying of R1x1cm meat strips.

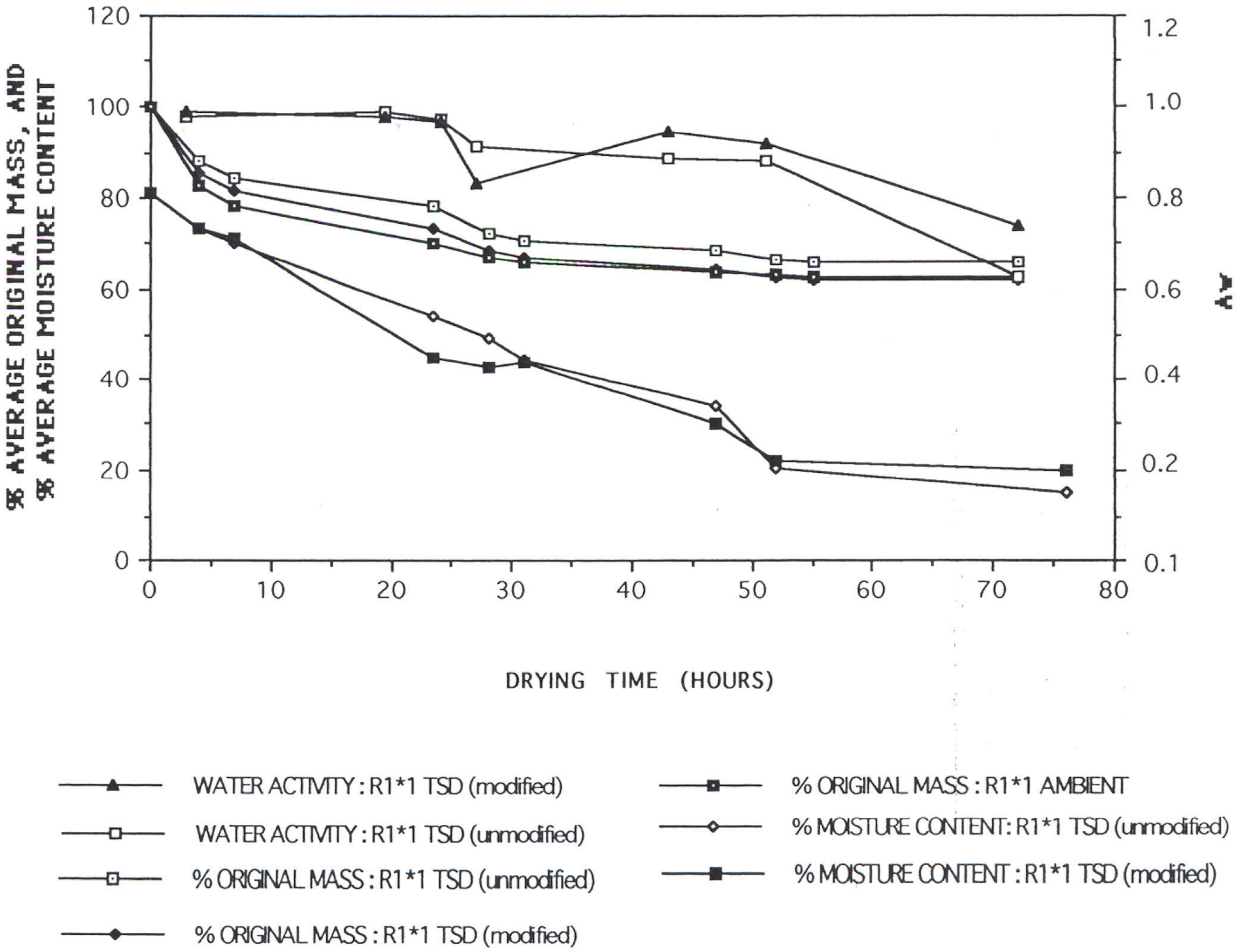
With the drying of 2x2cm meat strips (Fig. 8), the unmodified TSD performed better than the TSD (modified) and ambient drying in that order, based on weight losses.

The TSD (unmodified) was again better in drying performance than the TSD (modified) based on water activity and moisture content results (Fig.8)

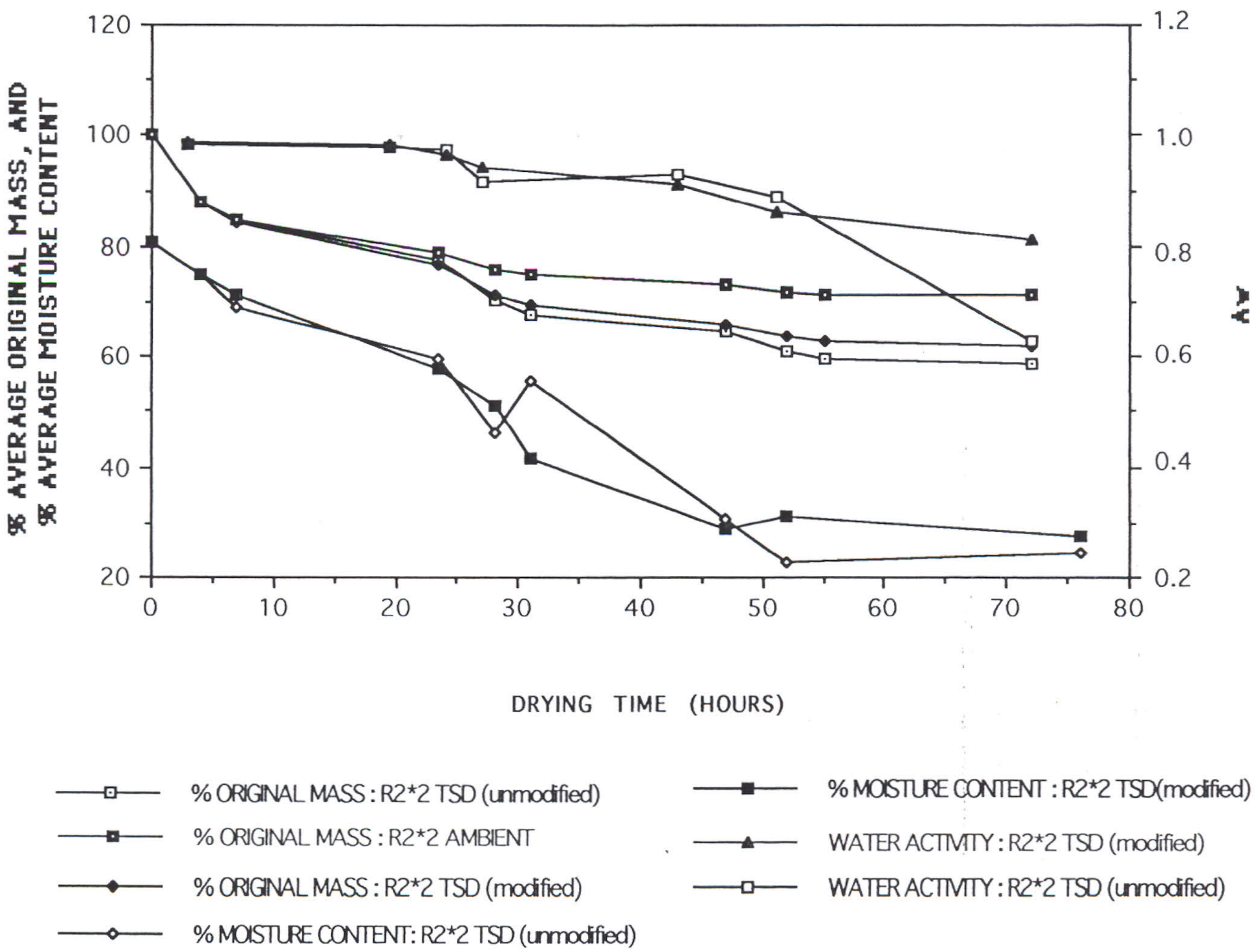
Results of Experiment 3 indicated the following:

That further modification to the TSD by increasing ventilation to the drying chamber, led to lowering of drying performance of the TSD

EXPT. 3 (FIG. 7) : COMPARISON BETWEEN TSD (unmodified), TSD (modified) AND AMBIENT ON THEIR DRYING PERFORMANCE WITH RAW 1 *1 MEAT STRIPS.



EXPT. 3 (FIG. 8) : COMPARISON BETWEEN TSD (unmodified), TSD (modified) AND AMBIENT ON THEIR DRYING PERFORMANCE WITH RAW 2*2 MEAT STRIPS.



(modified), over that of the TSD (unmodified). Results based on weight losses was slightly inconsistent in predicting drying performance however, moisture content and water activity results were fairly more consistent and reliable in predicting the drying performance of solar dryers for the meat strips dried.

In Experiment 4, it was planned to compare the drying performance of the TSD (modified) as obtained in Experiment 3 with the CSD to identify any differences which would enable comparison with the performance of the TSD (unmodified), using R1x1cm meat strips.

3.3.4. Experiment 4

Weight loss results in this experiment indicated that the CSD and ambient drying method were slightly better than the TSD (modified) in the drying of R1x1cm meat strips (Fig. 9). Moisture content and water activity results were basically very similar and indicated better performance for the CSD over the TSD (modified).

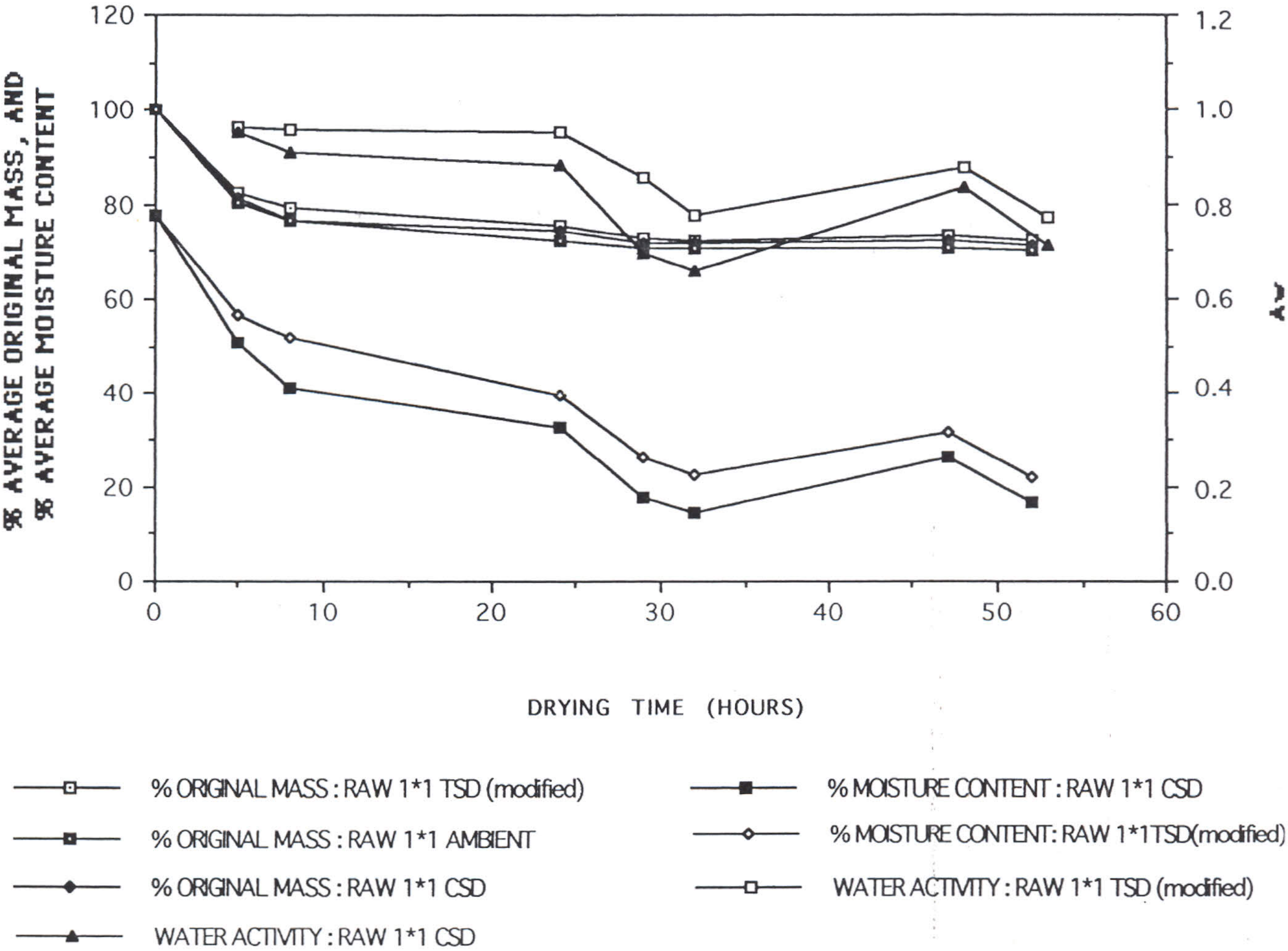
Results of Experiment 4 indicated that based on weight loss results, there was only a slight difference in performance between the CSD and the TSD (modified) in favour of the CSD, for the drying of R1x1cm meat strips.

Moisture content and water activity results however, indicated a clearer difference in performance in favour of the CSD. This results proves the earlier assumption that weight loss results were unreliable as in index for predicting drying performance, but moisture content and water activity results were fairly reliable indices.

There was also the indication that R1x1cm. meat strips were easily dried to moisture contents between 10 to 20%, using either the CSD or TSD (modified or unmodified), in all the experiments so far carried out.

In Experiment 5, the TSD (unmodified) was compared with the CSD for their drying performance as conducted in Experiment 1, to cross-check results of the latter.

EXPT. 4 (FIG. 9) : COMPARISON BETWEEN TSD (modified), CSD AND AMBIENT ON THEIR DRYING PERFORMANCE WITH RAW 1*1 MEAT STRIPS.



3.3.5 Experiment 5

Results of this experiment indicated the following:

The TSD (unmodified) and the CSD performed similarly and only slightly better than ambient drying method based on weight loss results for the drying of B1x1cm meat strips (Fig 10).

Moisture content and water activity results also showed no significant difference between the TSD (unmodified) and the CSD in their drying performance for B1x1cm. meat strips (Fig. 10).

With the drying of R1x1cm. meat strips, the TSD (unmodified) was slightly better in performance than the CSD and ambient drying method based on weight loss results (Fig. 11). Moisture content and water activity results however, showed a slightly better performance in favour of the CSD over that of the TSD (unmodified).

With the drying of B2x2cm. meat strips, and based on weight loss results, the CSD performed better than ambient drying, then TSD (unmodified) in that order (Fig. 12). Moisture content results showed no difference in drying performance between TSD (unmodified) and CSD for B2x2cm. meat strips however, water activity results indicated a slightly better performance in favour of the TSD (unmodified), (Fig. 12).

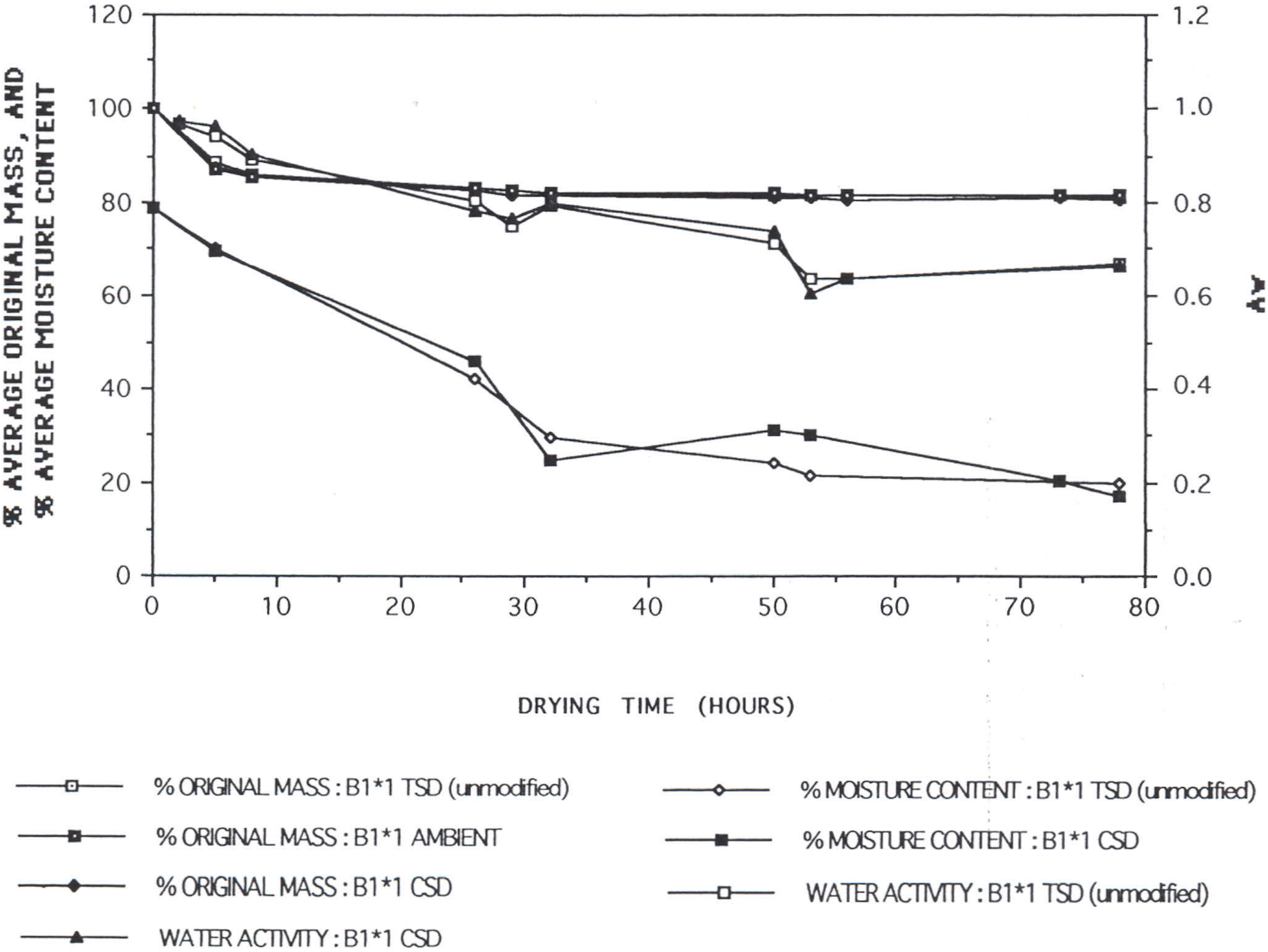
With the drying of R2x2 cm. meat strips (Fig. 13), and based on weight loss results, there was no significant difference in the drying performance of the TSD (unmodified), CSD and ambient drying method.

Moisture content and water activity results however, indicated only slight difference in drying performance in favour of the TSD (unmodified) over that of the CSD (Fig. 13).

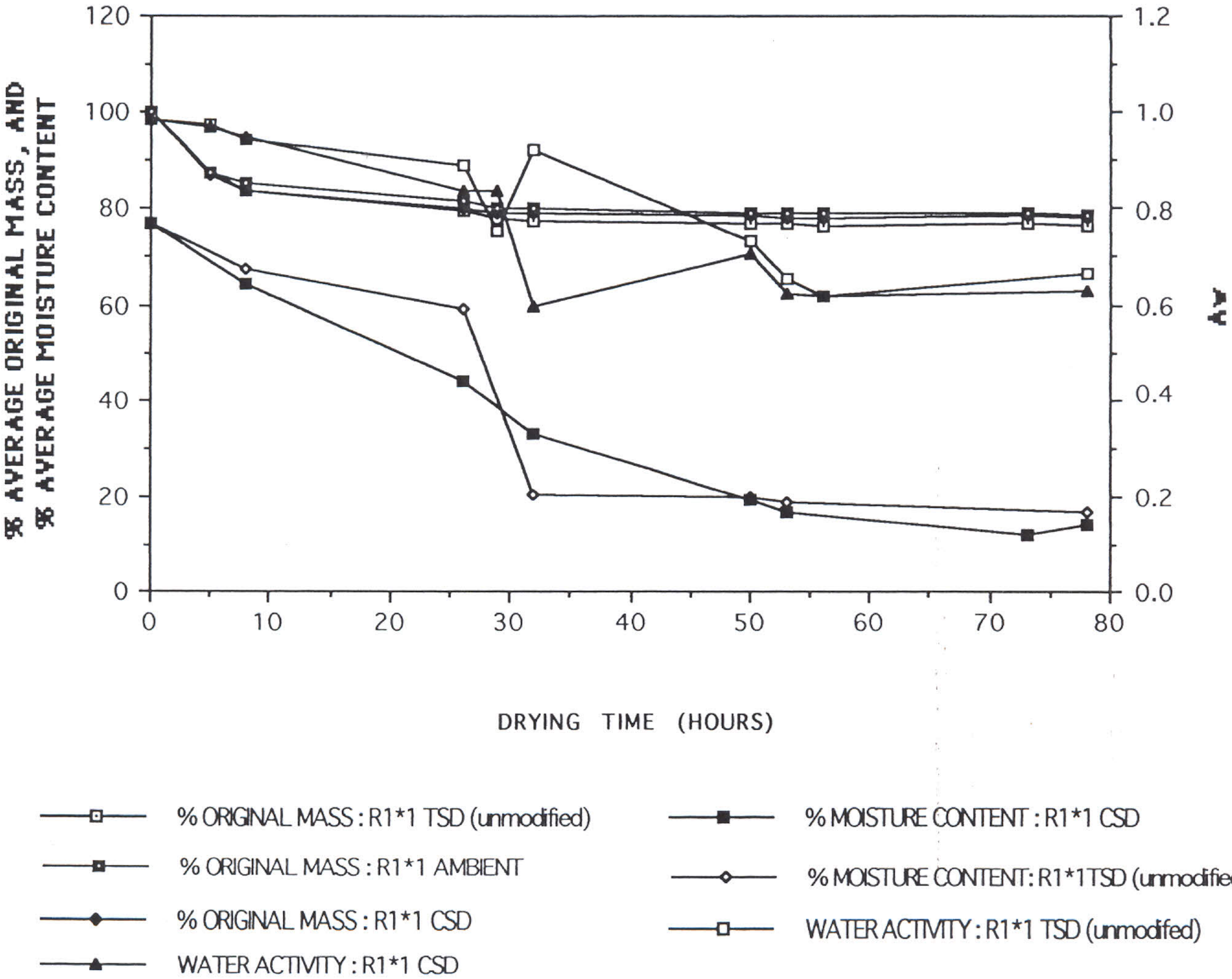
Results of Experiment 5 when compared with Experiment 1 results for the same meat strip size dried indicated the following:

The TSD (unmodified) performed better than the CSD based on weight loss results for R1x1 cm. meat strips, but based on moisture contant and water activity results, the CSD performed better than the TSD for R1x1 cm. meat strips.

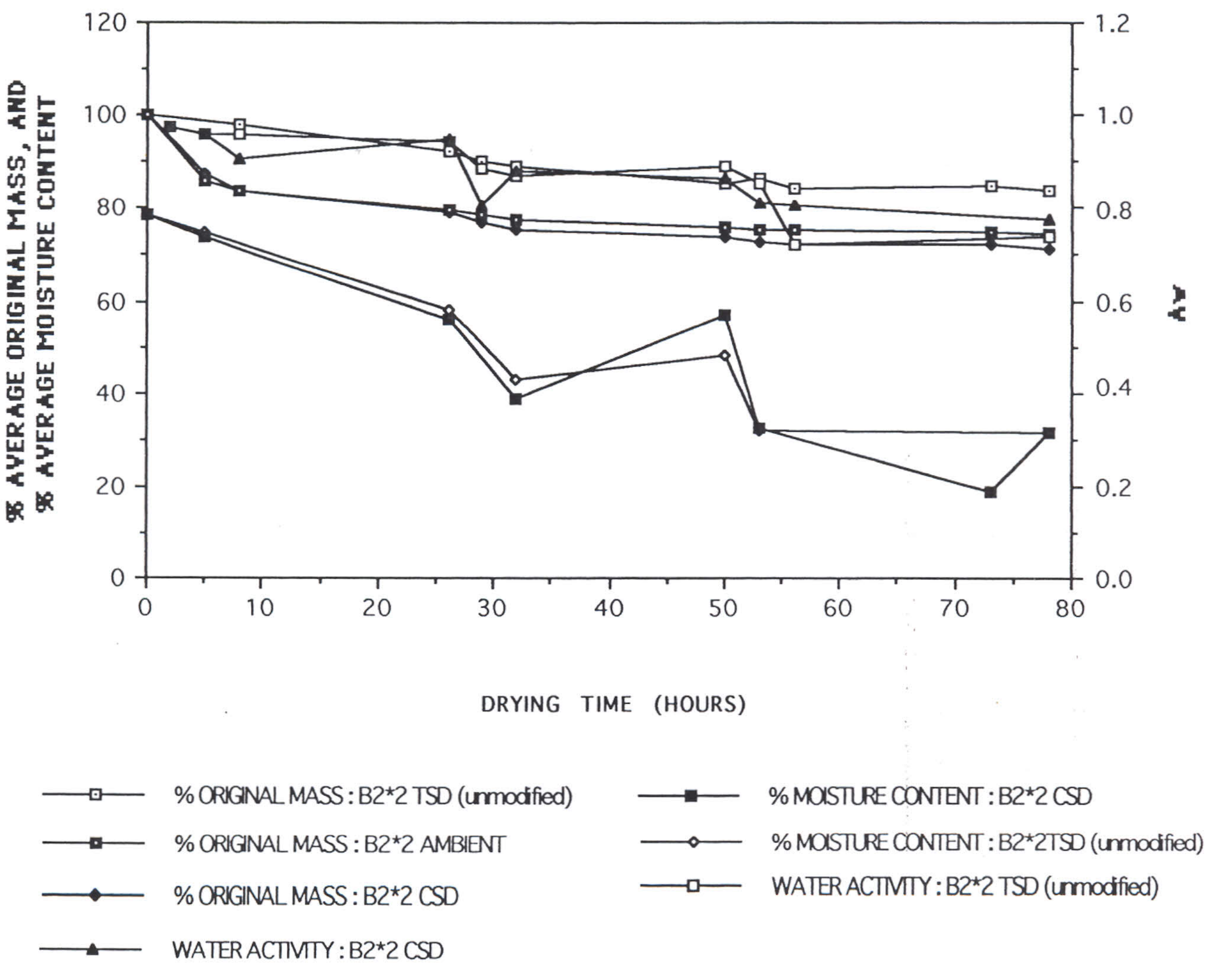
EXPT. 5 (FIG. 10) : COMPARISON BETWEEN TSD (unmodified), CSD AND AMBIENT ON THEIR DRYING PERFORMANCE WITH BRINED (5% SALT) 1*1 MEAT STRIPS.



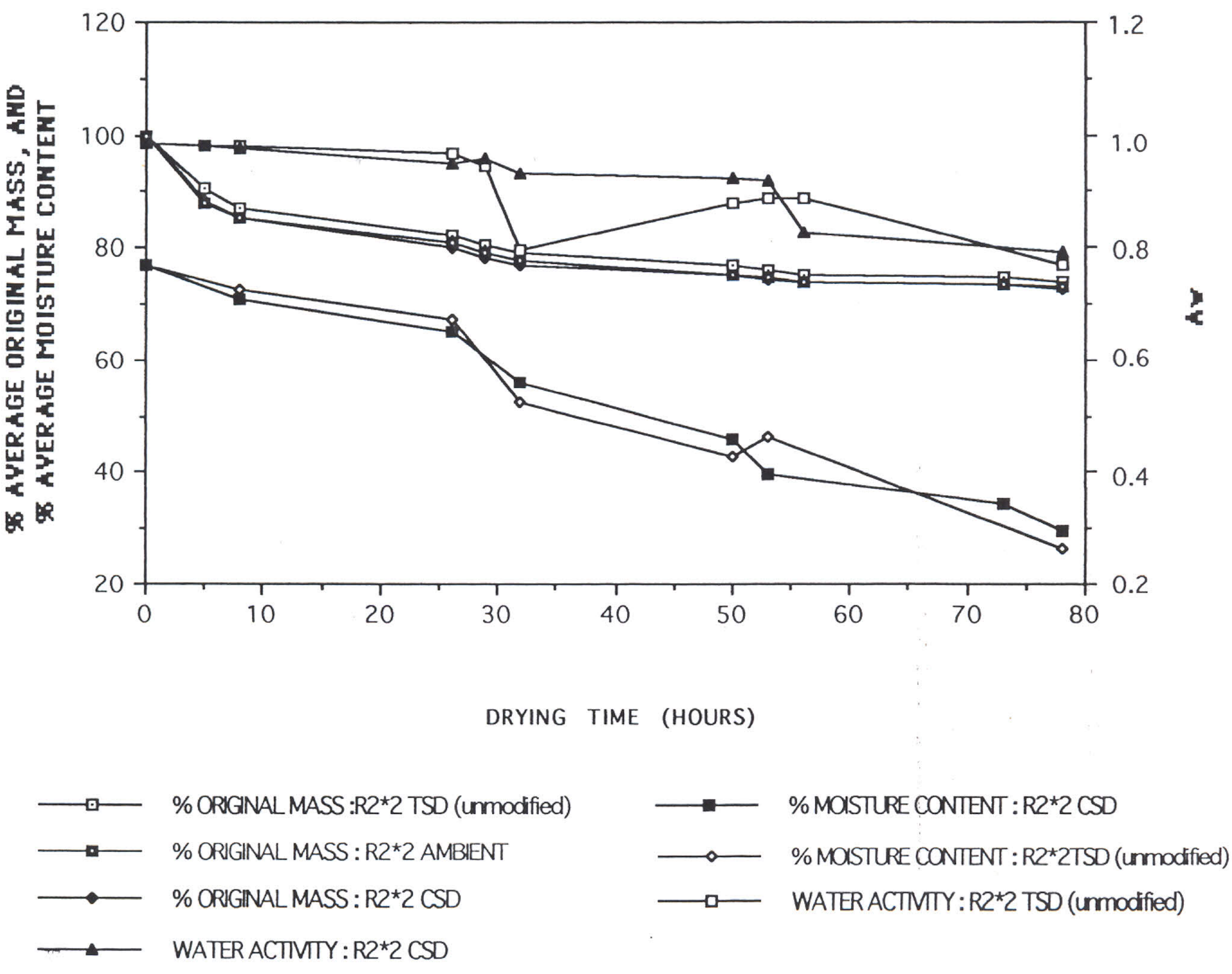
EXPT. 5 (FIG. 11) : COMPARISON BETWEEN TSD (unmodified), CSD AND AMBIENT ON THEIR DRYING PERFORMANCE WITH RAW 1*1 MEAT STRIPS.



EXPT. 5 (FIG. 12) : COMPARISON BETWEEN TSD (unmodified), CSD AND AMBIENT ON THEIR DRYING PERFORMANCE WITH BRINED (5% SALT) 2*2 MEAT STRIPS.



EXPT. 5 (FIG. 13) : COMPARISON BETWEEN TSD (unmodified), CSD AND AMBIENT ON THEIR DRYING PERFORMANCE WITH RAW 2*2 MEAT STRIPS.



The TSD (unmodified) performed better than the CSD for the drying of R2x2 cm. meat strips based on moisture content and water activity results.

With B1x1 cm. meat strips, there was no difference in the drying performance of the CSD and the TSD (unmodified) based on weight loss, moisture content and water activity results.

The CSD was slightly better than the TSD (unmodified) for the drying of B2x2 cm. meat strips, based on weight loss results. Moisture content results however, undicated the CSD to be similar in performance with the TSD (unmodified) but based on water activity results, the TSD (unmodified) was better in performance than the CSD for the drying of B2x2 cm. meat strips.

3.3.6. Experiment 6

This experiment was planned to compare the drying performance of the TSD (unmodified) and the CSD on one insolated muscle tissue (selected from hind-quarter cut), with results obtained from the same solar dryers using mixture of different muscle tissues as in previous experiments.

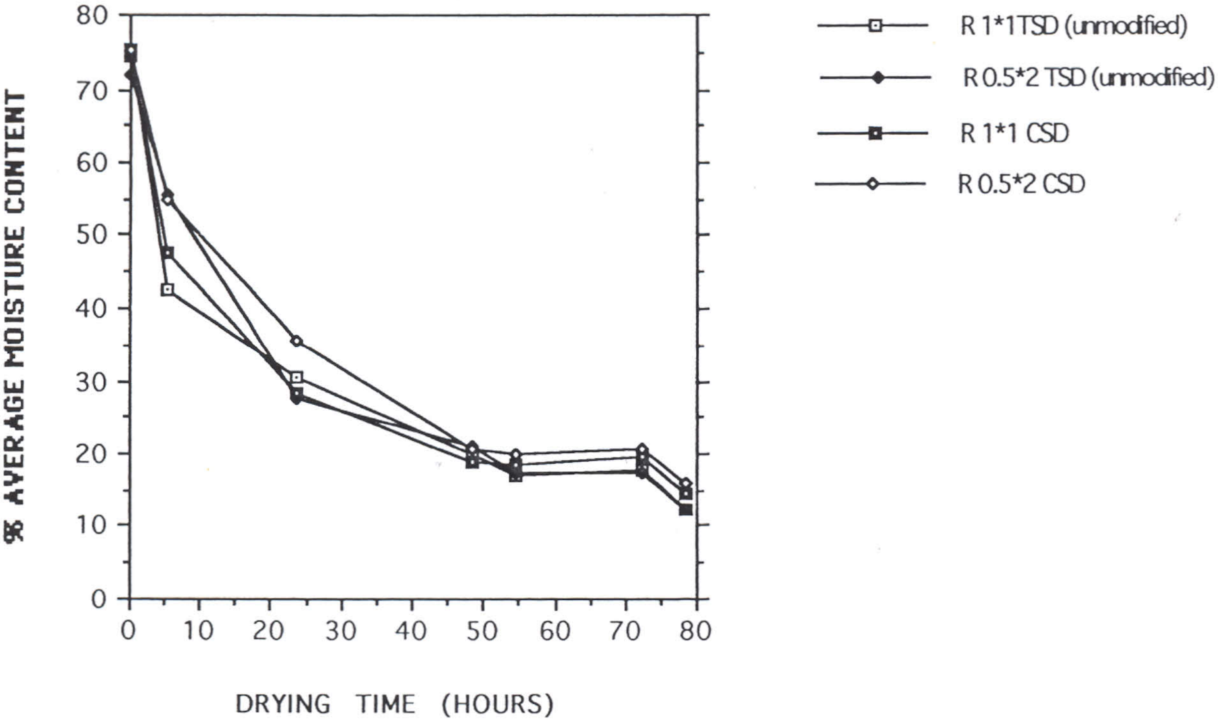
Results of Experiment 6 indicated that the TSD (unmodified) performed slightly better than the CSD in the drying of both raw and brined 1x1 cm. and 0.5 x 2 cm. insolated meat muscle strips (Figs 14 and 15).

It is known that isolated muscle tissues have identical characteristics, thus more reliable results were expected when they were used in the drying experiment than the use of mixture of different muscle tissues.

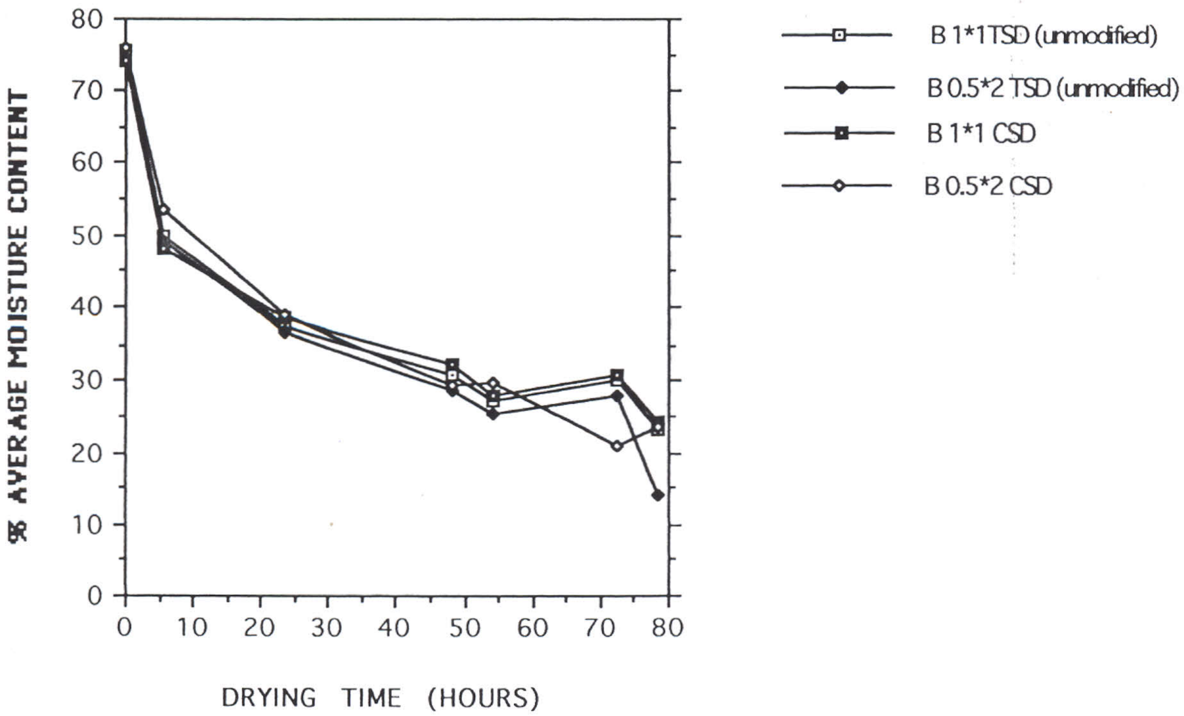
Experiment 6 results indicated that for the meat sizes dried, the TSD (unmodified) dried both raw and brined meat strips to lower moisture contents than did the CSD, thus indicating an overall slight superiority of the TSD (unmodified) over the CSD with respect to drying of the above meat sizes.

Effective comparison between the above results and results using the TSD (unmodified) and CSD in Experiments 1 and 5 cannot be accomplished because of differences in meat strip sizes and brining levels used. However, with R1x1 cm meat strips, Experiment 6 recorded the lowest

EXPT. 6 (FIG. 14) : COMPARISON BETWEEN TSD (unmodified) AND CSD ON THEIR DRYING PERFORMANCE WITH ISOLATED RAW 1*1 cm AND 0.5*2cm MEAT MUSCLE STRIPS.



EXPT. 6 (FIG. 15) : COMPARISON BETWEEN TSD (unmodified) AND CSD ON THEIR DYING PERFORMANCE WITH ISOLATED BRINED 1*1 cm AND 0.5*2 cm MEAT MUSCLE STRIPS.



moisture content with the TSD (unmodified), when compared with R1x1 cm. dried meat strips from Experiments 1 and 5 TSD (unmodified). At higher brining levels (10% brine infusion overnight), as in Experiment 6, the final moisture content of B1x1 cm. dried meat strips was higher than when 5% hot brine for 30 minutes was used for the same meat strip size as in Experiment 5.

3.4 Effect of drying method used on the quality of dried meat strips.

Summary of results on drying performances of solar dryers and of ambient for the different meat strips dried from Experiments 1 to 6 indicated the following:

The CSD showed a better performance to dry R1x1 cm. meat strips than the TSD (unmodified).

The TSD (unmodified) performed better in the drying of R2x2 cm. meat strips than the CSD.

The TSD (unmodified) performed similarly to the CSD to dry B1x1 cm. meat strips.

The TSD (unmodified) was slightly better in performance than the CSD to dry B2x2 cm. meat strips.

The TSD (unmodified) was again slightly better than the CSD to dry brined and raw 1x1 cm. and 0.5x 2cm. isolated meat muscle strips.

The TSD (unmodified) performed better than the TSD (modified) to dry R1x1 cm. and R2x2 cm. meat strips.

The CSD was better in performance than the TSD (modified) to dry R1x1 cm. meat strips.

Increased ventilation of the TSD lowered temperature increases within the drying chamber. Consequently, this led to the lowering of drying performance of the TSD and subsequently the storage life of dried meat strips.

The drying performance of the TSD (modified) approached that of ambient drying for the meat strips dried. Drying rate seemed apparently fast in the initial drying stages due to faster moisture removal from the moist meat strip surfaces. In the latter stages of drying however, due to the characteristic lowered temperature increases in the drying chamber of the TSD (modified) and of the ambient, moisture present within deeper meat tissues was trapped, consequently leading to higher final moisture contents and water activity levels in the dried meat strips (refer to Tables 4a and b and 5).

The advantage of ambient drying method over the TSD (modified) seemed to be the constantly abundant air flow over the drying meat surfaces which effectively dried meat surfaces thus inhibiting microbial activity at least on meat surfaces.

Storage life studies on dried meat strips, over an initial storage period of 6 weeks at room temperature in aerobically sealed plain LDPE bags indicated the following:

Raw and brined 1x1 cm. dried meat strips stored better than their 2x2 cm. counterparts, irrespective of method of drying over the storage period.

On the whole, R2x2 cm. dried meat strips stored better than B2x2 cm. dried meat strips.

Most of the raw and brined 2x2 cm. dried meat strips were particularly vulnerable to spoilage, and developed off odour and mould growth during the first week in storage (see Tables 4b. and 5).

TABLE 4: CHEMICAL ANALYSIS OF MEAT STRIPS

(a) Analysis on representative samples of fresh raw and brined meat strips.

Sample Description	Moisture Content (%)	Crude Protein (%)	Ash (%)	Fat (%)	Salt (Per 100g sample)
1. Fresh raw beef strips	78.34	18.63	1.36	3.24	0.29
2. Fresh brined beef strips (5% hot brined, ca.80°c. for 30 minutes).	79.62	-	1.52	-	1.45

(b) Analysis on representative samples of raw and brined ambient and solar dried meat strips

Sample Description	Crude Protein (%)	Fat (%)	Ash (%)	Salt (Per 100g sample)	pH (Ca.25°c)	Moisture Content (%)
R 1x1 cm.	69.03	1.96	4.43	0.48	5.72	15.35
R 2x2 cm.	58.27	2.10	3.95	-	5.60	28.19
R 0.5x2 cm.	-	-	-	-	5.80	12.47
*B 0.5x2 cm.	66.08	1.90	8.25	15.08	6.67	14.53
**B1x1 cm.	65.10	1.85	6.79	6.67	6.2	19.78
**B2x2 cm.	48.76	2.25	5.5	5.08	5.90	29.98

* 10% Brine infusion at 1:2 meat to brine ratio overnight.
** 5% hot brined (ca. 80°C) for 30 minutes.

TABLE 5: FINAL WATER ACTIVITY OF DRIED MEAT STRIPS

SAMPLE DESCRIPTION	EXPERIMENTS.				
	1	2	3	4	5
TSD(unmod.) R1x1	-	0.75	0.63	-	0.67
TSD(unmod,) R2x2	-	0.79	0.63	-	0.77
TSD(unmod.) B1x1	-	-	-	-	0.67
TSD(unmod.) B2x2	-	-	-	-	0.74
TSD(mod.) R1x1	-	0.75	0.74	0.77	-
TSD(mod.) R2x2	-	0.83	0.81	-	-
CSD: R1X1	-	-	-	0.72	0.63
CSD: R2x2	-	-	-	-	0.79
CSD: B1x1	-	-	-	-	0.67
CSD: B2x2	-	-	-	-	0.78
AR1X1	-	-	-	-	0.68
AR2X2	-	-	-	-	0.72
AB1X1	-	-	-	-	0.67
AB2X2	-	-	-	-	0.64

Room storage conditions recorded indicated the following:

temperature range (25 to 31.5°C) and relative humidity (60 to 85%). The plain LDPE used with high moisture and air transmission rates probably also affected the storage life of dried meat strips. Brined dried meat strips (1x1 and 2x2 cm) generally faired poorly in storage irrespective of the drying method used, and particularly for the 2x2cm brined dried meat strips.

Unmodified tent dried meat strips stored slightly better than the modified tent dried meat strips.

Solar cabinet dried R1x1 cm meat strips stored better than R1x1cm. dried meat strips from the unmodified TSD. Most dried meat strips of all sizes used and whether raw or brined were infested with Ascarus sirus mites at about 14 days in storage and the infestation reduced the dried meat strips to powdery substances, (see Plate 1, Appendix 19). The infestation was traced to the dryers where the mites laid their eggs on the drying meat strips. During storage of the dried meat strips, the eggs hatched out and the mites degraded the dried meat product. The solar dryers were consequently sprayed to destroy the mites.

The occurance of off odours and mould growth was attributed to delayed starting of the drying process for meat strips, especially in earlier experiments. This led to spoilage of meat strips during the early stages of drying. It was estimated that on the average, out of 24 hours in the day, meat strips were exposed to effective drying between 7 to 9 hours daily. Within this period, the maximum temperatures attained were maintained for not more than two hours or so, after which temperatures dropped gradually again (refer to Phase I Report).

For most part of late evenings throughout to early mornings the following day, temperatures were generally low (ca. between 22 to 28°c), and relative humidity high (ca. between 70 to 99%). These conditions did not allow for any effective drying during the period, but rather presented suitable conditions for microbial activity. Thus, unless some critical range of moisture content (ca. between 10 to 20%) was removed from the drying meat strips during the first day of drying, the drying meat strips may stand the risk of spoilage overnight.

The high microbial counts obtained in this study were attributed to the above conditions, in addition to the poor initial fresh meat quality (see Table 7, section 3.5).

With reference to drying method effects and dryer performance on the quality of dried meat strips, it is best to describe the methods as "Drying Systems", each system having its own merits and demerits. No one drying system fully satisfied all the suitable conditions necessary for the efficient drying of meat strips under the conditions studied, (See Table 6 below)

For an efficient drying system that fully satisfies all necessary conditions required for the drying of meat strips in the hot-humid zone, let us consider the following:

The general principle is to have two units of drying systems, each with different functional characteristics that could be incorporated into a single unit drying system. The first unit drying system will operate during the initial drying stages of meat strips. The system must allow for maximum ventilation as well as keeping off flies and pests. The function of this system is to ensure maximum removal of surface moisture from meat strips to enable achievement of the critical moisture content within hours on the first day of drying.

The second unit drying system will operate from the second day of drying to replace the first unit drying system. The function of this system is to allow for maximum concentration and retention of heat within the drying chamber at the expense of increased ventilation. This drying unit will then ensure maximum removal of moisture trapped within the deeper tissues of drying meat strips to achieve complete drying of the meat strips.

These two units of drying systems are required to operate to complement an efficient drying system.

TABLE 6: EVALUATION OF DRYING SYSTEM PERFORMANCES FOR MEAT STRIPS

	Parameters examined	Ambient drying Expts. 1-6	TSD (modified) Expt. 2	TSD(modified) Expt. 3	TSD (unmodified) Expts 1,5 & 6	CSD Expts 1,4,5 and 6
1.	Airflow rate:	Best, compared with the rest	Fair, better than TSD (unmod) and CSD	Better than TSD (mod) Expt 2	Poorer than TSD (mod) Expt 2	Poorer than TSD (unmodified)
2.	Temperature increases attained within drying chamber or for ambient:	Poorest compared with the rest. Poorer than TSD (mod) Expt 2	Better than TSD (mod.) Expt. 3, but poorer than TSD (unmod)	Poorer than TSD Expt 2	Better than TSD (mod) Expts 2 and 3	Best, compared with the rest.
3.	Drying stage best used for meat strip drying:	Best for initial stages compared with the rest	Fair, for initial drying stages	Better than TSD (mod) Expt 2 for initial drying stages	Poorer than TSD (mod) Expt 2 for initial drying stages	Best, for later drying stages compared with the rest.

The TSD (modified) as in Experiment 3, may be further ventilated to function as the first unit drying system. The CSD, with proper insulation of collector sides and reduction of heat loses on the drying chamber, may function as the second unit drying system.

It is possible to incorporate the functional characteristics of the two units drying systems into one unit drying system by either using the TSD or the CSD. This can be achieved by providing a removable plain polythene sheet over the whole drying chamber structure already covered with fine aluminium mesh. Then, the appropriate ventilation can be provided on the dryer initially, so as to function as the first unit drying system. The plain polythene sheet can then be put in place over the drying chamber for the dryer to perform the functions of the second drying system at the appropriate time.

The merits of ambient drying method is the provision of abundant air flow over the surfaces of meat strips constantly, thus this function perfectly assumes that of the first unit drying system described. However, the demerits of ambient drying becomes evident during the latter half of drying, when the lack of increased and sustained temperature affects complete drying of meat strips (ie. lack of second unit drying system functions).

Additional demerits of ambient drying method are the vulnerability of drying samples to attack by flies and pest, theft, contamination with dirt, and wetting by accidental rains.

The merits of the CSD is its ability to concentrate more efficiently heat within the drying chamber, leading to higher temperature increases. This function is required during the latter half of meat drying.

The demerits of the CSD include poor air circulation within drying chamber. During the initial stages of drying, dry air with a higher capacity to absorb moisture is required to flow within the drying chamber, and the moisture laden air must be expelled from the drying chamber to allow for fresh dry air intake. With poor air circulation within the drying chamber, initial moisture removal from meat strips will be impeded and the over all drying performance of the dryer lowered.

The merits of the TSD (unmodified) is its slightly more ventilated drying chamber over that of the CSD. This ability enabled the TSD (unmodified) to perform better during the initial stages of meat drying, with respect to moisture removal from meat strips.

The demerits of the TSD (unmodified) include poorer heat increments within drying chamber compared with the CSD, due to its slightly more ventilated structure.

The merits of the TSD (modified) include its more ventilated drying chamber which enabled better performance during the initial drying stages than the TSD (unmodified).

The demerits of the TSD (modified) include poor heat concentration and temperature increment within the drying chamber due to its more ventilated structure.

This ability was associated with poor performance of the TSD (modified) as far as latter stages of drying was concerned.

3.5 Effect of meat size on the quality of dried meat strips

The effect of increasing meat strip thickness (from 1 x 1 cm and 0.5 x 2cm to 2 cm), adversely affected drying of meat strips in terms of the rate of moisture removal (see Tables 4b., 5 and 7b).

Consequently, thicker dried meat strips were left with higher final moisture contents and water activity levels than with thinner dried meat strips. This condition led to shorter storage life and poorer quality of the thicker dried meat strips. Inconsistencies associated with experimental results were partly attributed to poor sampling of meat strips for analysis and the non uniformity of meat strips prepared.

Under the present conditions of study, 1x1cm. and 0.5 x 2cm meat strips seems to be the most suitable sizes to dry rather than 2x2cm meat strips, in terms of dried meat quality and storage life.

TABLE 7: MICROBIAL ANALYSIS OF MEAT STRIPS

(a) Microbiological analysis on representative samples of fresh raw and brined meat strips

	Sample description	Bacteria counts per gram	pH(ca.25°C)
1.	Fresh raw beef strips	2.83×10^5	5.5
2.	* Raw brined meat strips	3.59×10^8	5.4

* 3% cold brined for two hours.

(b) Microbiological analysis on representative samples of raw and brined solar and ambient dried meat strips during first week of storage at room temperature in aerobically sealed plain LDPE bags.

	Sample description	Drying method used	Bacteria counts per gram	Mould and yeast counts per gram	pH
1.	R2x2cm	CSD	6.9×10^{11}	<10	6.2
2.	R1x1cm	CSD	8.2×10^{11}	10	5.6
3.	*B1x1cm	CSD	3.3×10^{12}	10	6.0
4.	*B2x2cm	CSD	2.1×10^{12}	<10	6.8
5.	R1x1cm	TSD (unmod)	3.1×10^{11}	<10	5.5
6.	R2x2cm	TSD (unmod)	1.1×10^{12}	6.0×10^3	6.3
7.	*B1x1cm	TSD (unmod)	3.5×10^9	<10	5.9
8.	*B2x2cm	TSD (unmod)	1.5×10^{12}	<10	6.7
9.	R1x1cm	TSD (mod)	3.6×10^{17}	<10	6.8
10.	R2x2cm	TSD (mod)	3.7×10^{19}	40	6.5
11.	AR1x1cm	Ambient drying	4.5×10^{12}	10	6.2
12.	AR2x2cm	Ambient drying	6.2×10^{15}	2.5×10^4	6.6

* 3% cold brined for two hours

3.6 Effect of brining on the quality of dried meat strips

Generally, brining of raw meat strips prior to drying affected moisture removal from the drying meat strips. Consequently, the quality and storage life of brined meat strips were poor irrespective of meat size and the drying method used, (see Tables 4b and 7).

The infusion of 3% or 5% brine strengths to meat strips for the period studied did not show any appreciable difference in the quality of the final brined dried meat strips. However, the application of 10% brine strength infusion of meat strips overnight adversely affected the quality of dried meat strips and moisture removal from drying meat strips.

The effect of 10% brine treatment rendered brined dried meat strips pale, having lost virtually all meat pigment. The creamy-white appearance of the dried meat strips did not present any physical meaty appeal. Dried B1x1cm meat strips given the above treatment (Experiment 6), also showed higher final moisture contents than B1x1cm brined dried meat strips from Experiment 1 or 5, irrespective of the drying method.

On the whole, B1x1cm. dried meat strips stored better than B2x2cm dried meat strips, irrespective of the drying method used.

Raw meat strips seem to be the most suitable meat material to dry under the present conditions of study.

3.7. Effect of gelatine coating on the storage life of dried meat strips

Results from this experiment indicated difference in the thickness of gelatine coating on dried meat strips depending on the temperature of the gelatine solution preparation at the time of dipping dried meat strips.

At 40°C, gelatine solution gave a thin but uniform coating over all dried meat strips dipped in the preparation. At 80°C, the gelatine solution gave a thinner but less uniform coating over dried meat strips. The latter gelatine preparation was therefore discarded and the experiment was carried out with dried meat strips coated with gelatine solution preparation at 40°C.

Results on a 6 month storage life studies of gelatine coated dried meat strips aerobically sealed in plain LDPE bags at room temperature indicated the following:

All gelatine coated dried meat strips (R1x1, B1x1, R 0.5x2, B 0.5x2cm, (from the TSD (unmodified) and CSD of Experiment 6) when physically examined showed an exceptionally profound shelf stability over the storage period studied, (see Plate 2, Appendix 20). There was no mould growth and off flavour development and mite infestation on dried meat strips was absent. The shelf stability of all the gelatine coated meat strips was also prolonged beyond the storage period studied. Indications from this experiment showed that the gelatine coating acted as a protective barrier against deteriorative conditions on the dreid meat strips. For instance, the exclusion of air, moisture and dirt due to the gelatine coating, greatly enhanced the shelf stability of the dried meat strips. This protective function was also complemented by the packaging and sealing in plain LDPE bags.

The temperature at which dried meat strips were dipped (ie. 40°C), probably also acted in inhibiting the development of mite infestation.

The above results indicate that gelatine coated dried meat strips, when well packaged, may greatly extend the shelf stability of solar dried meat strips in hot humid zones under room storage conditions.

3.8 Effect of hot smoke treatment on the storage life of dried meat strips

Results from this experiment also indicated profound shelf stability for the smoke treated dried meat strips, when physically examined over the same storage period as for gelatine coated dried meat strips, (see Plate 3, Appendix 21). There was no mould growth, off-flavour or mite infestation over the storage period studied. After this period of study however, a localized infestation with mites and their powdery breakdown products were noticed on some few smoke treated dried meat samples.

Indications from the above experiment showed that the temperature at which dried meat strips were smoked (ca. 50°C), and the effect of smoke treatment, complemented each other to provide protection of dried meat strips aginst deteriorative conditions. Smoking at 50°c for 30 minutes may also have helped to further reduce moisture content of dried meat strips and the destruction of mites or their eggs where they occured.

The above results therefore indicate that hot smoke treatment of dried meat strips, followed by adequate packaging, may greatly enhance the shelf stability of solar dried meat strips in hot humid zones under room conditions.

3.9 Water rehydration capacity of dried meat strips

Results of water rehydration capacity on samples from Experiment 1 dried meat strips indicated the following:

Generally, 1x1 cm dried meat strips tended to rehydrate better than 2x2cm. dried meat strips, except for solar cabinet dried raw 2x2cm meat strips (see Figs 16 and 17 below). Solar cabinet dried raw meat strips rehydrated better than solar tent dried raw meat strips. On the other hand, solar tent dried brined meat strips, rehydrated better than solar cabinet dried brined meat strips.

Results from this experiment indicated that the final moisture content of dried meat strips seemed to affect their rehydration ability, (refer to Expt. 1. Figs 1 to 4). Thus, meat strips with lower final moisture contents tended to rehydrate better than those with higher final moisture contents, with the exception of solar cabinet dried raw 2x2cm meat strips.

Brine treatment (3% salt) seemed to have a positive effect but not conclusively, on the rehydration ability of meat strips, probably due to the water binding nature of salt.

All dried meat strips rehydrated in the experiment gained more than half of their original weight within six hours at room temperature irrespective of meat size, solar dryer type used and whether brined or raw.

FIG. 16 : WATER REHYDRATION CAPACITY (PER CENT) OF SOLAR TENT DRIED MEAT

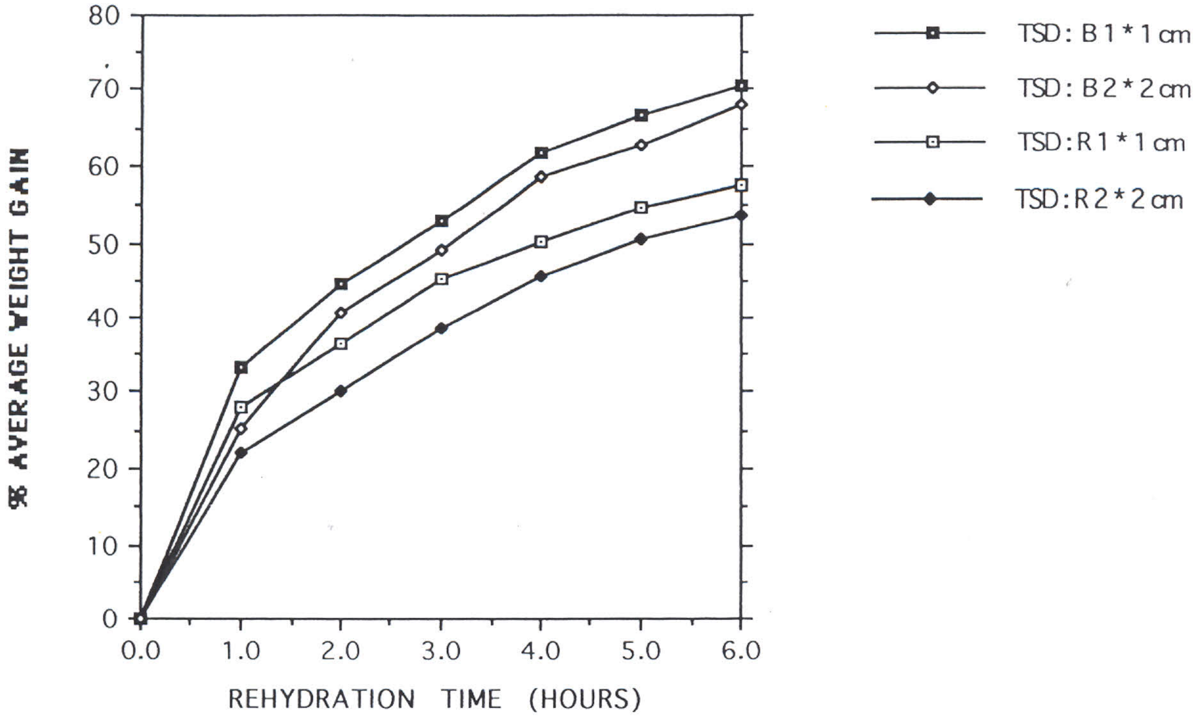
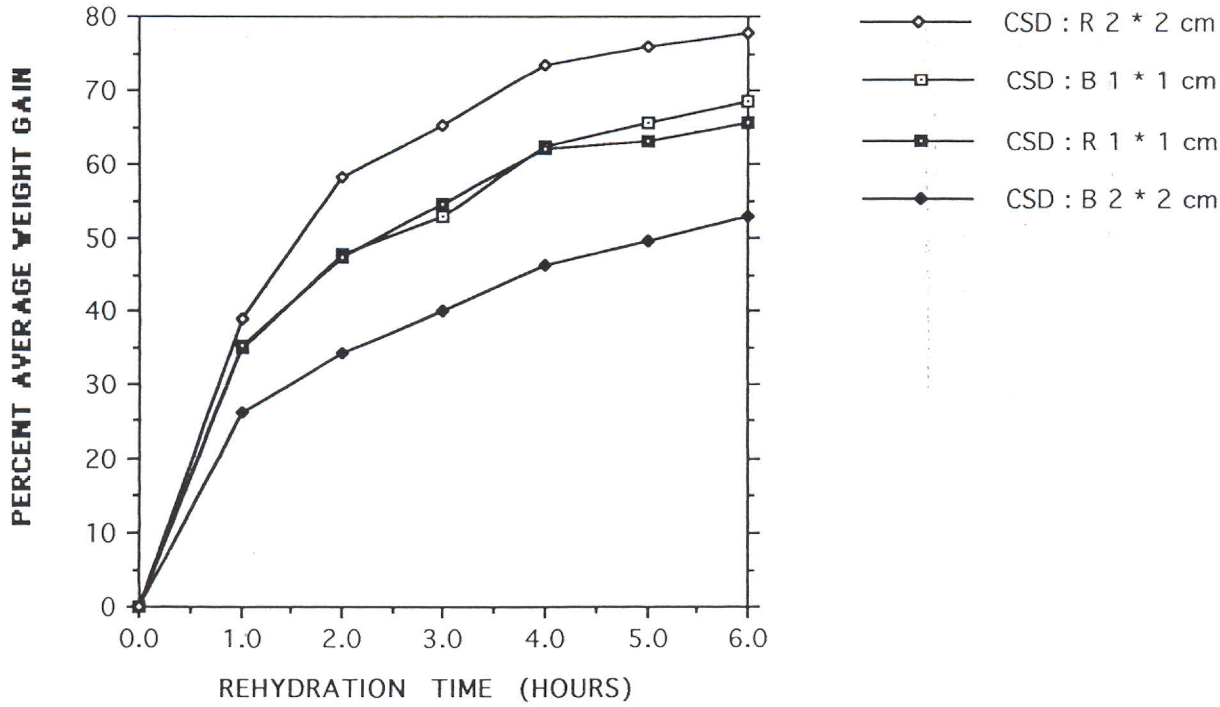


FIG. 17 : WATER REHYDRATION CAPACITY (PER CENT) OF SOLAR CABINET DRIED MEAT STRIPS



Other unconsidered factors which might have affected the water rehydration ability of dried meat strips were the meat muscle type used and pH of dried meat.

3.10 System Drying Efficiency (ηd)

System Drying Efficiency values obtained for the solar dryers (see Table 3 above) were very low. Brenndorfer et. al. (1987) reported typical values for natural convection, closed-type solar dryers to be within the range of 10-15%.

The value of 2.6% for the TSD (unmodified) in Expt. 1 for example represented drying efficiency at a meat loading capacity of only 41% of the TSD.

Assuming the TSD was fully loaded with 1x1cm. raw meat strips, then 6.8kg. of meat would be required to fill the TSD (refer to Phase I Report).

Assuming the same initial and dried moisture contents of R1x1 meat strips in the TSD (see Appendices 10 and 11(i)), then the moisture evaporated during drying would be 4.9 kg. Then assuming, the same drying conditions for meat in the TSD (unmodified) as in Expt 1, the System Drying Efficiency would be 6.4%.

This result indicates that the moisture evaporated during drying is a critical factor in the determination of System Drying Efficiencies. It is also necessary to load solar dryer to full capacity before the true drying efficiency can be estimated. Results obtained in this study for drying efficiencies therefore represented efficiencies for less than half meat loading capacity of the solar dryers.

In the Phase I Report, lapses such as leakages and poor insulation around collectors were identified. These lapses contributed to heat losses which lowered the true efficiency of the solar dryers.

Calculations on total moisture evaporated during drying of meat strips in the experiments conducted have been shown in Appendices 10 to 15.

3.11 Collection Efficiency (η_c)

The collection efficiency for the CSD collector was estimated using data from Experiment 1 results (see Table 8 and Appendix 17). The value of 1.84% efficiency obtained was very low. From the collection efficiency formula, it can be seen that the critical factors affecting the efficiency are the volumetric airflow rate through the collector air duct and the temperature elevation of air passing through the collector into the drying chamber.

With the inherent low airflow rate within the solar dryers, then a low volumetric airflow rate through the collector air duct will be associated with a low collection efficiency of the collector (as occured in the present experiment).

An increase in volumetric airflow rate through collector, for instance, by increasing the collector air duct area, will lead to an increase in the collection efficiency of the collector. However, an increase in the airflow rate will also lead to lowering of temperature increases within the drying chamber.

Brenndorfer et. al (1987), stated that collection efficiency was only a definition and therefore should not be used to predict collector efficiencies.

The collection efficiency result can therefore, at best be used as a guideline on the construction and modification of solar collectors. Other important factors which could increase the collection efficiency is the limitation of heat losses through the collector. This can be achieved by applying the appropriate covers on collector surfaces and insulation around collectors.

3.12. Sensory evaluation on dried meat strips

Results of sensory evaluation conducted on representative samples of dried meat strips are presented below in Table 8.

Sensory attribute scores on dried meat strips as presented in Table 8 below indicated the following:

Dried meat colour (light to dark brown), was fairly maintained and judged slightly desirable in all samples offered for evaluation.
Dried meat samples were only slightly tender after cooking. Brined dried meat samples were however slightly more tender than raw dried meat samples after cooking.

Flavour of dried meat strips were judged to be slightly weak in all samples evaluated however, dried meat strips cooked in soup had slightly stronger meat flavour than samples cooked in ordinary water.

All dried meat samples offered for evaluation showed a slightly dry feel in the mouth when chewed.

There was no distinct off flavour detection in all the dried meat strips evaluated.

The overall acceptability of all dried meat strips offered was fair except for those cooked in ordinary water which showed a poor acceptability.

The judgement of taste panelists on dried meat strips evaluated indicated the following:

Drying did not adversely affect the meat colour of dried meat strips used for the sensory evaluation.

Meat texture and flavour were slightly affected due to drying, so was meat juiciness. The latter attribute may be related to the rehydration ability of dried meat strips (see Section 3.9). Off flavour presence in dried meat strips was slightly more pronounced in samples cooked in ordinary water than those cooked in soup. The presence of spices and

TABLE 8: MEAN SENSORY SCORES OF ATTRIBUTES EVALUATED ON DRIED MEAT STRIPS

Description of dried meat strips used	MEAN SENSORY SCORES OF ATTRIBUTES					
	Colour	Tenderness	Flavour	Juiciness	Off flavour	Overall acceptabilty
1.* Brined dried, cooked in soup	3.5 (±0.52) slightly desirable	3.1(±0.73) slightly tender	2.6 (±1.17) slightly weak flavour	2.1 (±0.73 slightly dry	4.3 (±0.94) slight off flavour	3.2 (±0.91) Fair
2. Raw dried, cooked in soup	3.6 (±0.96) slightly desirable	2.8(±1.03) Tough	2.6 (±0.70) slightly weak flavour	2.2 (±0.91) slightly dry	5.0 (±0.90) No off-flavour	3.2 (±0.63) Fair
3. Raw dried, cooked in water only.	3.6 (±0.52) slightly desirable	3.4 (±0.70) slightly tender	2.1 (±0.01) slightly weak flavour	2.8 (±0.79) slightly dry	3.1 (±1.10) moderate off flavour	2.8 (±0.42) Poor

(i) * 3% brined raw meat strips for 30 minutes prior to drying
(ii) Standard deviation values are shown in brackets
(iii) Response by panelists to buy dried meat on the market was 6 to 4 in favour of buying dried meat.

seasoning in the soup may have masked slightly off flavour detection in the dried meat strips cooked in soup.

Overall acceptability of dried meat strips cooked in soup was better than those cooked in ordinary water. This result may be related to the higher off flavour detection in dried meat strips cooked in ordinary water.

seasoning in the soup may have masked slightly off flavour detection in the dried meat strips cooked in soup.

Overall acceptability of dried meat strips cooked in soup was better than those cooked in ordinary water. This result may be related to the higher off flavour detection in dried meat strips cooked in ordinary water.

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations have been drawn based on results and discussions on the above studies:

i. The type of meat cut selected affected the preparation of boneless meat and cutting of uniform meat strips, thus hind-quarter cuts were preferred to fore-quarter cuts.

ii. Ambient airflow rate was variable and depended upon the height above ground level at which measurments were taken and the direction of wind flow.

Airflow rate within the TSD (unmodified) and the CSD was negligible, indicating an inherently poor air circulation within natural convection, closed-type solar dryers.

Increasing ventilation to the TSD (unmodified) drying chamber led to increasing airflow rate within the drying chamber.

iii. The CSD registered the highest mid-point of drying chamber temperature followed by the TSD (unmodified). Increasing ventilation to the TSD (unmodified) led to lowering of temperature increases within the drying chamber.

iv. Relative humidity levels were generally high within solar drying chambers and for the ambient during late evenings throughout to early mornings. The lowest relative humidity value usually occured around mid-day when temperature was about maximum.

v. Insolation values were directly related to the amount of sunshine received during the day and the ability of the solar dryer to retain the heat increases obtained, this was dependent upon the level of insulation on the dryer collector and limitation of heat losses around drying chamber.

vi. The drying system capable of providing maximum airflow rate over drying meat strips was the preferred system for initial drying of meat strips. Hence, ambient drying method and the TSD (modified) as in Experiment 3 showed the desired functions.

vii. The drying system capable of providing maximum temperature increases within the drying chamber during the later stages of drying (from second day of drying onwards), was the preferred system for the later stages drying of meat strips. Hence, the CSD showed the desired functions.

The desirable functions can be incorporated into a single unit drying system through modification of the CSD or the TSD (unmodified) to complement an efficient drying system for the drying of meat strips in the hot humid zone.

viii. Raw 1x1 cm. meat strips generally stored better than raw and brined 2x2 cm. meat strips when aerobically sealed in plain LDPE bags, irrespective of the drying method used, during a 6 week storage period at room temperature.

ix. 1x1 cm. and 0.5x2 cm. raw meat strips seemed to be the preferred meat size to dry based on shelf life and quality of the dried meat product under the present conditions of study.

x. Gelatine coated (10% gelatine solution preparation at 40°C) and hot smoked (ca. 50°C for 30 minutes),dried meat strips aerobically sealed in plain LDPE bags, greatly extended the shelf life of the solar dried meat strips under room storage conditions during a 6 month storage period.

xi. All dried meat strips studied rehydrated to more than half their original weights during a 6 hour rehydration period in water at room temperature.

xii. Sensory evaluation on dried meat strips cooked in a traditional soup indicated better meat flavour and acceptability than when cooked in ordinary water.
Six out of 10 panelists were in favour of buying solar dried meat strips from the open market.

5. FURTHER WORK

Further work on the assessment of meat drying parameters using solar dryers in hot humid climates will entail the design and construction of an efficient solar drying system incorporating the following:

i. Provision of maximum air flow rate within drying chamber during initial drying stages, and

ii. Provision of maximum temperature increases and retention in the drying chamber during later stages of drying. This will involve collector modifications and insulation and reduction of heat losses on the drying chamber.

This drying system will then be evaluated for its efficiency in drying different meat strip sizes. The storage life and quality of dried meat strips will be determined through storage trials, chemical and microbiological analysis. Sensory aspects of dried meat strips will also be assessed.

Guidelines and recommendations based on favourable results obtained will then be proposed for application at the rural level for identified target groups.

6. REFERENCES

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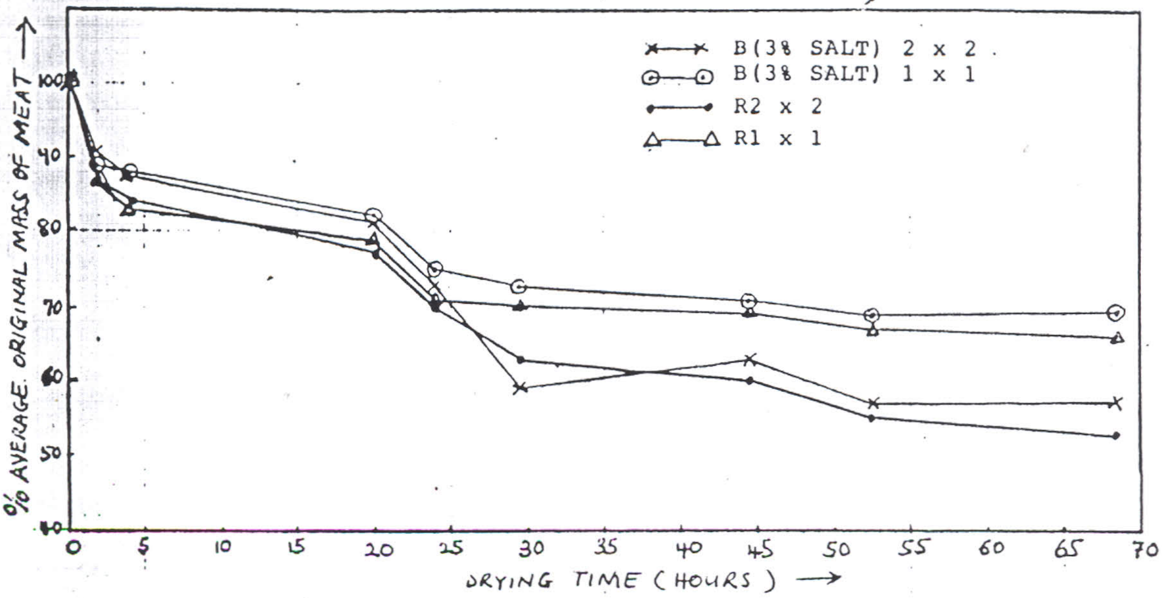
Assessment of meat drying in hot humid climates using natural convection, closed-type solar dryers and investigation of practicable meat drying parameters - Phase I Report. FAO/FRI Collaboration Project Report.

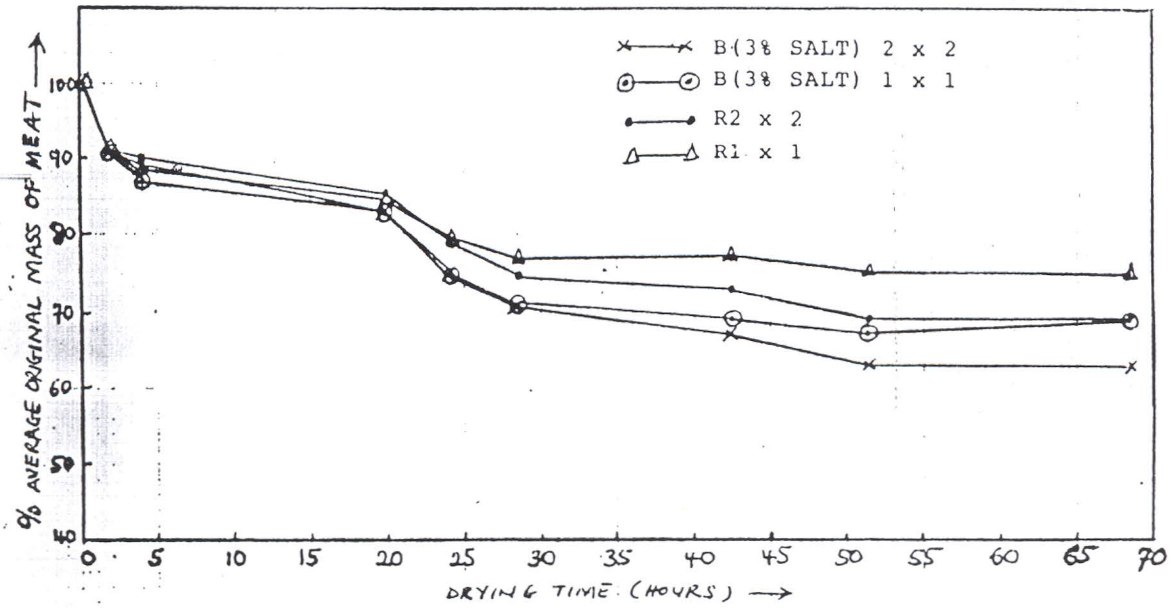
7. APPENDICES

APPENDIX 1

EXPT.1 (a): PER CENT AVERAGE OF ORIGINAL MASS OF MEAT
(TSD - unmodified)

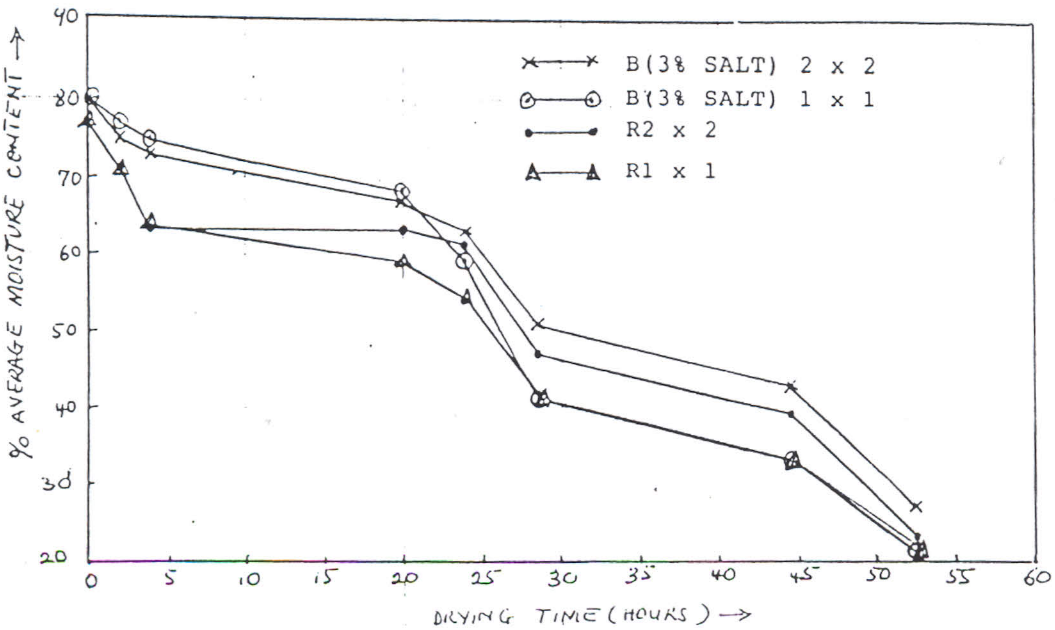


EXPT. 1(b): PER CENT AVERAGE OF ORIGINAL MASS OF MEAT (CSD)

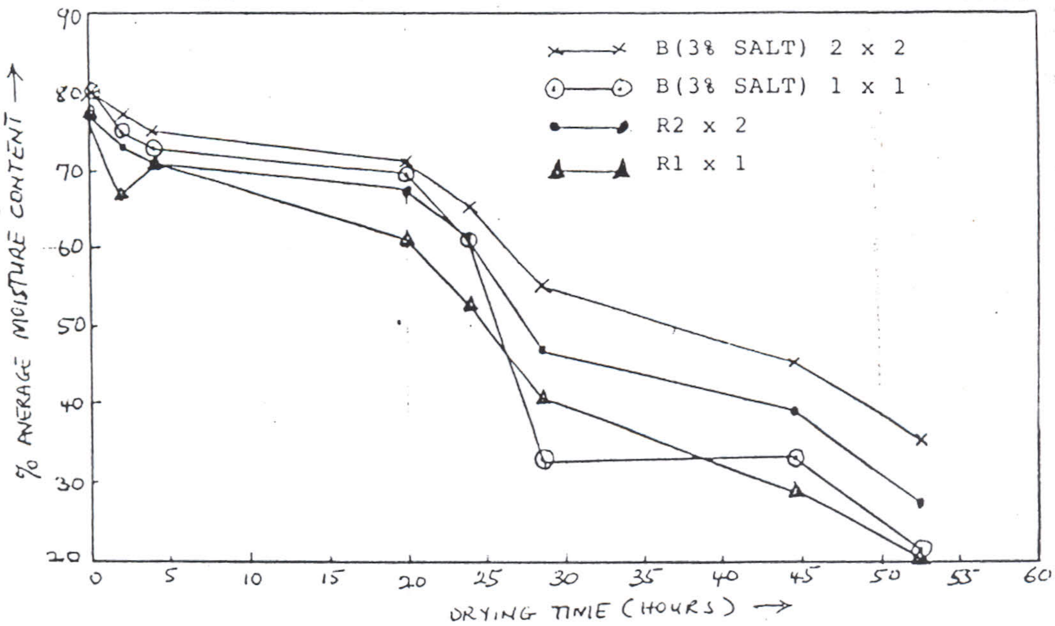


APPENDIX 2

EXPT. 1(c): PER CENT AVERAGE MOISTURE CONTENT OF MEAT (TSD - unmodified)

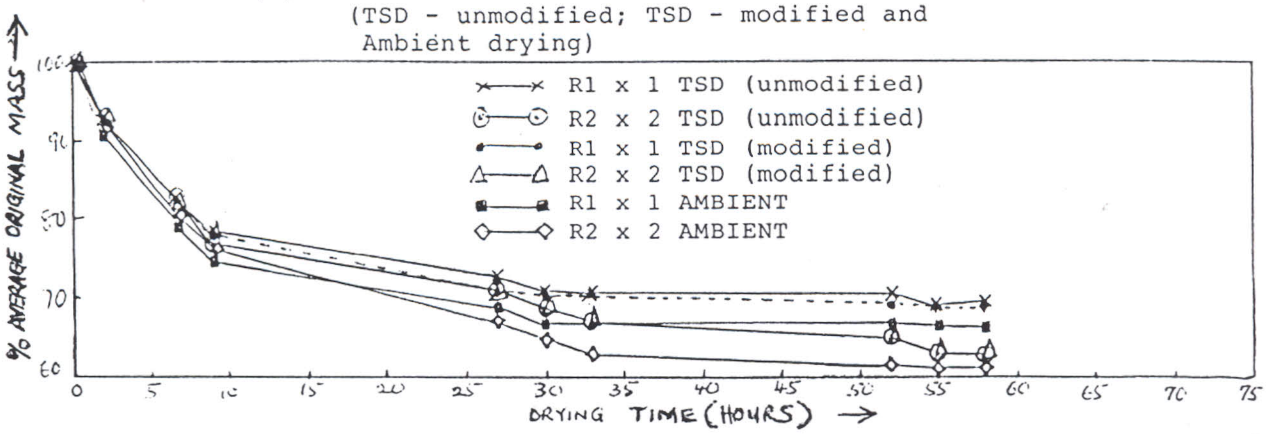


EXPT. 1(d): PER CENT AVERAGE MOISTURE CONTENT OF MEAT (CSD)

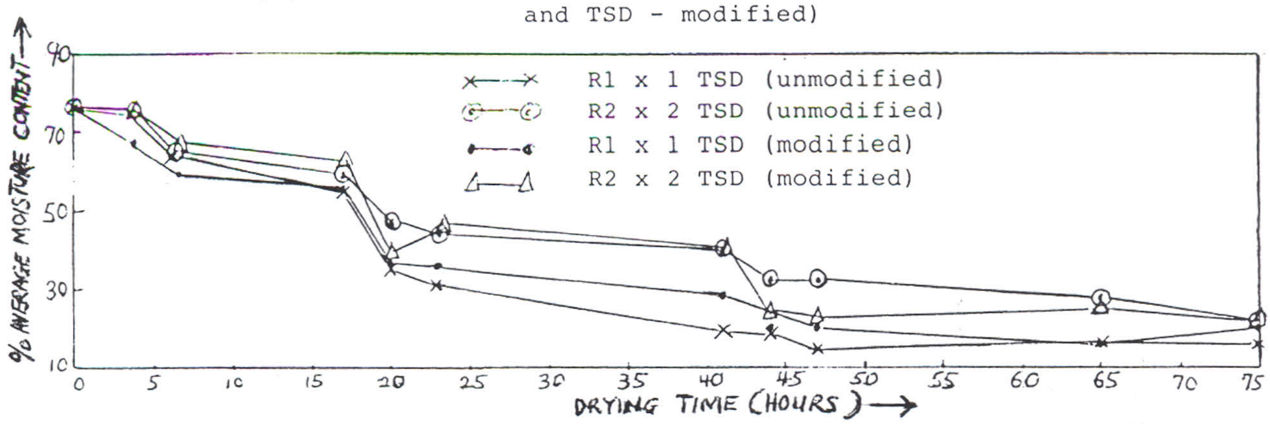


APPENDIX 3

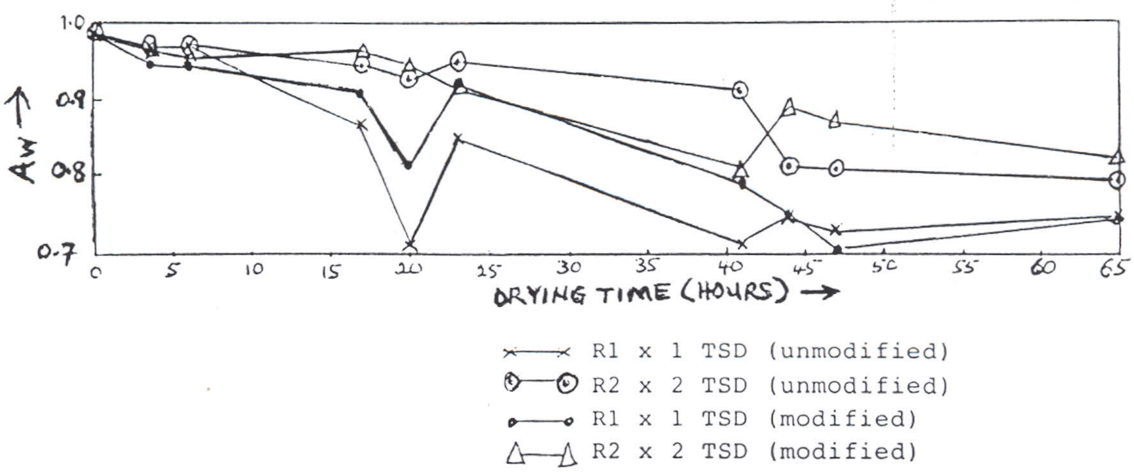
EXPT. 2(a): PER CENT AVERAGE OF ORIGINAL MASS OF MEAT (TSD - unmodified; TSD - modified and Ambient drying)



EXPT. 2(b): PER CENT AVERAGE MOISTURE CONTENT (TSD - unmodified) and TSD - modified)

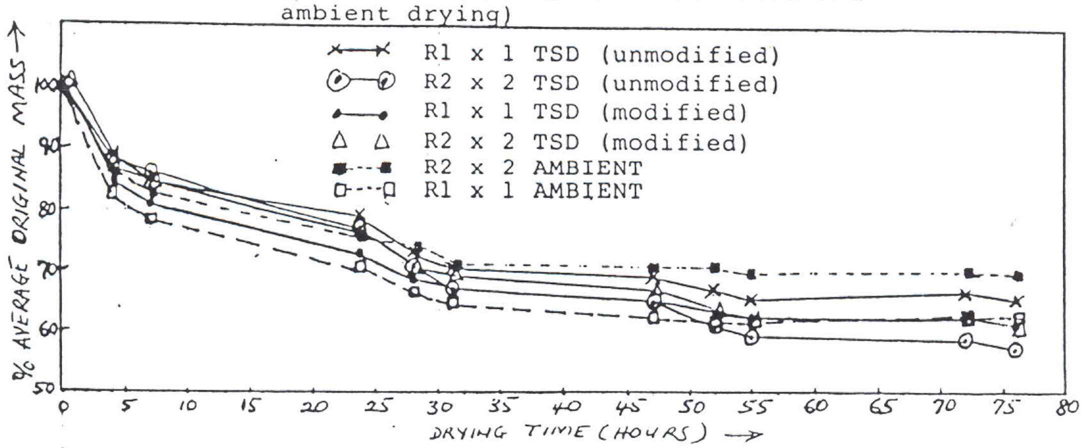


EXPT. 2(c): WATER ACTIVITY (Aw) CHANGES IN MEAT STRIPS DURING DRYING (TSD - unmodified and TSD - modified)

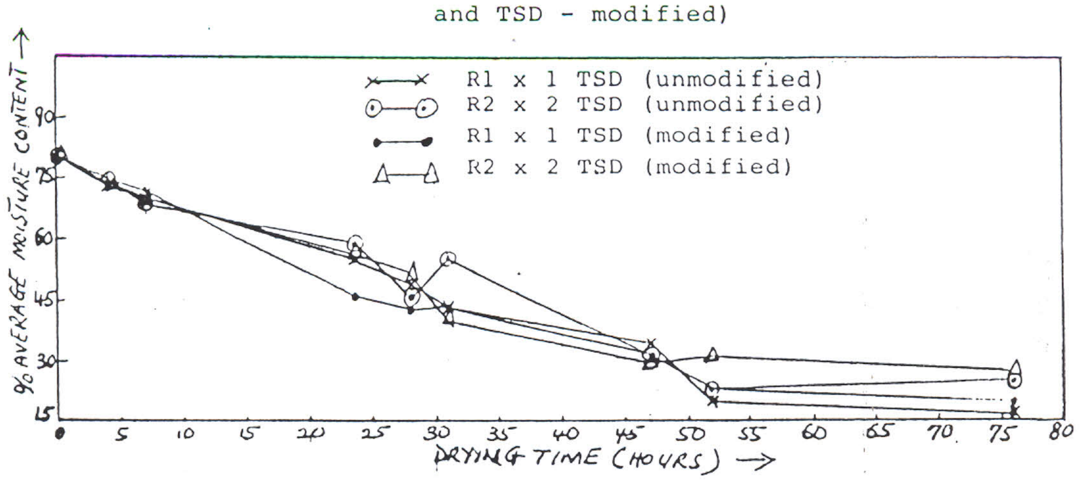


APPENDIX 4

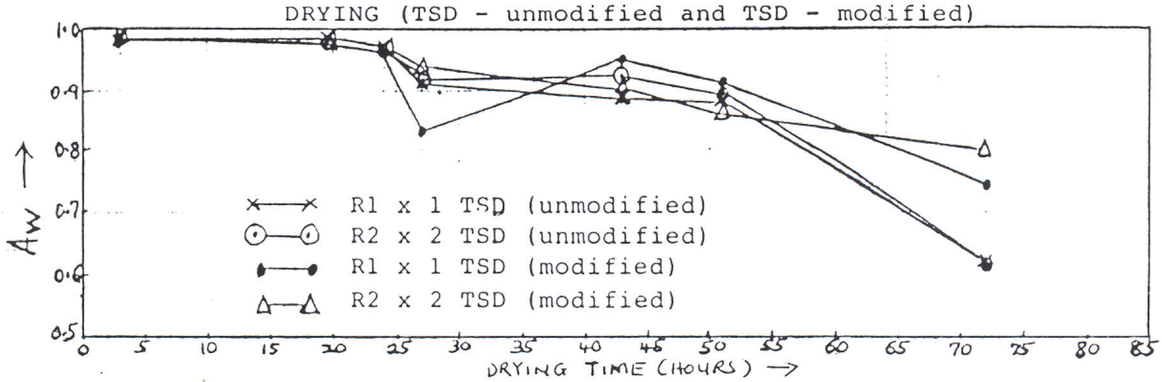
EXPT. 3(a): PER CENT AVERAGE OF ORIGINAL MASS OF MEAT (TSD - unmodified; TSD - modified and ambient drying)



EXPT. 3(b): PER CENT AVERAGE MOISTURE CONTENT (TSD - unmodified and TSD - modified)

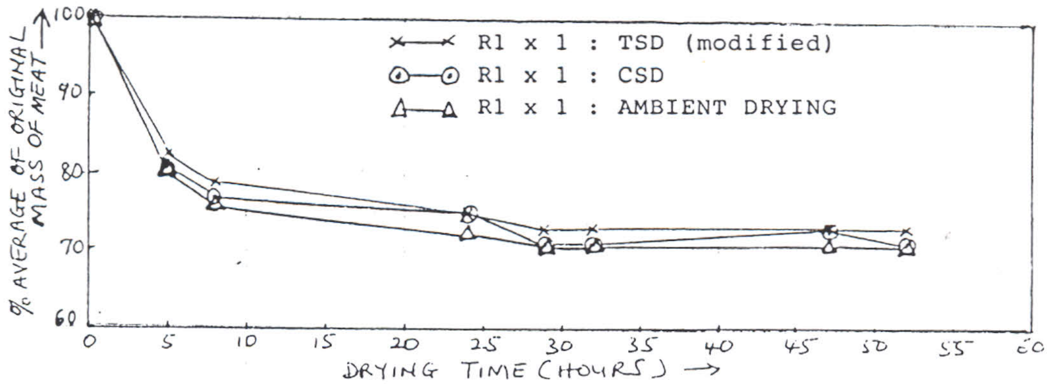


EXPT. 3(c): WATER ACTIVITY (Aw) CHANGES IN MEAT STRIPS DURING DRYING (TSD - unmodified and TSD - modified)

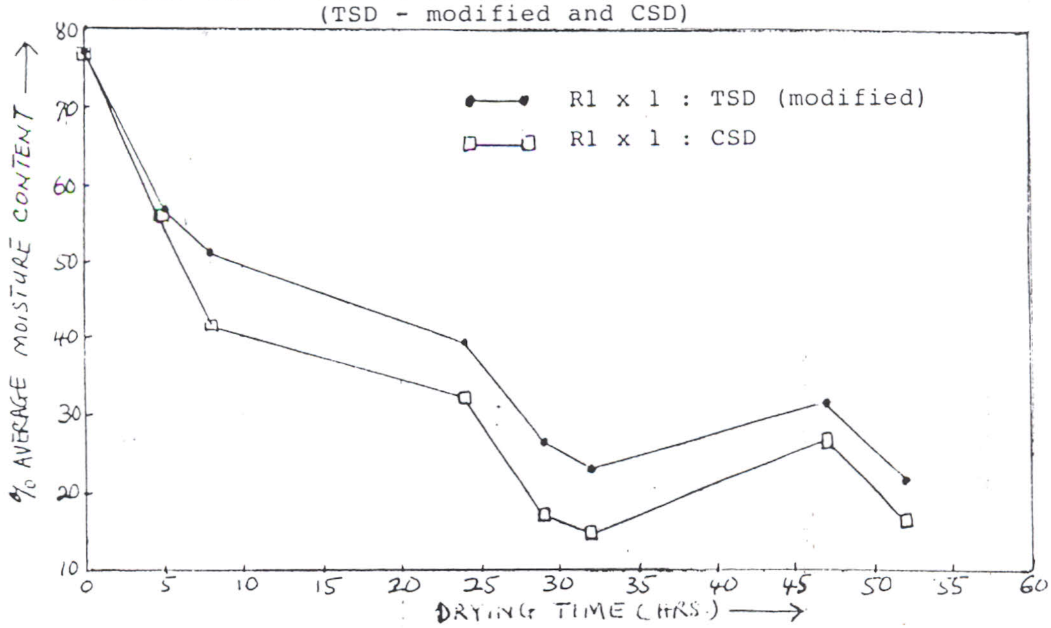


APPENDIX 5

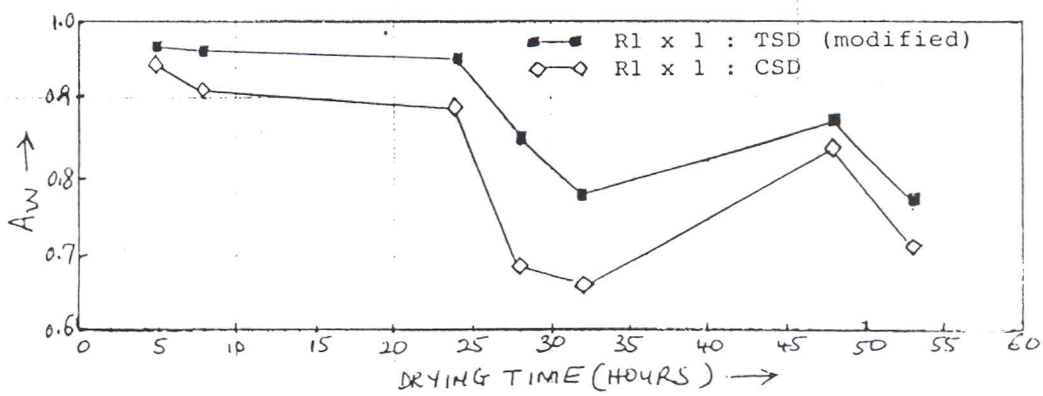
EXPT. 4(a): PER CENT AVERAGE OF ORIGINAL MASS OF MEAT (TSD - modified, CSD and AMBIENT DRYING)



EXPT. 4(b): PER CENT AVERAGE MOISTURE CONTENT (TSD - modified and CSD)

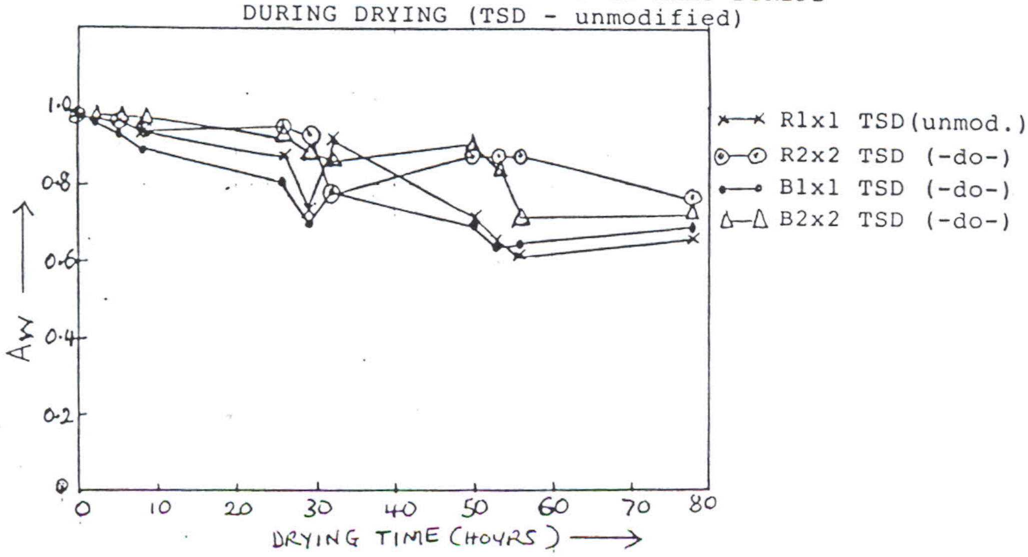


EXPT. 4(c): WATER ACTIVITY (Aw) CHANGES IN MEAT STRIPS DURING DRYING (TSD - modified and CSD)

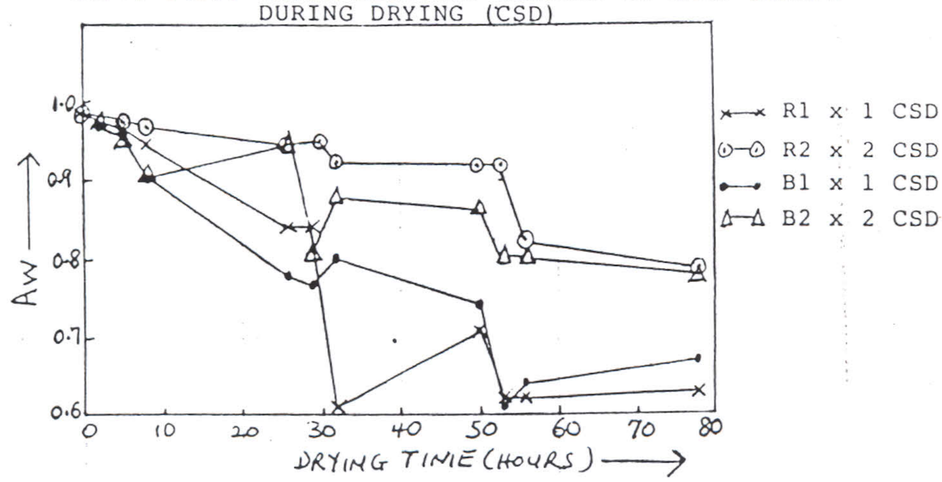


APPENDIX 6

EXPT. 5(a) WATER ACTIVITY CHANGES IN MEAT STRIPS DURING DRYING (TSD - unmodified)

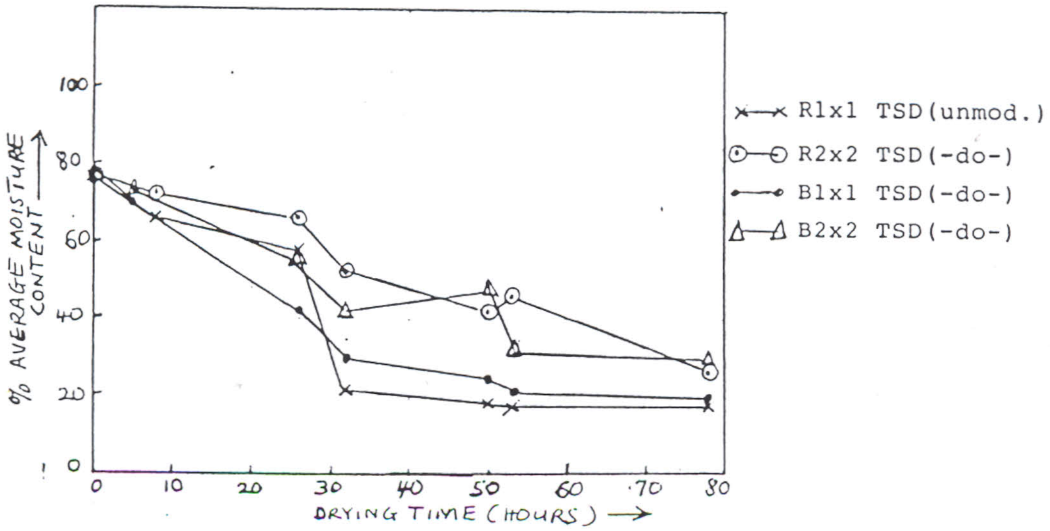


EXPT. 5(b): WATER ACTIVITY CHANGES IN MEAT STRIPS DURING DRYING (CSD)

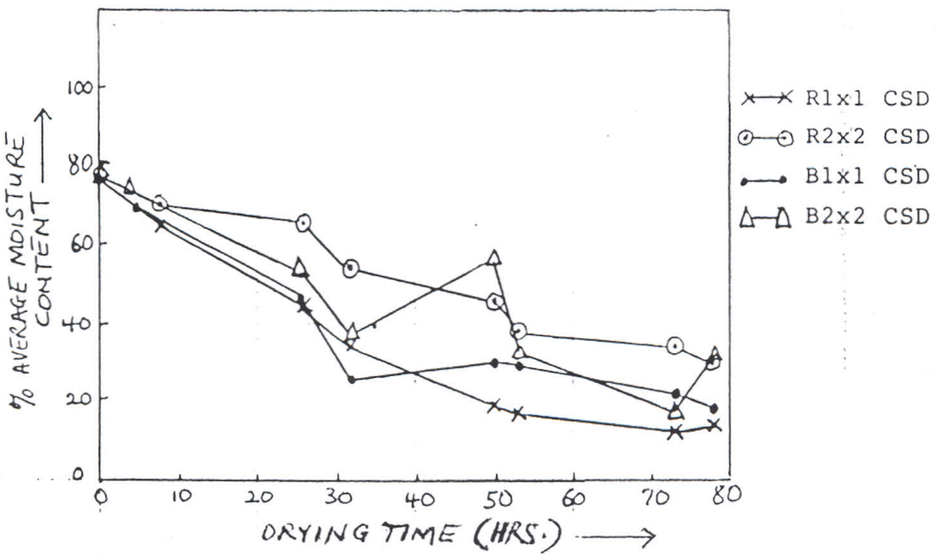


APPENDIX 7

EXPT. 5(c): PER CENT AVERAGE MOISTURE CONTENT IN MEAT (TSD - unmodified)

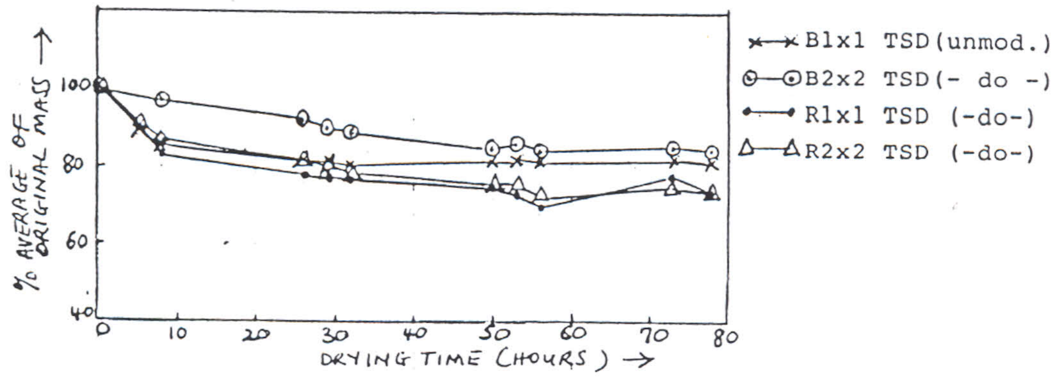


EXPT. 5(d): PER CENT AVERAGE MOISTURE CONTENT IN MEAT (CSD)

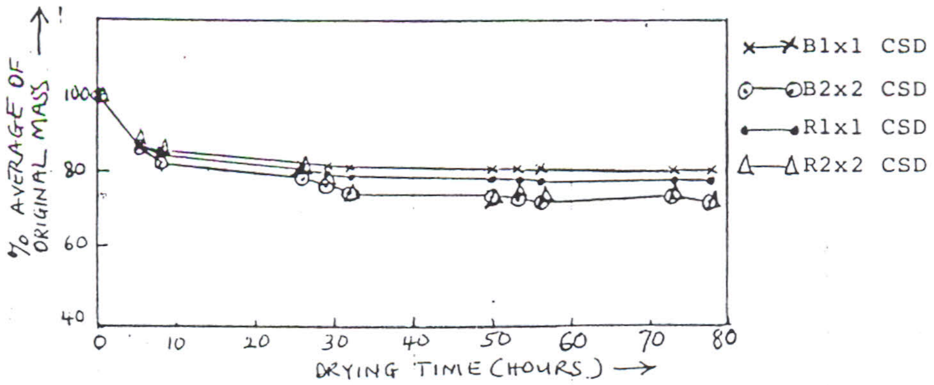


APPENDIX 8

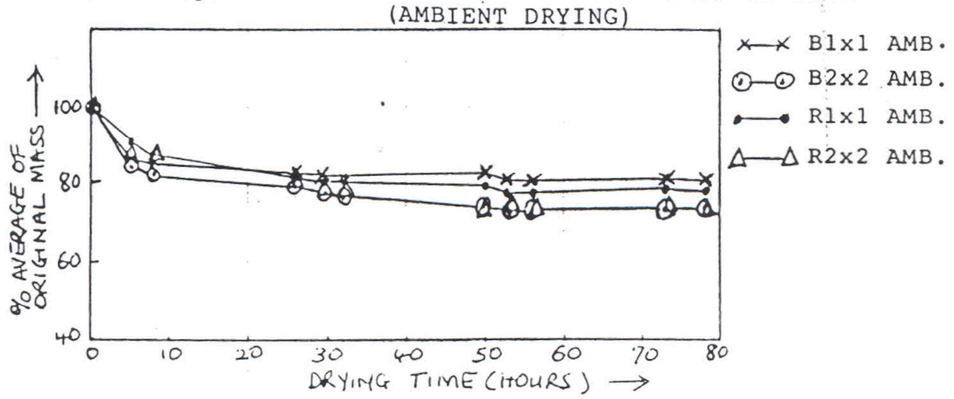
EXPT. 5(e) PER CENT AVERAGE ORIGINAL MASS OF MEAT (TSD - unmodified)



EXPT. 5(f): PER CENT AVERAGE ORIGINAL MASS OF MEAT (CSD)

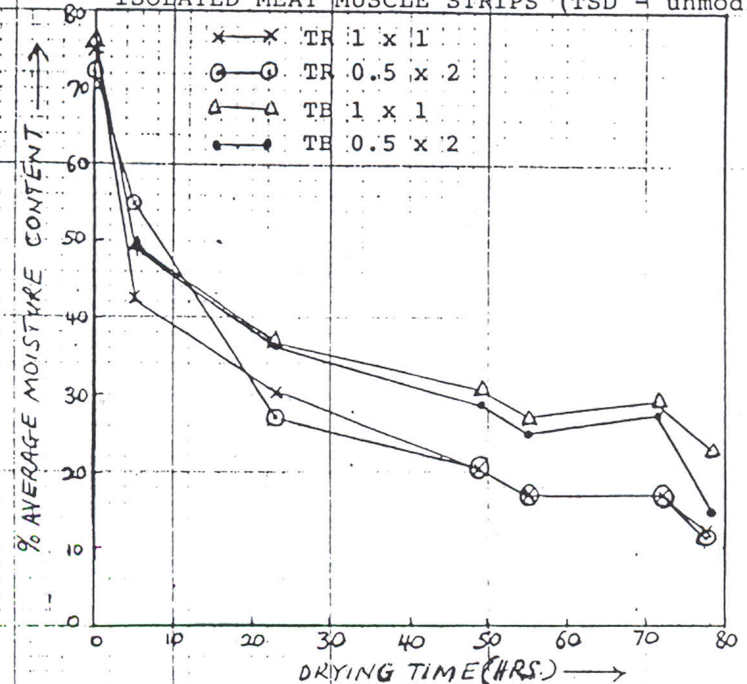


EXPT.5(g): PER CENT AVERAGE ORIGINAL MASS OF MEAT (AMBIENT DRYING)

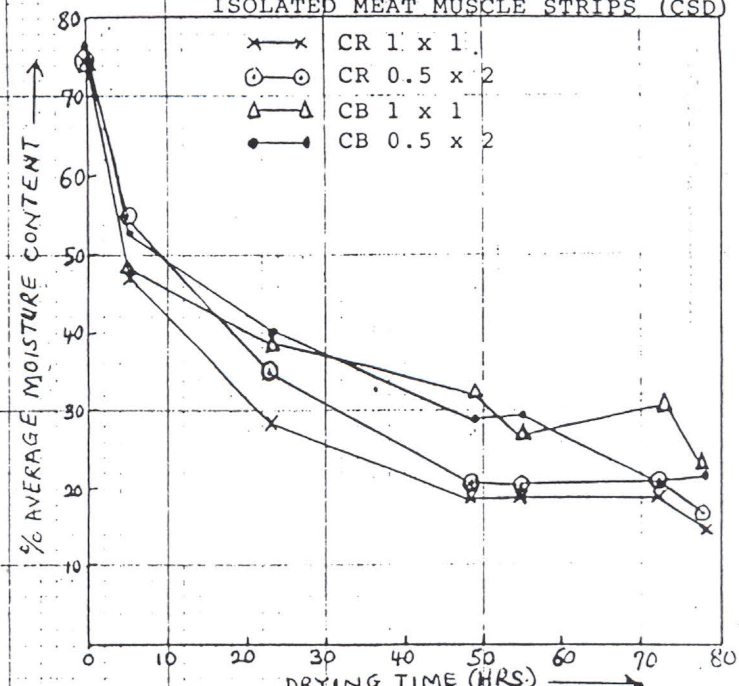


APPENDIX 9

EXPT. 6(a): PER CENT AVERAGE MOISTURE CONTENT OF ISOLATED MEAT MUSCLE STRIPS (TSD - unmodified)



EXPT. 6(b): PER CENT AVERAGE MOISTURE CONTENT OF ISOLATED MEAT MUSCLE STRIPS (CSD)



APPENDIX 10:

CALCULATION OF MOISTURE EVAPORATED DURING DRYING OF MEAT STRIPS

Using Experiment 1 (TSD - unmodified) values as an example (see Appendix 11), as follows:-

Initial moisture in B2x2 meat strips = 80.0%
Initial meat weight (B2x2) meat strips = 0.826 kg.
Moisture in dried meat strips (B2x2) = 26.17%

Thus:

Moisture in meat (initial) = [0.826 x 80/100] = 0.66 kg ......(i)

∴ Bone dry weight of meat = (0.826 - 0.66)kg
= 0.166kg......(ii)

Moisture in dried meat = $\frac{(0.166 \times 26.17\%)}{(100 - 26.17)}$ %
= 0.0588kg.....(iii)

∴ Moisture evaporated in B2x2 dried meat strips
= (i) - (iii) = (0.66 - 0.0588) kg. = 0.60 kg.

APPENDIX 11

CALCULATION OF MOISTURE EVAPORATED DURING DRYING OF MEAT STRIPS

EXPERIMENT 1

(i) TSD (unmodified):

	Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
B2x2 :	0.826 kg	0.66 kg	0.166kg	0.0588 kg	0.60 kg
B1x1 :	0.399 kg	0.27 kg	0.069kg	0.0183 kg	0.252 kg
R2x2 :	1.229 kg	0.95 kg	0.279kg	0.083 kg	0.867 kg
R1x1 :	0.392 kg	0.304kg	0.088kg	0.022 kg	0.282 kg
TOTAL :	2.79 kg	2.184 kg	0.602kg	0.182 kg	2.0 kg

Initial moisture in meat:

Brined meat strips = 80.0%
Raw meat strips = 77.6%

Moisture in dried meat:

B2x2 = 26.17%
B1x1 = 20.92%
R2x2 = 23.0 %
R1x1 = 20.02%

(ii) CSD

	Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
B2x2 :	0.541 kg	0.433 kg	0.108kg	0.057 kg	0.376 kg
B1x1 :	0.353 kg	0.282 kg	0.071kg	0.019 kg	0.263 kg
R2x2 :	0.396 kg	0.307 kg	0.089kg	0.034 kg	0.273 kg
R1x1 :	0.230 kg	0.178 kg	0.052kg	0.012 kg	0.166 kg
TOTAL :	1.52 kg	1.2 kg	0.32 kg	0.122 kg	1.078 kg

Initial moisture in meat:

Brined meat strips = 80.0%
Raw meat strips = 77.6%

Moisture in dried meat:

B2x2 = 34.63%
B1x1 = 21.08%
R2x2 = 27.87%
R1x1 = 18.49%

APPENDIX 12:

CALCULATION OF MOISTURE EVAPORATED DURING DRYING OF MEAT STRIPS

EXPERIMENT 2

(i) TSD (unmodified):

		Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
R1x1	:	2.09 kg	1.62 kg	0.47 kg	0.10 kg	1.52 kg
R2x2	:	2.09 kg	1.62 kg	0.47 kg	0.13 kg	1.49 kg
TOTAL	:	4.18 kg	3.24 kg	0.94 kg	0.23 kg	3.01 kg

Initial moisture in meat:

Raw meat strips = 77.63%

Moisture in dried meat:

R1x1 = 17.85%
R2x2 = 22.05%

(ii) TSD (modified):

		Initial meat weight	Initial moisture in meat	Bone dry weight	Moisture in dried	Moisture evaporated
R1x1	:	2.09 kg	1.62 kg	0.47 kg	0.12 kg	1.5 kg
R2x2	:	2.09 kg	1.62 kg	0.47 kg	0.14 kg	1.48 kg
TOTAL	:	4.18 kg	3.24 kg	0.94 kg	0.26 kg	2.98 kg

Initial moisture in meat:

Raw meat strips = 77.63%

Moisture in dried meat:

R1x1 = 20.38%
R2x2 = 22.85%

APPENDIX 13:

CALCULATION OF MOISTURE EVAPORATED DURING DRYING OF MEAT STRIPS

EXPERIMENT 3

(i) TSD (unmodified)

		Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
R1x1	:	1.422 kg	1.15 kg	0.272 kg	0.049 kg	1.101 kg
R2x2	:	1.422 kg	1.15 kg	1.272 kg	0.088 kg	1.062 kg
TOTAL	:	2.844 kg	2.3 kg	0.544 kg	0.137 kg	2.163 kg

Initial moisture in meat:

Raw meat strips = 80.84%

Moisture in dried meat:

R1x1 = 15.15%
R2x2 = 24.42%

(ii) TSD (modified):

		Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
R1x1	:	1.422 kg	1.15 kg	0.272 kg	0.069 kg	1.081 kg
R2x2 cm	:	1.422 kg	1.15 kg	0.272 kg	0.103 kg	1.047 kg
TOTAL	:	2.844 kg	2.3 kg	0.544 kg	0.172 kg	2.128 kg

Initial moisture in meat:

Raw meat strips = 80.84%

Moisture in dried meat:

R1x1 = 20.20%
R2x2 = 27.50%

APPENDIX 14:

CALCULATION OF MOISTURE EVAPORATED DURING DRYING OF MEAT STRIPS

EXPERIMENT 4:

(i) TSD (modified):

		Initial meat weight	Initial moisture in meat	Bone Dry meat weight	Moisture in dried meat	Moisture evaporated
R1x1	:	2.707 kg	2.097 kg	0.61 kg	0.171 kg	1.926 kg

Initial moisture in meat:

Raw meat strips = 77.48%

Moisture in dried meat :

R1x1 = 21.93%

(ii) CSD

		Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
R1x1	:	2.670 kg	2.068 kg	0.602 kg	0.118 kg	1.95 kg

Initial moisture in meat:

Raw meat strips = 77.48%

Moisture in dried meat:

R1x1 cm = 16.36%

APPENDIX 15:

CALCULATION OF MOISTURE EVAPORATED DURING DRYING OF MEAT STRIPS

EXPERIMENT 5:

(i) TSD (unmodified):

	Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
B1x1 :	0.669 kg	0.53 kg	0.139 kg	0.035 kg	0.495 kg
B2x2 :	0.641 kg	0.50 kg	0.141 kg	0.065 kg	0.435 kg
R1x1 :	0.786 kg	0.61 kg	0.176 kg	0.036 kg	0.574 kg
R2x2 :	0.707 kg	0.54 kg	0.167 kg	0.060 kg	0.48 kg
TOTAL :	2.803 kg	2.18 kg	0.623 kg	0.196 kg	1.984 kg

Initial moisture in meat:

Raw meat strips = 77.06%
Brined meat strips = 78.67%

Moisture in dried meat:

B1x1 = 19.89%
B2x2 = 31.61%
R1x1 = 16.82%
R2x2 = 26.52%

(ii) CSD

	Initial meat weight	Initial moisture in meat	Bone dry meat weight	Moisture in dried meat	Moisture evaporated
B1x1 :	0.616 kg	0.485 kg	0.131 kg	0.027 kg	0.458 kg
B2x2 :	0.641 kg	0.504 kg	0.137 kg	0.063 kg	0.411 kg
R1x1 :	0.674 kg	0.519 kg	0.155 kg	0.025 kg	0.494 kg
R2x2 :	0.765 kg	0.589 kg	0.176 kg	0.075 kg	0.514 kg
TOTAL :	2.696 kg	2.097 kg	0.599 kg	0.19 kg	1.907 kg

Initial moisture in meat:

Raw meat strips = 77.06%
Brined meat strips = 78.67%

Moisture in dried meat:

B1x1 = 17.08%
B2x2 = 31.56%
R1x1 = 13.89%
R2x2 = 29.85%

APPENDIX 16:

CALCULATION OF SYSTEM DRYING EFFICIENCY OF SOLAR DRYERS

The System Drying Efficiency (ηd) is given by the relationship :-
(Detailed description given in Phase I Report).

$$\eta d = \frac{W \times \Delta Hl}{Id \times Ac}$$

Where: W = Moisture evaporated in dried meat (Kg)

ΔHl = Latent heat of vaporization of water ($KJKg^{-1}$)

Id = Total insolation incident upon collector (Wm^{-2})

Ac = collector area (m^2)

Then, using Experiment 1 results as an example for the TSD - unmodified (See tables 2 and 3).

W = 2.0 kg
ΔHl = 2303 KJ Kg^{-1} (by interpolation) from standard tables, based on maximum temperature recorded in the TSD unmodified.

Id = 21942.16 Wm^{-2} (Total insolation per half hour recording)

W = Js^{-1} (Joules per second)

Thus: J = W x S

Hence:

$$Id = \frac{21942.16 \times 30 \times 60}{1000} \text{ KJ}$$

Id = 39495.88 KJ

Ac = 4.47m^2

Therefore: $$\eta d = \frac{2.0 \times 2303}{39495.88 \times 4.47} \%$$

ηd = 2.6%

APPENDIX 17:

CALCULATION OF COLLECTION EFFICIENCY (ηc) OF THE CSD COLLECTOR

The Collection Efficiency (ηc) is given by the relationship (Detailed description given in Phase I Report):-

$$Nc = \frac{V \times P \times \Delta T \times Cp}{Ac \times Ic.} \%$$

Where :- V = volumetric air flow rate through collector (m^3s^{-1})
P = air density (kgm^{-3})
ΔT= air temperature elevation (°c)
Cp= air specific heat $KJkg^{-1}$ $°C^{-1}$
Ac= collector area (m^2)
Ic= insolation on collector (Wm^{-2}) or (Js^{-1} m^{-2})

$$\eta c = \left[\frac{V (m^3s^{-1}) \times P(kgm^{-3}) \times \Delta T(°c) \times Cp\ (KJkg°c^{-1})}{Ac(m^2) \times Ic\ (Js^{-1}\ m^{-2})} \right] \%$$

$$\therefore \eta c = \left[\frac{V \times P \times \Delta T \times Cp \times 10^3}{Ac \times Ic} \right] \%$$

Then using Experiment I CSD results as an example (see Table 3).

V = (mean air flow rate) x (collector air duct area)
= (1.29 x 0.133) m^3s^{-1}
V = 0.17157 m^3s^{-1}
P = 1.28 Kgm^{-3}
ΔT = (mean air temp. entering drying chamber from collector) - (mean air temp entering collector from outside)
ΔT = (31.58 - 27.95)°c
ΔT = 3.68 °C
Cp = 1.005 Jkg^{-1} $°C^{-1}$
Ac = 2.013 m^2
Ic = 21942.16$Js^{-1}m^{-2}$

Thus: $$\eta c = \left(\frac{0.17157 \times 1.28 \times 3.68 \times 1.005 \times 10^3}{21942.16 \times 2.013} \right) \%$$

ηc = 1.84%

APPENDIX 18

SENSORY EVALUATION OF DRIED BEEF

Name:..............................   Date:..........................

Please evaluate the meat. Do not write anything or comment on the soup.

Quality Factor	Scoring Scale					Comments
Colour	Very desirable 5	Moderately desirable 4	Slightly desirable 3	Slightly undesirable 2	Undesirable 1	
Tenderness	Very tender 5	Moderately tender 4	Slightly tender 3	Tough 2	Very tough 1	
Flavour	Very natural beef flavour 5	Slightly Natural beef 4	Natural beef flavour 3	Slightly Weak 2	Lacking any beef flavour 1	
Juiciness	Very Juicy 5	Moderately Juicy 4	Slightly Juicy 3	Slightly dry 2	Very dry 1	
Off-flavour	No off flavour 5	Slight off flavour 4	Moderately off flavour 3	Pronounced off flavour 2	Very Pronouced off flavour 1	
Overall Acceptability	Very good 5	good 4	fair 3	poor 2	very poor 1	

Will you buy the dried meat in the market?   Yes................   No.................

PLATE 1: APPENDIX 19

Picture showing solar dried meat strips infested with Ascarus sirus mites and their powdery breakdown products.

Date packed: 20/04/91

Aerobically packed in LDPE bags at room storage conditions

PLATE 2: APPENDIX 20

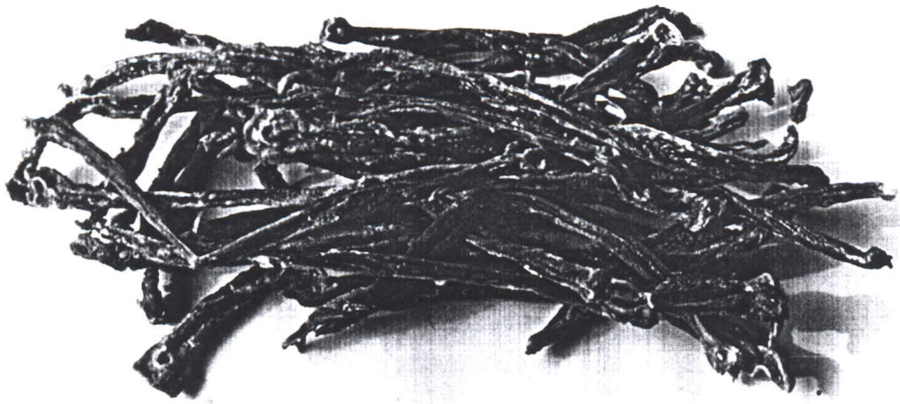


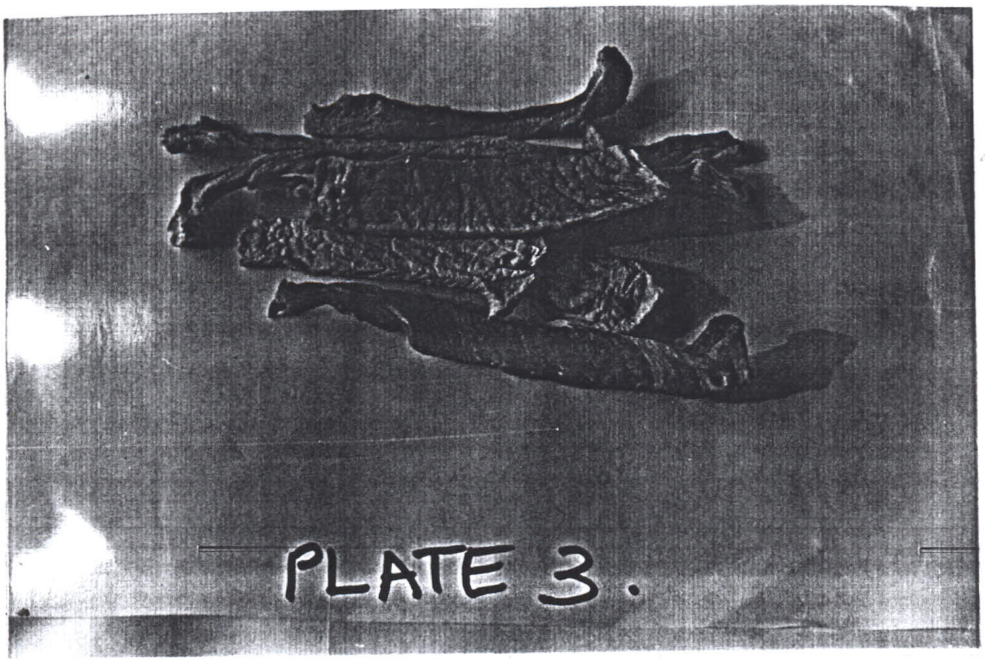
PLATE 2.

Picture showing gelatine coated, solar dried meat strips.

Date packed: 20/04/91

Aerobically packed in LDPE bags at room storage conditions.

PLATE 3 : APPENDIX 21



Picture showing hot smoked (ca 50°C for 30 minutes) solar dried meat strips.

Date packed: 20/04/91

Aerobically packed in LDPE bags at room storage conditions.