"STUDIES ON DRYING CHARACTERISTICS OF BANANA SLICES"

M. Tech. (*Agril. Engg.*) THESIS

by

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"STUDIES ON DRYING CHARACTERISTICS OF BANANA SLICES"

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CERTIFICATE - I

This is to certify that the thesis entitled **“Studies on Drying Characteristics of Banana Slices”** submitted in partial fulfillment of the requirements for the degree of **“Master of Technology in Agricultural Engineering”** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **SHRI KALNE ABHIMANNYU ARUN** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instructions.

No part of this thesis has been submitted for any other degree or diploma (certificate awarded *etc*.) or has been published/ published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

(Dr. A. K. Dave)
Chairman Advisory Committee

Date:

THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE

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Member	(Dr. R.R.Saxena)	------------------------------

CERTIFICATE – II

This is to certify that the thesis entitled **"Studies on Drying Characteristics of Banana Slices**" submitted by **SHRI KALNE ABHIMANNYU ARUN** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur (CG) in partial fulfillment of the requirements for the degree of **Master of Technology** (Agricultural Engineering) in the **Department of Agricultural Processing and Food Engineering** has been approved by the Student's Advisory Committee after oral examination in collaboration with the external examiner.

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Place: Raipur *(Abhimannyu A. Kalne)*
Date:

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LIST OF SYMBOLS AND ABBREVIATIONS

%	-	Per cent
^{o}C	-	Degree Celsius
^{o}		Degree
CG	-	Chhattisgarh
cm	-	Centimeter
cm^2		Square centimeter
db	-	Dry basis
e.g.	-	Example
et al.	-	Etlli and others
etc.	-	Excetra
F.A.E.	-	Faculty of Agricultural Engineering
Fig.	-	Figure
g	-	Gram
GI	-	Galvanized iron
GN	-	Grand Naine
h	-	Hour
i.e.	-	that is
I.G.A.U.	-	Indira Gandhi Agricultural University
ISCD	-	Indirect solar cabinet dryer
kg	-	Kilogram
LPG	-	Liquefied Petroleum Gas
m	-	Meter
m^2		Square meter
m.c.	-	Moisture content
MS	-	Mild steel
mg	-	Milligram
min	-	Minute
mm	-	Millimeter
Rob	-	Robusta
Rs.	-	Rupees
OSD	-	Open sun drying
STD	-	Solar tray dryer
Temp.	-	Temperature
Viz.	-	Videlicet
wb	-	Wet basis

CHAPTER I
INTRODUCTION

1.1 General

Being a rich source of energy producing food, banana is consumed in several varieties of preparations and forms. Based on gross value, banana is considered to be the fourth most important food crop in world just after rice, wheat and milk products. Proudly, India is a leading producer of banana among all the countries, with more than 20 per cent production (16.91 million tonnes). Within the country banana contributes 37 per cent to total fruit production and occupy 20 per cent area among the total area under crop in India. (Ikisan, 2006).

Banana is being cultivated in India from antiquity, in varying agro climatic conditions having various production systems and cultivars. On a commercial scale it is being cultivated mainly in Tamil Nadu, West Bengal, Kerala, Maharashtra, Gujarat, Karnataka, Assam, Andhra Pradesh and Bihar. Some inferior types of banana are also found growing as far north as the Himalayas. Maharashtra, Tamil Nadu and Gujarat together contribute over 62 per cent to the country's total banana production. (Sarode, 2001).

The fruit banana has a great socio–economic significance and is closely interwoven in our national heritage. Banana is a rich source of starch, mineral and vitamins and thus makes very good food for babies. Banana is also useful in managing patients with high blood pressure and heart diseases as it contains low amount of sodium, very little fat and no cholesterol. It is also good for arthritis, kidney diseases, ulcer and gastro-enteritis. (Pethe, 2001).

1.2 Status of processing

Being highly perishable in nature, like to other horticultural commodities there is a need to preserve this important fruit by processing it to produce banana pulp, banana chips, banana powder *etc.* to cater to the needs of different sections of the society and thereby provides incentives to the growers (Chakraverty *et al*. 2005).Though there are varying views about the extent of losses in these commodities, it is roughly estimated that the losses are 20-30 per cent of highly perishable horticultural produce amounting to a loss of Rs. 30,000 crore per annum (FAO, 2005). These post harvest losses directly affect the producers and suppliers of the product due to lesser financial gain, which in turn affect the consumers who are forced to pay higher prices for the losses in the marketing chain. Quality deterioration is also quite substantial. It has been observed that the farm gate price available to the farmers is only 25 per cent of the retail price in India, as compared to 70 per cent in the Netherlands and USA. (ikisan.com).

Best approach to reduce this huge wastage of perishable commodities is processing and value addition of these products. Though the total quantum of production of fruits and vegetables by the country is quite impressive, its share in the global processed food trade of horticultural produce is negligible. It is roughly estimated that only 2 per cent of the total produce is being processed in India against 30 per cent in Thailand, 70 per cent in Brazil, 78 per cent in Philippines and 80 per cent in Malaysia (ikisan.com). As banana fruits are available in plenty in India, processing and product development using bananas is of utmost importance. Various processed products like figs, clarified juice, banana powder, flour, starch, jam, chips, stem candy and fermented products like ethanol, brandy and beer are prepared and used commonly in India. (ikisan.com).

Air drying alone or together with solar or sun drying is largely used for preserving bananas. Besides the preservation, drying adds value to banana. Banana chip is one such value added product with a crispy and unique taste consumed as a snack food and an ingredient in breakfast cereals. It can be consumed as produced or further processed by coating with sweeteners, frying in oil, *etc*. (Hermann, 1977).Drying is the basic step giving the characteristics properties to the banana chip. Understanding drying behavior of banana slices is very important for the control of the drying process itself, any subsequent processes, and quality of the final product. (Demirel and Turhan, 2003).

1.3 Need of the study

Banana requires humid tropical climate. It grows well in region with temperature range of 10^{o}C to 40^{o}C. However temperature above 40^{o}C causes burning of leaves. This is one of the important horticultural crops, which can be grown in almost all districts of Chhattisgarh. (Sarode, 2001).

In Chhattisgarh state proper infrastructure development for post harvest management is not taken care of. Therefore, there is need to develop suitable infrastructure for post harvest management, marketing and processing if achieved at farm level will help in increasing the farm returns by way of value addition .(Patil, 2002).

No study has been done in Chhattisgarh agro climatic condition on drying of banana slices. Considering the high production of banana in Chhattisgarh (5155.25 tonnes) and looking to the lack of post harvest management in the state, a study on drying characteristics of banana slices is to be thought for value addition of the banana fruit with the following specific objectives.

Objectives:

1. To study drying characteristics of banana slices.
2. To study comparative performance of different drying methods for banana slices.
3. To compare the cost economics of different drying methods used for banana slices drying.

CHAPTER II

REVIEW OF LITERATURE

In this chapter the banana production scenario in India and Chhattisgarh, composition and use of banana, post harvest losses, need for drying, the previous work done on the drying methods of bananas, the effect of pretreatment and drying air temperature on the drying characteristics are briefly enumerated under the following heads.

2.1 Indian position among fruit production

2.2 Availability of bananas in Chhattisgarh

2.3 Varieties grown in Chhattisgarh

2.4 Composition and use of banana

2.5 Post harvest losses and processing status of India

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2.1 Indian position among fruit production

Banana is one of the important fruits in India and occupies about 4.90 lakh hectares with a production of about 16.91 million tonnes, which is approximately 20 % of the world production of banana. Considered as a rich source of energy producing food, it is consumed in several varieties of preparations and forms. Though major share of banana production in the country is consumed in the fresh form, small percentage of it is exported to Middle East, Gulf, Russia, Ukraine and other European countries (ikisan, 2006).

2.2 Availability of bananas in Chhattisgarh

Banana requires humid tropical climate. It grows well in region with temperature range of 10^oC to 40^oC. Temperature above 40^oC causes burning of leaves. This is the first crop, which can be grown in almost all districts of Chhattisgarh plain and Bastar plateau (Patil, 2002). District wise area and production of banana crop is given in Table 2.2

Table 2.1 Area and production of banana in Chhattisgarh

District	Area (ha)	Production (Tonne)
Raipur	75.00	760
Durg	129.32	1399
Rajnandgaon	27.00	135
Bilaspur	39.39	NA
Sarguja	88.55	NA
Raigarh	72.70	2834
Bastar	19.00	27.25

2.3 Varieties grown in Chhattisgarh

From 1965 to 1980, 85 banana varieties were screened for growing in Chhattisgarh region. Seven varieties (Bhusavali, Robusta, Lacatan, Chinichampa, Sonkela, Batteesa and local) were found suitable. These varieties except Chinichampa were awarded in all India fruit show (Sarode, 2001).

2.4 Composition and use of banana fruit

Banana is the cheapest, plentiful and most nourishing of all fruits. It contains nearly all the essential nutrients including minerals and vitamins and has several medicinal properties. Thus this important fruit is considered as a rich source of energy (Pethe, 2001). About 24 bananas each weighing around 100 g would provide the energy requirement (2400 cal/day) of a sedentary man. The composition of the fruit is presented in Table 2.1(ikisan, 2006).

Table 2.2 Composition of banana fruit

Moisture	70.0%
Carbohydrate	27.0%
Crude fibre	0.5%
Protein	1.2%
Fat	0.3%
Ash	0.9%
Phosphorus	290.0 ppm
Calcium	80.0 ppm
Iron	6.0 ppm
b -carotene	0.5 ppm
Riboflavin	0.5 ppm
Niacin	7.0 ppm
Ascorbic acid	120.0 ppm

As banana fruits are available in plenty in India, processing and product development using bananas is of utmost importance. Various processed products like figs, clarified juice, banana powder, flour, starch, jam, chips, stem candy and beer are prepared and used commonly in India. Chips are the most commonly consumed first generation snack foods. They are used as snack food both in domestic as well as in fast food centers and restaurants as side dish and garnishers. Moreover, the product can be safely stored for up to six months without any change in quality (ikisan, 2006).

2.5 Post harvest losses and processing status of India

Being highly perishable in nature banana and other horticultural produces also often wasted. It is being increasingly realized that food-processing capacity needs to be increased so as to reduce wastage. It is roughly estimated that the losses are 20-30 % of horticultural produce amounting to a loss of Rs. 30,000 crore per annum (ikisan, 2006). The post harvest losses directly affect the producers and suppliers of the product due to lesser financial gain, which in turn affect the consumers who are forced to pay higher prices for the losses in the marketing chain.

The total quantum of production of fruits and vegetables by India is quite impressive, but its share in the global processed food trade of horticultural produce is negligible. It is roughly estimated that only 2% of the total produce is being processed in India against 30% in Thailand, 70% in Brazil, 78% in Philippines and 80% in Malaysia. (ikisan, 2006).

Surendranathan (2004) stated that fruits have a limited shelf life and it is imperative need to adopt preservation technologies to overcome post harvest losses of fruits in India. One way of achieving this could be by developing feasible technologies to extend the post harvest shelf life. An alternative is value addition of the produce by developing innovative products of consumer interest.

2.6 Need of drying

Drying of agricultural products is an important unit operation under post harvest phase. It is the removal of excess moisture from food products to a predetermined level. It's a thermo physical and physico-chemical process. Drying makes the food products suitable for safe storage as it protects them against attack of insects, molds and other microorganisms during storage. During drying, the moisture from solid gets vaporized and diffused in dilute environment. Removal of moisture takes place by high pressure or high temperature conditions.

Food products are hygroscopic in nature and if the vapour pressure of the water present in the food is more than that of the surrounding air, the moisture vapourizes and diffuse to the atmosphere, but if the vapour pressure of the water in the surrounding air is more than that of the water present in the food, than it absorbs moisture from the air. This property of losing and gaining moisture is called hygroscopicity. The food material loses or gains moisture till it attains a balance with the surrounding air. The amount of water present in the food material at this moment is called equilibrium moisture content (Sahay and Singh, 1994).

2.7 Drying and Dehydration Theory

Bongirwar and Srinivasan (1977) reported a method of partial dehydration of banana by osmosis in sugar solution of 70 per cent concentration and observed that fruit reduced to about half of its original weight in 3 hours. They concluded that high temperature above 60^{o}C modifies the tissue characteristics favouring impregnation phenomena and thus solid gain.

Bhuyan and Prasad (1990) conducted thin layer drying experiments on the siliguri variety of ginger to study its drying characteristics and evaluated the quality of the dried product by determining its volatile oil and oleoresin content. They also designed a small capacity tray dryer. The evaluation of the dryer showed that the performance was satisfactory at an air temperature of 60^{o}C which was also found to be most suitable temperature for drying ginger slices.

Das and Bhatnagar (1990) developed a multistage dehydration process for garlic. They employed drying air temperatures from 60, 70, 80 and 90^{o}C up to 20, 30, 40 and 50 per cent cut off moisture levels. They recommended a two stage and three stage dehydration process which resulted in saving of about 16 and 17 per cent of total drying time respectively, compared to the single stage drying at 60^{o}C.

Sankat and Castaigne (1992) dried osmotically treated and untreated banana slices at 40, 60 and 80^{o}C and reported that drying was only in the falling rate period. The drying constants were established for first and second falling rate period. Increased drying temperature positively influenced the drying rate of fresh fruit slices as well as osmotically treated slices. Dried, osmotically treated bananas with added SO_2 had an attractive, yellow colour compared to dull, dark brown colour of dried fresh fruit slices.

Kar *et al*. (2001) concluded that in case of banana slices osmotic dehydration can be practiced as a better method of removal of moisture over other conventional methods where the drying load is sufficiently reduced.

Desai *et al.* (2002) stated drying is one of the most practical methods of preserving food and the quality of agricultural products. Drying refers to removal of moisture up to safe level so that activities of yeast mould and bacteria that cause spoilage prevented.

Garg *et al.* (2003) carried out drying of raw mangoes at Central Institute for Sub-tropical Horticulture, Lucknow. Raw mangoes were peeled manually and one cm thick slices were cut. Four treatments were given to slices *viz* open sun drying (control), slices dried in solar dehydrator developed at the institute, 1000 ppm potassium metabisulphite added uniformly to slices and dried in open, Slices given KMS treatment and then dehydrated in solar dehydrator. They observed that dried mango powder prepared from dried raw mango slices in solar dehydrator was more energy efficient and hygienic than dried in open sun drying.

Narayana *et al.* (2003) stated that preservation of fruits by drying is one of the oldest methods which involve reducing the moisture content to a point at which the concentration of dissolved solids in the product is so high that osmotic pressure will prevent the growth of micro organism. Dried fruits are in more concentrated form, less expensive and require lesser space for storage and transportation.

Chakraverty *et al.* (2003) stated that banana might be dried in different forms by different methods. Sun or solar dried bananas are used for flour or powder. To prevent darkening of the product, SO_2 pretreatment is normally used. Banana pulp is dried in to flakes by drum drying, typically in double drum atmospheric dryers. The flakes may be pulverized to make a powder. Spray dried banana powder is produced after special preparation of the feed, mainly dilution with water. Several other procedures have been developed for banana drying

Kephas Nowakunda *et al.* (2004) stated that it is therefore necessary to devise drying techniques that reduce the bulk of the bananas, extend their shelf life, preserve quality, enable wider utilization base and convert the banana into convenient food products, which are easy to transport and prepare. Other drying methods have been developed to improve the dehydration rate and quality of the products.

2.8 Pre drying treatments

(Herrmann, 1997) suggested some of the common pretreatments applied for banana slices, which are given as below:

1. Use of preservatives such as sulphur dioxide, carbon dioxide, benzoic acid, ascorbic acid and citric acid.

2. Blanching: consist of immersing of product in water at a room temperature of 95^0C for a variable period of time. The temperature and the duration depend on the species, its state of maturity and its size.

3. Use of sulphites: bi-sulphites of sodium, potassium, and calcium. Meta bisulphites of sodium and potassium.

2.8.1 Blanching

Dandamrongrak *et al*. (2003) stated that blanching is an important step in fruit and vegetable processing because of many advantages that can be obtained. An important role of blanching is to inactivate enzymes. However, blanching has also resulted in increasing the drying rate of products such as sugar beet (Vaccarezza and Chirife, 1975), carrot cubes (Mazza, 1983), apples and peaches (Barbanti *et al.*, 1991), and red peppers (Turhan *et al.*, 1997).

Sankat *et al.* (1996) have used the blanching in order to improve either drying kinetics or product quality.

Kar *et al.* (2003) made a study to optimize hot water blanching (97^{o}C), steam blanching and microwave blanching of banana slices based on the total inactivation of peroxidase and polyphenol oxidase enzymes. They found that hot water blanching of 5 min.; steam blanching for 4 min.; and microwave blanching of 1.5 min. is sufficient to achieve complete inactivation of peroxidase and polyphenol oxidase of banana slices.

2.8.2 Treatment of potassium metabisulphite and benzoic acid

Narayana *et al.* (2003) studied the drying process of fully maturated Karpooravalli banana bunches. After ripening, the fruits were peeled and divided into five lots of 3 kg each. Each lot was subjected to the following treatments with three replications: Dipped in 1% potassium metabisulphite (KMS) solution for 5 minutes. Blanched in hot water (80^{o}C) for 5 minutes. Blanched in hot water (80^{o}C) for 2 minutes followed by dip in 100 ppm KMS solution for 5 minutes. KMS (100 PPM) infiltration for 5 minutes and Ascorbic acid infiltration (1000 ppm) for 5 minutes. Study concluded that banana figs of acceptable quality having better shelf and maximum output could be produced by adopting treatments like infiltration either potassium metabisulphite (100 ppm) or ascorbic acid (1000 ppm) before dehydration of fruits.

Herrmann (1997) recommended in case of banana slices, benzoic acid is also a good preservative besides sulphur di oxide and ascorbic acid.

Garg *et al*. (2003) studied one cm thick slices of manually peeled raw mangoes for drying experiment. Four treatments were given to slices viz. open sun drying (control), slices dried in solar dehydrator developed at central institute for subtropical horticulture, Lucknow, 1000 ppm potassium metabisulphite added uniformly to slices and dried in open, Slices given KMS treatment and then dehydrated in solar dehydrator . They found that drying of raw mango in open sun drying shows more count of yeast and mould whereas solar drying shows very less count of yeast and mould.

2.9 Drying methods and equipments

Dandamrongrak *et al*. (2003) examined the thin-layer drying behaviour of bananas in a heat pump dehumidifier drier. Four pre-treatments (blanching, chilling, freezing and combined blanching and freezing) were applied to the bananas, which were dried at 50^{o}C with an air velocity of 3.1 m s^{-1} and with the relative humidity of the inlet air of 10-35 per cent.

Nono *et al.* (2002) conducted an experiment in which 10 mm thickness banana slices soaked in two successive sucrose baths with respective concentrations of 35^{o}Brix and 70^{o}Brix, acidified at 3.5 pH with ascorbic acid. The first bath, which contained 1 per cent calcium chloride to ensure the firmness of the fruit, served also in blanching the fruit. This consisted of soaking the fruit in the solution initially heated at 85^{o}C and leaving them to dehydrate while cooling slowly to room temperature over a period of 24 h. The mass ratio of fruit to solution for this bath was 1:6. Dehydration in the second bath at 70^{o}Brix was conducted with a fruit to solution ratio of 1:4 and at room temperature, for economic reasons and for the quality of final product. This second treatment was doubly important: there was an increase in the sugar content of the fruit and further water loss maintaining the banana slice shape during the final drying. It also conferred on final product a good mouth-texture (the final product was softer), a pleasant sweet taste and spread the banana aroma more widely. Treatment in two successive baths led to a weight reduction of 60.2 per cent and a solute gain of 2 per cent. Bananas then underwent a moderate drying at 40°C for 72 h with an air relative humidity of less than 60 per cent. The water content of the final product was 16.5 per cent. The final product had an attractive colour and did not show any brown pigmentation.

Chouhan and Patel (1989) studied the sun drying characteristics of whole groundnut plant practiced by Gujarat farmers. The groundnut crop is generally heaped in the field for open sun drying after harvest. To study the moisture loss, samples from three different locations in the heap (top, middle and bottom) were taken and analyzed. After 96 h of exposure the initial moisture content of 61.5 per cent wb was reduced to 17.1, 15.1 and bottom layers. During the period of study, the average RH was 72 per cent and the maximum and minimum temperature were 40 and 29.8°C, respectively.

Mathew and Sachcev (1989) conducted a comparative study to evaluate the quality of selected leafy vegetables (fenugreek, coriander, bathua and spinach) dried in a solar dryer and in open sun. The initial moisture content of the fresh vegetables varied from 86 to 94 per cent wb. Drying time varied from three to four h in the solar dryer which was 60 to 65°C and 8 to 12 h under open the sun, indicating 50 to 75 per cent reduction in the drying time as compared to sun drying.

Sankat and Castaigne (1992) conducted a drying study on osmotically treated and untreated banana slices at 40, 60 and 80°C and reported that drying was only in the falling rate period. The drying constants were established for first and second falling rate period. Increased drying temperature positively influenced the drying rate of fresh fruit slices as well as osmotically treated slices. Dried, osmotically treated bananas with added SO_2 had an attractive, yellow colour compared to dull, dark brown colour of dried fresh fruit slices.

Zeb *et al.* (1994) conducted study on disc-shaped banana slices, dipped in 1% citric acid and blanched, were processed into 'intermediate moisture sweetened banana' using 20, 40 and 60^o Brix solutions of crystalline sucrose containing 0.2 per cent potassium metabisulphite as chemical preservative for long shelf life. After soaking for 1, 2 or 3 days at room temperature for sucrose absorption, the slices were dried off and their water activity (a_w, equal to the equilibrium relative humidity) determined before and after dehydration at 70^{o}C. The banana products were also tested organoleptically for colour, flavour and taste. Results showed that the best product quality resulted from treatment for 1 day at 20^{o}Brix, higher Brix causing stickiness and difficulties in drying and packing. The new product can serve as a dried fruit and is suitable for use in confectionery, sweetened yogurt, ice creams and many other products.

Sankat *et al.* (1996) observed that when ripe banana slabs were treated osmotically in 35, 50 and 65^o Brix sugar solutions at 25^{o}C for 36 h, the thickness decreased from 10 to 9, 6 and 5 mm. Treated and freshly cut untreated slabs were air-dried nearly to equilibrium on trays in a cross-flow drying cabinet at fixed temperatures from 40 to 80 degrees and at constant air speed 0.62 m/s. Both untreated and treated slices exhibited only falling-rate drying; 2 drying constants K_1 and K_2 were established for 1st and 2nd falling-rate periods of drying. Increasing the drying air temperature significantly enhanced the drying rate and the K-values, except at 80^{o}C when the rates fell, possibly because of case hardening of the slabs.

Tests with whole bananas and slabs of thickness 20, 10 and 5 mm showed that thinner slabs dried quicker. As the sugar content of the banana slabs increased through the osmotic treatment, drying rates fell. After osmotic treatment and air-drying, banana slabs showed appealing colour and texture in comparison with fresh banana.

Pokharkar *et al.* (1997) studied osmotic dehydration of banana slices, at initial ratio of banana slices to sugar solution 1:4, in relation to temperature (30-50 ^oC) and initial sugar syrup concentration (50-70^o Brix). The water loss varied with temperature and brix, the mass transfer coefficient increasing with increase in brix and temperature. The developed model can be used for prediction of water loss during osmotic dehydration of banana slices within the range of experimental study.

Maeda *et al.* (1998) stated that the traditional processes for drying bananas usually lead to the enzymatic browning of fruits, producing non-attractive dark products. The osmotic dehydration of bananas in sucrose solutions was performed to verify the possibility of producing banana figs with no enzymatic browning. The effects of processing time (1 to 33 hours), temperature (60, 65, 70, 75^{o}C) and sucrose solution concentration (60, 70 ^{o} Brix) upon the loss of water and gain of sugar of the fruits were studied using the response-surface methodology.

Unde *et al.* (2002) conducted an experiment on fully matured banana slices of variety Basarai (5 mm thick) treated with 0.25 per cent KMS, 0.5-1 per cent $CaCl_2$, 0.1 per cent turmeric for 10 min, and with sugar syrup (50, 60, and 70^o Brix), 2 per cent NaCl, 0.5 per cent $CaCl_2$ for one h before drying. Drying was carried out in a tray drier at 60^{o}C for 5 h. Moisture content of the banana slices during the drying period decreased exponentially. The drying rate varied from 156.0 to 1.2 (g h^{-1}/100 g) for all the treatments. The quality of dehydrated banana slices treated with 0.25 per cent KMS + 0.5 per cent $CaCl_2$, 0.25 per cent KMS + 1 per cent $CaCl_2$ and 60^o Brix sugar syrup + 0.5 per cent $CaCl_2$ was found to be very good/excellent, whereas products from all other treatments were graded as good/fair.

Chandra and Samsher (2002) conducted an experiment to investigate the effect of various pretreatments and drying methods on the quality characteristics of oyster mushroom. They also evaluated the quality of dehydrated mushrooms after drying *i.e.* before storage and after six months storage at room temperature and found that mushroom samples treated with combination of blanching plus steeping in KMS (0.5 per cent) and citric acid (0.25 per cent) solution and dried in tray dryer rated highest sensory score for colour, texture, flavour and overall quality followed by polyhouse sun and vacuum drying.

2.9.1 Natural solar drying

In hot sunny areas where the solar radiation is abundant, solar drying seems to be the most promising and modest approach for preservation of various agricultural products (Desai *et al*. 2002).

Solar energy is used for drying various industrial and agricultural products in open sun and in solar dryer. A majority of industrial dryers use conventional fuel such as diesel, L.P.G., kerosene, electricity for heating purpose required for removal of moisture. Most of these dryers work at temperature ranging between 60 and 70^0C. This reveals the enormous potential for saving of conventional fuels by conversion to and adoption of solar energy based drying system, whenever possible further, solar energy is freely available and many devices for use in drying was successfully attempted at various places in India (Seveda *et al*. 2004).

2.9.1.1 Open sun drying

Mandhyan *et al.* (1988) stated that for sun drying the vegetable samples were spread in single layer and exposed to the sun on a polyethylene sheet.

Jayaraman *et al.* (1991) studied the drying characteristics of some vegetables. The pretreated vegetables were dried as by direct exposure to sun on tray. In direct sun drying, the material spread on aluminum trays (80 x 40 cm) was exposed directly to suns ray in the open. The average temperature of the air over the trays ranged from 34-38^{o}C.

2.9.1.2 Solar tray drying

Desai *et al.* (2002) fabricated a multi rack solar dryer and its performance was evaluated for grapes drying at College of Agricultural Engineering, Raichur. The results indicated that the drying time required for solar drying using the dryer was 50 hours to reduce the moisture content from 83.0 per cent (w.b.) to 15.0 per cent (w.b.), while the corresponding drying time for open sun drying was 80 hours. Thus there was net saving of 37.5 per cent in drying time over open sun drying.

Rawat *et al*. (2005) studied the drying of fresh chilli by using tray dryer in winter season. They found that the drying time required with solar dryer was 46 h to reduce the moisture content from 82 per cent (w.b.) to 15 per cent (w.b.), while the corresponding drying time for sun drying was 70 h. This resulted a net saving in the drying time of 34.28 per cent over sun drying.

2.9.1.3 Indirect solar cabinet drying

Philip (1999) studied the dehydration of agricultural products using solar energy. During experimentation a forced circulation solar dryer was designed and installed to demonstrate its technical feasibility. The system consisted of solar air heaters, blower, drying chamber and electrical backup. The results indicate that onion flakes could be dried in the solar dryer in 6.5-7 h during the month of April-June. The cost of drying was estimated to be Rs. 5.00 per kilogram of dried onion flakes. The quality of dried product was found to be acceptable.

Kalra and Bhardwaj (1981) fabricated two models of solar dehydrators for dehydration of fruits and vegetables. Model-I has a solar collector and a chamber to accommodate 8 aluminum mesh trays of 50 x 90 cm size. There is clearance of about 8 cm between trays. The air inlet is controlled by means of sliding plates (6x 6 cm) at the lower end of solar collector and the outlet is similarly regulated by sliding plates (4 cm wide) on all the four sides at the top of the chamber. The chamber is reported to have a chimney effect and may increase airflow. The chamber can attain a temperature of 10-12^{o}C higher than the outlet air temperature.

Malviya and Gupta (1987) designed and developed a cabinet type natural convection solar dryer with chimney. The air is heated up in the solar cabinet dryer. A 1 m high conical metal chimney blackened from outside to produce a tall column of warm air to increase the convection effect is also provided as the top. The air heating unit, a wooden box painted dull black is glazed from the top with transparent glass fixed at an angle of 20^{o}, unit is coupled with the drying cabinet having wooden trays and metallic mesh at the base for the entry of the hot air coming from the heating unit. A cap is provided at the top of the chimney to protect the product from dust. Temperature in the drying box was 50 $\pm$ 5^{o}C.

Jayraman *et al*. (1991) studied the drying characteristics of some vegetables. The pretreated vegetables were dried in solar cabinet drier away from direct sunshine. The solar cabinet dryer used consisted of drying chamber, which could accommodate five wire mesh trays. The chamber was connected to a flat plate collector with solar energy catching area of 2.04 m^2 consisting of corrugated iron sheet absorbed with polystyrene foam below and on sides. A chimney of about 0.304 m height is provided at the top of cabinet to improve air circulation. Maximum temperature attained inside the cabinet when run empty was 55^{o}C at an ambient temperature.

Shaw (2005) developed a indirect solar cabinet dryer with mild steel sheet of 20 guage. The frame for the indirect solar cabinet dryer was fabricated by using iron angle. A reflector glass is attached to the ISCD to collect the maximum possible solar energy reflected from the surface of the earth. This reflector is adjustable and can be rotated through nearly 120^{0} at three different positions to receive the maximum possible solar energy. The cabinet used for tray drying has a chimney, attached to it at the top, to provide an outlet for the outgoing air from the product. A float glass (thickness: 3 mm) is used as a solar collector for the ISCD. The approx. angle of tilt of the float glass from the horizontal is 30^{0}.The dryer was used for drying of khoa and chhana over a period of 5 hours and readings were taken at intervals 1,2,3,4 and 5 hours for moisture content. The rate of drying distinctly depends on the atmospheric temperature and relative humidity of the atmosphere.

2.9.2 Mechanical drying

2.9.2.1 Tray drying

Unde *et al.* (1999) studied critical moisture content of fruits and vegetables during drying. The sample prepared after pretreatment was dried in a laboratory tray dryer at 50 to 60^{o}C temperature. The reduction in weight of samples due to removal of moisture was recorded with drying time.

Jain *et al.* (2003) worked on the dehydration characteristics of spinach in air recirculatory tray drier. Spinach was dehydrated in an air recirculatory tray drier at different temperatures with different degree of air recirculation. It was found that spinach did not have any constant rate drying period but two clear cut falling drying rates were observed. It was also observed that with the decrease in 5^{o}C drying air temperature, electrical energy requirement reduces by 25 per cent without significantly affecting the total drying time. Whereas for every 10 per cent increase in recirculation of air the electrical energy requirement decreased by 10-15 per cent. The dehydrated spinach could be stored safely for 6 month in the polypropylene bags.

2.10 Drying characteristics

Mandhyan *et al.* (1988) plotted drying curves on semi-log paper. They found near straight-line relationship between drying time and initial moisture content. It was observed that the drying ratio increases when the vegetables were dried in the solar cabinet dryer. It has been found that 3 h can be saved if peas and cabbage are dried in the solar cabinet dryer instead of ordinary sun drying. Sun drying took additional 1 h for carrot and 2.5 h for spinach as compared with drying time taken in solar cabinet dryer.

Singh (1994) shows the relationship between drying time and moisture per cent (db) of cauliflower, cabbage and onion slices. This shows that during the initial stage of drying, there was rapid moisture removal from the product, which later decreased with increase in drying time.

Unde *et al*. (1999) reported that drying of fruits and vegetables could be accomplished in two stages, viz., constant rate and falling rate periods. The critical moisture content was found between 60 to 80 per cent for fruits and vegetables under study. About 10 to 12 per cent moisture could be removed economically during constant rate period drying.

Prakash *et al.* (2004) studied the drying characteristics of carrots using a solar cabinet drier, fluidized bed dryer (at temperatures 50,60,70^{o}C) and a microwave oven drier (at power levels 2,3,4) were studied. It was found that drying occurred mainly in falling rate period.

Abhay Thakur and Jain R.K. (2006) conducted a thin layer drying of fresh cauliflower florets at 50, 60 and 70^{o}C air temperatures in a tray dryer with loading density of 6.2 kg/m^2. They observed that moisture content of cauliflower decreased with respect to time in continuous order irrespective of drying air temperature.

2.11 Quality of final product

Srivastava and Nath (1985) reported that the blanching time of 6 min in boiling water was necessary for inactivating peroxides. Dried product obtained from raw cauliflower was very dark and had poor rehydration ratio. Reducing agent like sulphites or sulphur di oxide ($S0_2$) are known to suppress browning and have been used with good results in blanching of cauliflower. Blanching and dipping in starch lowered the concentration of reducing and total sugar.

Tripathi and Nath (1989) showed that tomato slices possessing good colour can be obtained by blanching them whole in boiling 2.5 per cent brine for 60 s and cutting in to 2.5 per cent starch solution containing 5 per cent KMS and drying in cabinet dryer at 78^oC and 55^oC. These slices retained their red colour well during 6 months storage as observed visually.

2.12 Economics of drying

Singh and Alam (1982) reported the cost of chilli drying with solar dryer was Rs. 26.63-133.62 per quintal as against Rs. 25.15-93.91 per quintal for open yard sun drying.

Birewar *et al*. (1982) worked out the cost for operation for drying of 1 kg of chilli in natural draught fuel operated farm level crop dryer using agricultural waste which was Rs. 0.40 against Rs. 0.50 under conventional method of sun drying and Rs. 0.81 by electrical blower operated dryer.

Philip (1999) estimated the cost of drying to be Rs.5.00 per kg for dried onion flakes was possible, if 100 per cent depreciation benefits available.

Rawal and Samuel (1980) worked out that the cost of dehydration per kg of onion was Rs. 1.20 in year 1977-78, when the samples were dried in a tunnel dehydrator costing Rs. 40,000.00.

Singh (1994) estimated the cost for drying cauliflower, cabbage and onion slices, which were Rs. 2.16, Rs. 2.76 and Rs. 2.37 per kg respectively, when an electrical dryer was used.

Jain, N.K. *et. al.* (2004) worked out the cost of operation of for solar and mechanical dryer and estimated that drying cost of ginger, garlic and ground nut under mechanical dryer was found about 100, 130 and 20 per cent more in comparison to solar drying system.

To dry vegetables by using solar energy is very economical as compared to other modes of energy. The readily availability and non-pollution are other advantages of solar drying.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the material and methods employed for pre treatments, drying of banana slices. This chapter is divided into the following sub headings:

3.1 Raw material and sample preparation

3.2 Pre-treatments, and

3.3 Drying of banana slices

The drying experiments were planned and carried out in the Faculty of Agricultural Engineering, Indira Gandhi Agricultural University, Raipur. Experimental plan is shown in Fig.3.1.

3.1 Raw material and sample preparation

Two banana varieties *viz.,* Grand Naine and Robusta were procured from V.N.R. Horticultural Farm, Malpuri, District- Durg (Chhattisgarh) are used in the present experiment. Fully matured unripe green bananas of both varieties were washed thoroughly in running water to remove the adhering soil and extraneous matter. Grand Naine and Robusta banana variety is shown in Fig.3.2 and Fig.3.3.

The peeled bananas were sliced into slices of 2-3 mm thickness by means of adjustable slicer. The thickness of the slices was measured by vernier caliper. These disc shaped slices were then washed softly in water to remove their stickiness and place in open air for surface moisture evaporation.

Initial moisture content of the banana was determined by oven dry method at 70 $^{o}C \pm 2^{o}C$ till constant weight occurred (Ranganna, 1995).

3.2 Pre-treatments

Many pretreatments have been tried and their effects on drying characteristics have been reported to different fruits and vegetables.

Some of the common pretreatments applied for banana slices are:

1. Use of preservatives such as sulphur dioxide, carbon dioxide, benzoic acid, or ascorbic acid.
2. Blanching and
3. Use of Bi-sulphites of sodium, potassium and Meta bisulphites of sodium and potassium.

The following pretreatments were given to the banana slices. Weight of the each sample was kept as 100 g for all the experiments.

1. Hot water blanching at 97^{o}C for 5 minutes
2. Slices treated with 100 ppm of potassium meta bisulphite for 5 minutes,
3. Slices treated with 1000 ppm of benzoic acid for 5 minutes.

Washed disc shaped banana slices of same thickness were divided in to four groups and treated as per the treatments (Table 3.1). The water was drained out completely and the slices were taken for the drying experiments.

Table 3.1 Pre-treatments given to banana slices

Treatment	**Symbol**
Control (Without any pretreatment)	T_1
Blanching in hot water at 97^{o}C for 5 minutes	T_2
Treated with 100 ppm of potassium meta bisulphite	T_3
Treated with 1000 ppm of benzoic acid	T_4

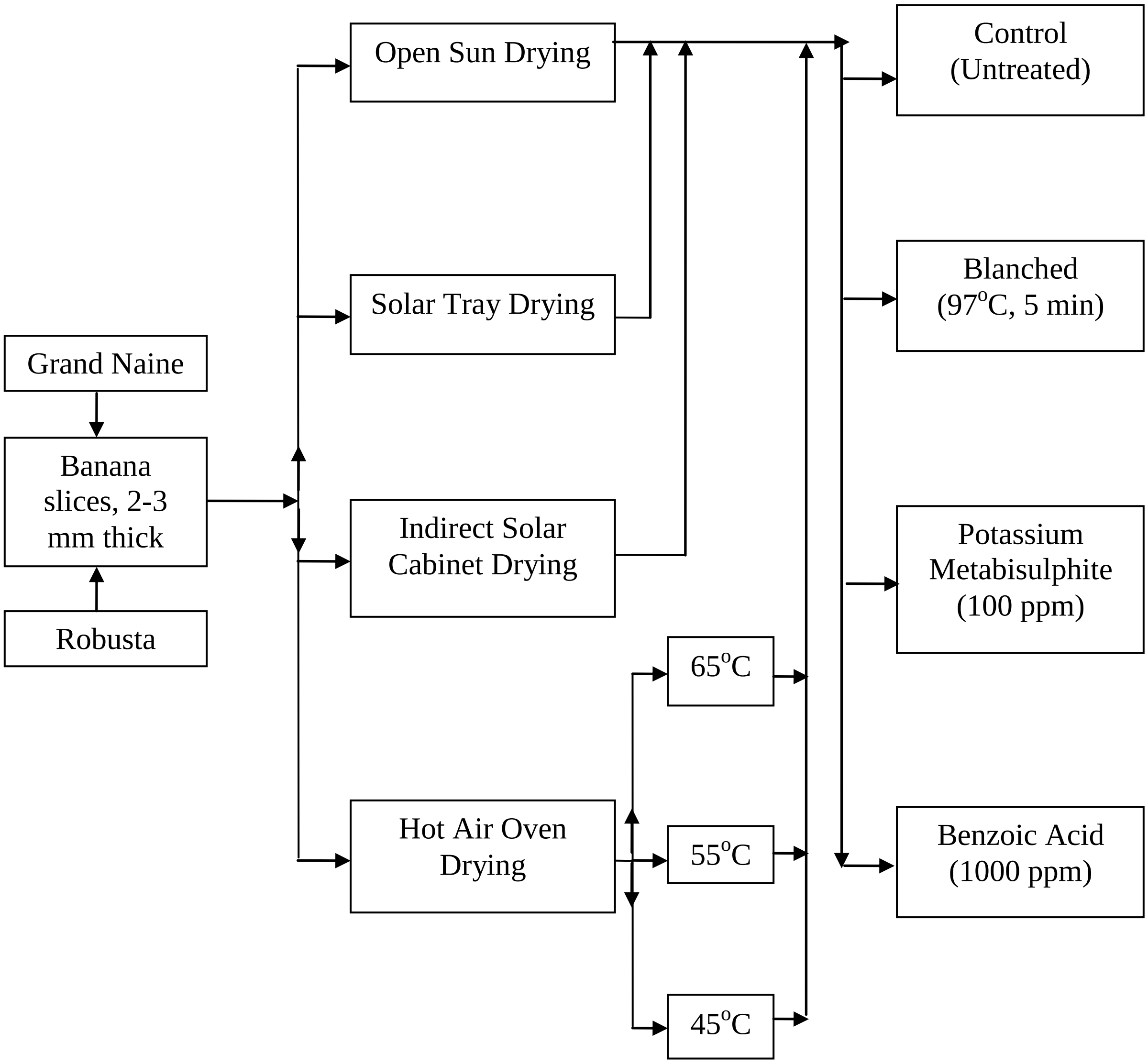

Fig. 3.1 Experimental procedure for banana slices drying

Fig. 3.2 Grand Naine Variety of Banana

Fig. 3.3 Robusta Variety of Banana

3.3 Drying of banana slices

In the present study, an attempt was made to compare the drying characteristics of the banana slices using different drying methods. The banana slices (2-3 mm) were dried using four methods *viz*., open sun drying, solar tray drying, indirect solar cabinet drying and oven drying at temperature of 45, 55 and 65^{o}C.

3.3.1 Open Sun drying

Sun drying is the cheapest method of drying and adopt for drying various industrial and agricultural products. Black polythene sheets were mostly used as drying platform because it absorbs almost solar radiations.

To accomplish the sun drying experiments, a black polythene sheet was selected for better absorption of solar radiations. The surface area of the sheet was sufficient to spread 100 g of slices. The sun drying method is shown in Fig. 3.4.

Black polythene sheets were completely cleaned and the samples were spread over the sheets uniformly in a single layer. The sample was weighed at 1 h interval, by means of an electronic balance (accuracy 0.001 g, capacity 3000 g). Drying air temperature on this sheet was also measured periodically with the help of a thermometer. Relative humidity was recorded by means of a hygrometer. Drying was continued till the sample attained a constant weight.

3.3.2 Solar tray drying

A multi rack solar tray dryer was fabricated at Faculty of Agricultural Engineering, IGAU Raipur (CG) used for drying of banana slices. It consisted of a transparent glass to transmit the solar radiations and three trays for loading the produce. The cabinet of the dryer is made up of GI sheet with thermocol insulation

Fig. 3.4 Open Sun Drying

Fig. 3.5 Solar Tray Drying

fitted on frame of iron angle. The front portion fitted with glass is tilted at an angle of 45^{o} to facilitate maximum exposure to the solar radiation. The solar tray drying method is shown in Fig. 3.5.

The samples of banana slices were put in a single layer on the black polythene sheet over the trays (1.1 kg/m^2). The loss of moisture was recorded at every 15 min interval for the first two hour drying, at every 30 minutes for next two hour interval and at every one hour for rest of drying period. At the time of observation complete polythene sheet (0.3 m x 0.3 m) with sample was taken out, weighed immediately and again put into the dryer. The entire process of opening the door, withdrawing and weighing the sample and closing the door took not more than one minute, which eliminate the error. The drying was performed continuously for 8 h. The weight of sample was taken on a precise electronic balance having least count 0.001 g. After the termination of experiments the samples were filled in polyethylene bags (resealable) and stored in a dry place under atmospheric pressure. The initial and final moisture contents of banana slices were determined in a static hot air oven at $70^{o}C \pm 2^{o}C$ till constant weight occurred (Ranganna, 1995). The moisture content values were calculated on dry matter basis and expressed in percentage.

3.3.3 Indirect solar cabinet drying

An indirect solar cabinet dryer (ISCD) developed at Department of Dairy Engineering, IGAU, Raipur was used for drying of banana slices. A reflector glass attached to the ISCD helps to collect the maximum possible solar energy reflected from the surface of the earth. This adjustable reflector can be rotated through nearly 120^{o}.Chimney is attached at the top of the dryer, to provide an

Fig. 3.6 Indirect Solar Cabinet Drying

Fig. 3.7 Hot Air Oven Drying

outlet for the outgoing air from the product. A float glass (thickness: 3 mm) is used as a solar collector for the ISCD. Approximate angle of tilt of the float glass from the horizontal is 30^o.

100 g sample of banana slices was kept in the dryer on black polythene sheet in a single layer. Similar procedure was adopted as in case of tray dryer Section 3.3.2). The indirect solar drying method is shown in Fig. 3.6.

3.3.4 Hot air oven drying

Banana slices were dried in the hot air oven at three temperatures *viz*., 45, 55 and 65^{o}C. The banana slices were spread directly on the shelves of the oven. The oven was initiated about an hour of the experiment and when predetermined temperature attained, pre-treated samples were placed. The drying of slices was continued for a period of 8 h. Weighing of the samples was done regularly at an interval of 15 min initially for the first 2 h of drying. The interval of weighing was kept 30 min for next 2 h of drying. The interval of weighing was kept 30 min for next 2 h of drying and finally the interval was kept 1 h. The dried samples were collected in resealable polyethylene bags and kept in a dry place. The moisture content of the dried sample was determined as per the method explained earlier. The specifications of the hot air oven are listed in appendix III. The oven drying method is shown in Fig. 3.7.

3.4 Method of analysis

The analysis of different properties of dried banana slices was done to deduce valuable information on mechanism of drying of banana slices. Statistical analysis with the Factorial Completely Randomized Design (Panse and Sukhatme, 1995) of drying process was done to know the relative effect of different pretreatments under various drying conditions on the final moisture content of banana slices.

3.4.1 Determination of moisture content

$$M(wb) = \frac{M_w}{M} \times 100 \qquad \text{-------- 3.1}$$

where,

M (wb) = Moisture content, % wet basis

M_w = Mass of water, g

M = Initial mass of sample, g

$$M(db) = \frac{M_w}{M_d} \times 100 \qquad \text{-------- 3.2}$$

where,

M (db) = Moisture content, % dry basis

M_w = Mass of water, g

M_d = Initial mass of sample, g

3.4.2 Drying rate

Drying rate of the banana slices at any time was calculated by the following formula (Bakane, 2000)

$$R = \frac{W_r}{T \times W_d} \times 100 \qquad \text{-------- 3.3}$$

where,

R= Drying rate (g/min)

Wr = Amount of moisture removed (g)

T = Time taken (min)

W_d= Total bone dry weight of sample (g)

Conversion factor was used to convert this drying rate in g/h and is given as follows.

R (g/h) = R (g/min) x 60

where,

R (g/h) = Drying rate (g/hour)

R (g/min) = Drying rate (g/minute)

CHAPTER IV

RESULTS AND DISCUSSION

Results and discussion of the experiments carried out on drying of banana slices are presented in the chapter. The results have been discussed under the following subheadings, inferences have been drawn and possible reasons have been given.

4.1 Properties of banana slices

4.2 Drying characteristics of banana slices under different drying conditions

4.3 Comparison of different drying conditions

4.1 Properties of banana slices

The mean value of the moisture content of fresh banana slices was found in the range of 79 and 83 per cent (wb) in both the varieties. Average weight and length of green fruit in case of Grand Naine variety was recorded as 198 g and 19 cm, respectively. Pulp to peel ratio for the same was observed as 64:36. Similarly average weight and length of green fruit in case of Robusta variety was recorded as 124 g and 14.5 cm respectively. Pulp to peel ratio was found as 59:41.

More or less similar range of weight and dimensions were observed by Pruthi *et al.* (1977) during their study in Kerala.

4.2 Drying characteristics of banana slices under different drying conditions

The drying characteristics of banana slices for both the varieties namely Grand Naine and Robusta under different drying conditions are summarized below.

4.2.1 Sun drying

The drying behavior of Grand Naine and Robusta variety banana slices of different pre-treatments for sun drying is presented in Fig. 4.1 and Fig. 4.2, as a plot of moisture content (per cent db) *versus* drying time.

The drying air temperature on black polythene sheet was measured at an interval of 15 min. for first 2 hours, at 30 min for next 2 hours and at hourly for rest of drying period for both the varieties. During the drying of Grand Naine banana slices air temperature on black polythene sheet varied from 39 to 55^{o}C. The observations are given in Appendix IV. Whereas in case of Robusta banana slices observations of air temperature on black polythene sheet varied from 39 to 51^{o}C and are given in Appendix V.

From Fig. 4.1 and Fig. 4.2 it can be seen that the moisture removal at the initial period of drying was higher in all treatments for both the varieties. It was observed that there was not much variation in the drying behaviour of banana slices with different pre treatment and without pre-treatment. However, the final moisture content of the samples was differed slightly (Fig.4.1). For Grand Naine variety the final moisture content of samples was recorded to be 15.63, 20.78, 16.72 and 20.70% (db) for the slices pretreated with blanching, potassium meta bisulphite, benzoic acid and control, respectively. This indicated that there was not much effect of different chemicals on drying behaviour of samples. Similarly, the time required to bring down the above mentioned levels of moisture contents were 240, 240, 240 and 210 min. respectively. The lesser time required of control samples suggests comparatively faster removal of moisture. This was due to the fact that there might have been some changes in the textural properties of the samples due to chemical treatment. Similar observations have been recorded for the slices prepared from Robusta variety of bananas except the final moisture content and corresponding drying time. The final moisture content obtained were 16.79, 17.13, 17.95 and 18.11% (db) and drying time was 420, 360, 360 and 360 min. for the samples treated with blanching, potassium meta bisulphite, benzoic acid and control, respectively.

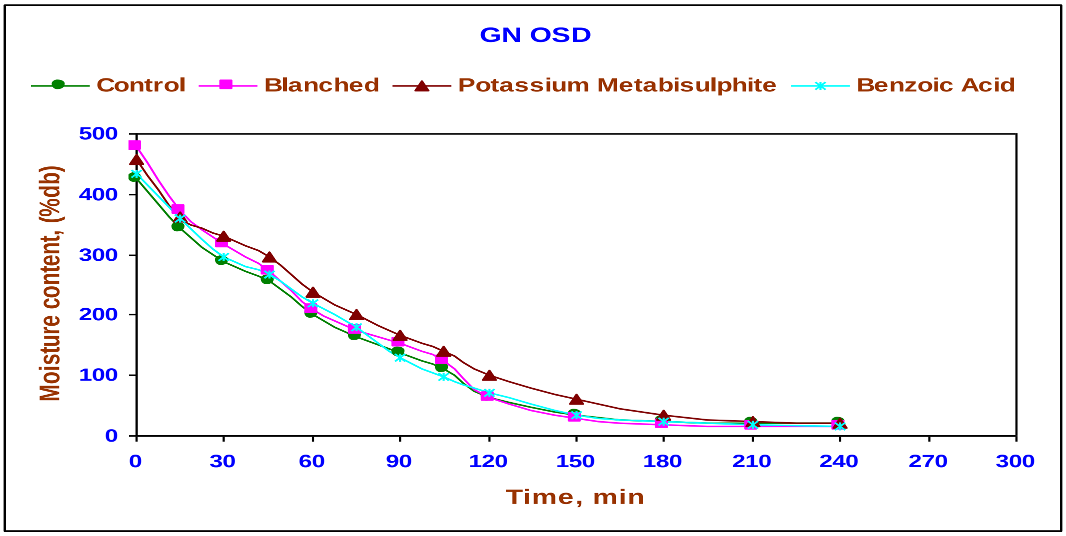

Fig 4.1 Drying characteristics of banana slices (Grand Naine) under sun drying for different pre-treatments

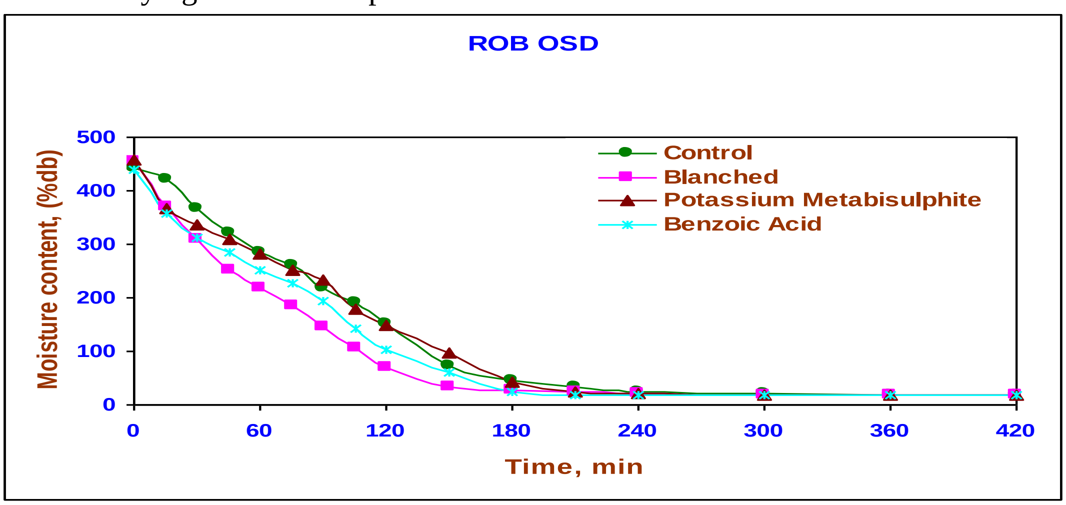

Fig 4.2 Drying characteristics of Robusta banana slices under sun drying at different pre-treatments

Another possible reason could be that the more availability of free moisture in blanched slices and due to the resistance offered by the surface of the slices, which were pretreated with preservatives like potassium meta bisulphate and benzoic acid. It was also observed that the benzoic acid treated Robusta samples take more time to attain a constant amount of moisture than other pre-treatments.

The changes of drying rate (g of water/100 g of dry matter/h) with drying time under different pre-treatments are shown in Fig. 4.3 and Fig. 4.4. It is evident from the Fig. 4.3 and Fig. 4.4 that the entire drying process followed the falling rate period of drying like all other biological materials, which is a natural phenomenon in these materials. Further, it can be seen that at the initial stages of drying, the rate of drying was higher which gradually reduced with the progress of drying time and at the final stages of drying the rate of drying was very much less compared to that of at initial stages. This was obvious, because at the onset of drying process the amount of moisture being high, higher moisture was available to evaporate per unit time. At later stages of drying, the diffusion of moisture from entire part of the slices and to the surface was limited which eventually caused the reduction in drying time.

Absence of constant rate period of drying suggests that there was no free water available on the surface of the slices.

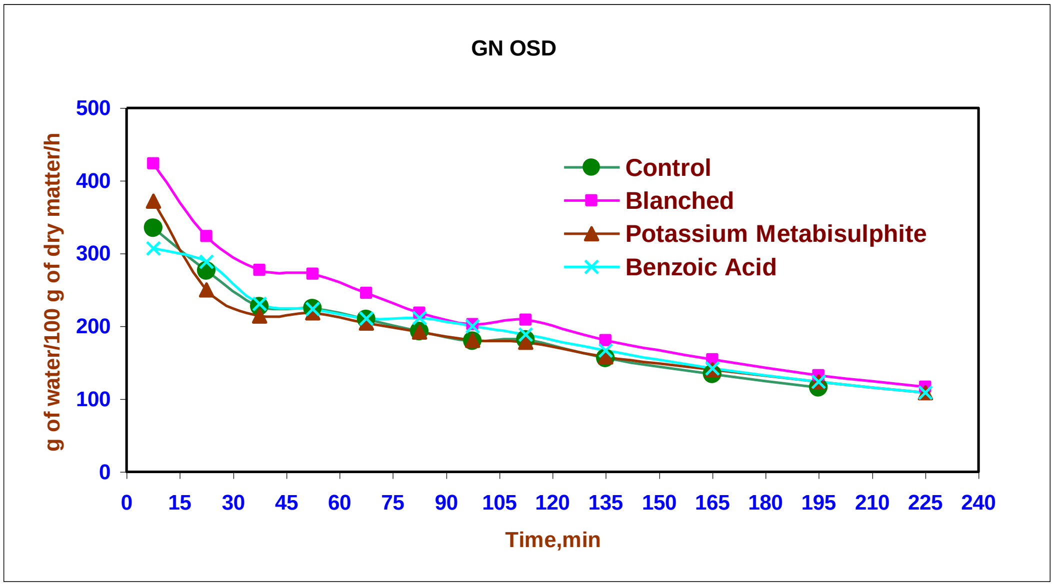

Fig. 4.3 Drying rate *versus* time curves for banana slices (Grand Naine) under sun drying for different pre-treatments

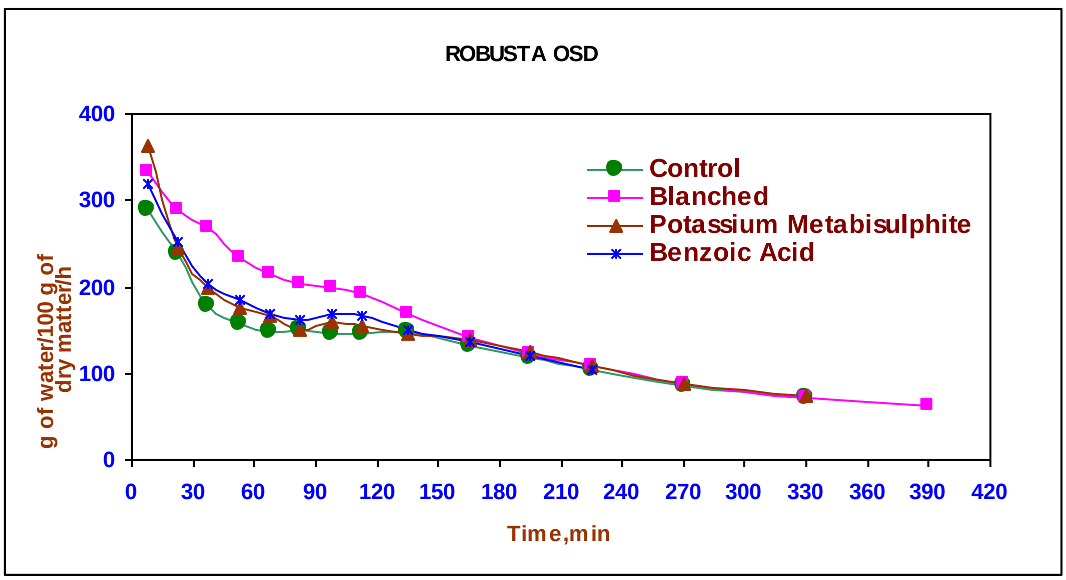

Fig. 4.4 Drying rate *versus* time curves for banana slices (Robusta) under sun drying for different pre-treatments

The relationship between drying rate and drying time for both the variety was found to be polynomial for all the samples (slices dried under different pre treatments). The equations and the corresponding R^2 (Coefficient of determination) for both the varieties are presented in Table 4.1.The value of R^2 was found to be less for slices treated with potassium meta bisulphite as compared to other treatments for both the varieties.

Table 4.1 Drying rate equations for sun dried Grand Naine and Robusta banana slices

S. No.	Variety	Pre-treatment	Drying rate equation	Coefficient of determination, R^2
1	Grand Naine	Control	$Y = 0.0047X^2 – 1.9817X +335.57$	0.9421
2		Blanching	$Y = 0.0057X^2 - 2.5293X + 412.24$	0.9367
3		Potassium Meta bisulphite	$Y = 0.0047X^2 - 2.001X + 336.6$	0.8471
4		Benzoic Acid	$Y = 0.0022X^2 - 1.3651X + 312.56$	0.9586
5	Robusta	Control	$Y = 0.0016X^2 - 1.039X + 248.65$	0.8035
6		Blanching	$Y = 0.0018 X^2 - 1.3565 X + 325.64$	0.98
7		Potassium Meta bisulphite	$Y = 0.0024 X^2 - 1.4103 X + 290.54$	0.7669
8		Benzoic Acid	$Y = 0.0045 X^2 - 1.8191 X + 303.21$	0.8593

where, Y=Drying rate, g of water/100 g of dry matter/h
X= Time, min

4.2.2 Solar tray drying

During the process of drying of Grand Naine banana slices, the air temperature on black polythene sheet was observed to vary from 39 to 55 ^oC and inside the cabinet it varied from 44 to 81^{o}C. The relative humidity of the ambient air and inside the chamber was measured to be 36 to 58 per cent and 34 to 57 per cent respectively. The observations made during the process of drying are given in Appendix VI. Whereas for the Robusta banana slices air temperature on black polythene sheet was observed to vary from 39 to 55^{o}C and inside the cabinet it varied from 42 to 75^{o}C. The relative humidity of the ambient air and inside the chamber was measured to be 37 to 57 percent and 34 to 60 per cent respectively. The observations made during the process of drying are given in Appendix VII.

From Fig.4.5 and 4.6, it can be seen that the moisture removal was higher at the initial period of drying in all treatments for both varieties. Not much variation was observed in the drying behaviour of slices with different pre-treatment and without pre-treatment. However, the final moisture content of the samples were differed slightly (Fig.4.5). For Grand Naine variety, the final moisture content of samples were recorded to be 10.95, 14.42, 13.87 and 16.96 per cent (db) for the slices pretreated with blanching, potassium meta bisulphite, benzoic acid and control respectively. This shows that there was not much of effect of different chemicals on drying behaviour of samples. Similarly, the time required to bring down the above mentioned level of moisture contents were 420, 420, 360 and 360 min respectively. It was observed that there was not much variation in the time required to attain constant moisture content by pretreated and control sample. Similar observations have been recorded for the slices prepared from Robusta variety of bananas except the final moisture content and corresponding drying time.

The final moisture content obtained were 14.00, 14.20,15.00 and 14.31 percent (db) and drying time was 360, 360, 420 and 360 min for the samples treated with blanching, potassium meta bisulphite, benzoic acid and control respectively.

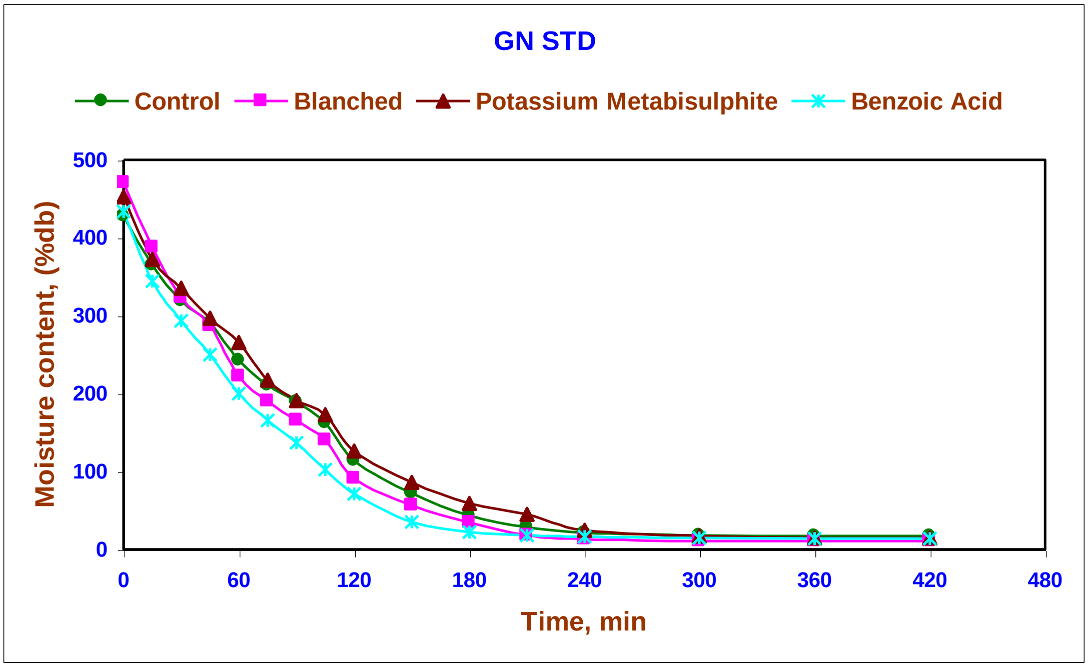

Fig. 4.5 Drying characteristics of banana slices (Grand Naine) under solar tray drying at different pre-treatments

Desai *et al*. (2002) recorded similar observations of temperature inside the multi rack solar dryer while drying of grape. Also the upper tray temperature was found comparatively high than lower and middle trays. This may be due to the fact that the air entered through the bottom air inlet and while moving from the bottom to top it goes on absorbing the heat from the collector. Devlet and Turhan (2003) also suggested the falling rate period during the air drying of ripe banana slices of 2-3 mm thickness.

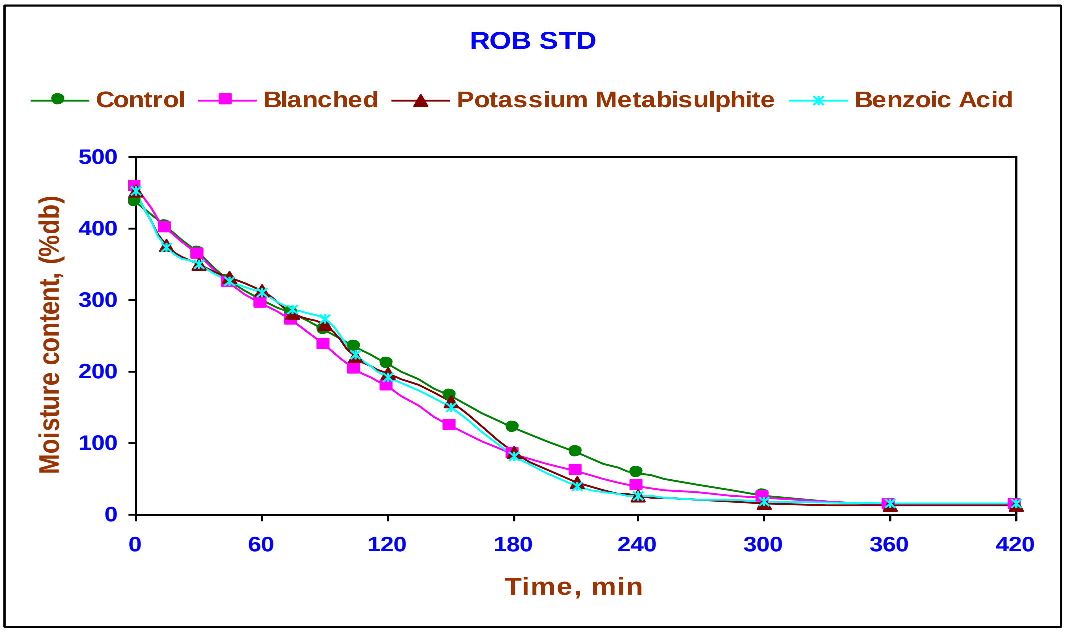

Fig.4.6 Drying characteristics of banana slices (Robusta) under solar tray drying at different pre-treatments

This may be probably because during the initial stages of drying, free moisture was available in the product, which evaporates at a faster rate, but in the later stages capillary moisture was available and took more time in evaporation from the product. It was also observed that the benzoic acid treated Robusta samples take more time to attain a constant amount of moisture than other pre-treatments.

Fig.4.7 and 4.8 shows the changes in drying rate (g of water/100 g of dry matter/h) with drying time under different pre-treatments.

These curves show clearly that the entire drying process followed the falling rate period of drying like all other biological materials. More over at the initial stages of drying, the drying rate was higher and gradually reduces with the drying process. This indicates that with progress of drying time availability of free moisture had reduced. Blanched banana slices show the higher drying rate compared to rest of the pre-treatments in both the varieties. However potassium meta bisulphite treated slices of Grand Naine variety and untreated slices of Robusta variety had the lowest drying rate compared with other pre-treatments. Slices without any pre-treatment and treated with benzoic acid were found to have drying rates between blanched and potassium meta bisulphite in case of Grand Naine variety. On the other hand, Slices treated with potassium meta bisulphite and benzoic acid were found to have drying rates in between blanched and untreated samples in case of Robusta variety.

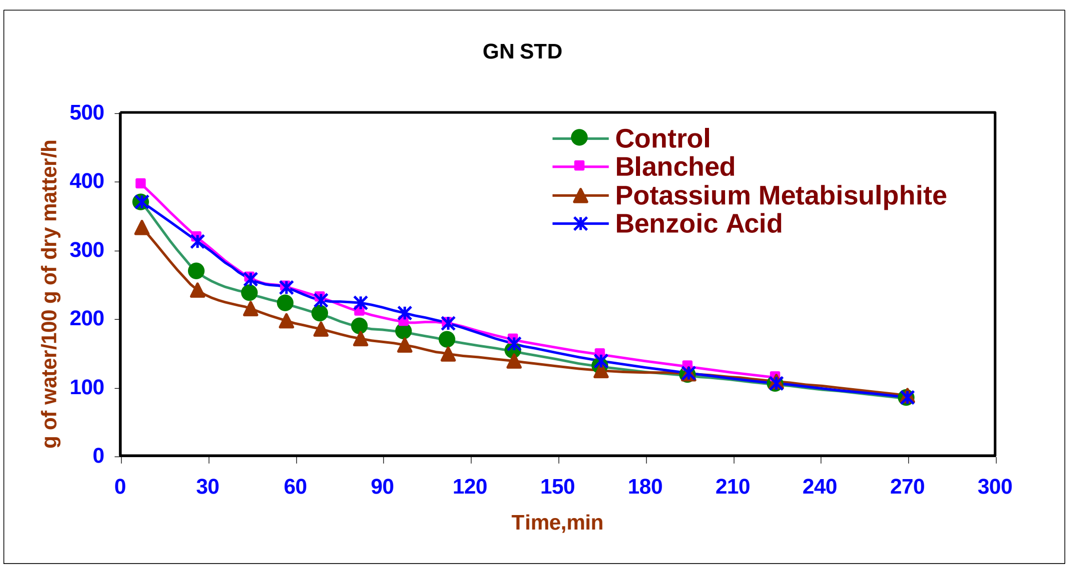

Fig. 4.7 Drying rate *versus* time curves for banana slices (Grand Naine) under solar drying at different pre-treatments

Sankat and Castaigne (1992) and Dandamrongrak *et al*. (2002) also observed falling rate period during drying of banana slices in case of untreated and osmotically treated samples.

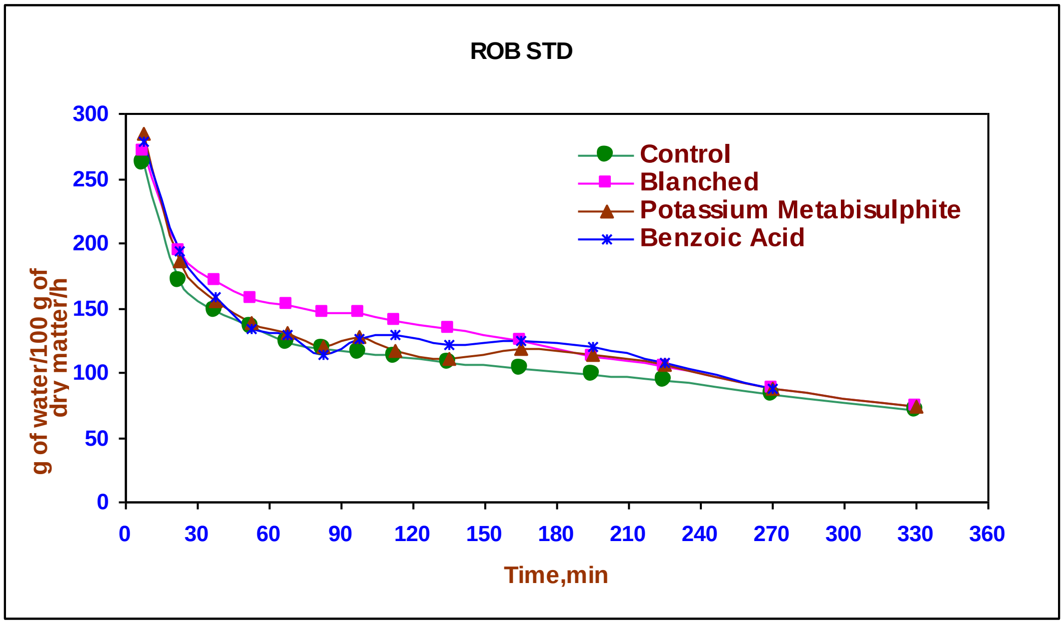

Fig. 4.8 Drying rate *versus* time curves for banana slices (Robusta) under solar tray drying at different pre-treatments

The relationship between drying time and drying rate was found to be polynomial for all the samples of both the varieties. High value of coefficient of determination, (0.91 to 0.97) observed in case of Grand Naine variety indicates that there exists a good relationship between dependent and independent variables. In case of Robusta variety the value of coefficient of determination, ranged between 0.66 to 0.83 and shows that there exists a fairly good relationship between dependent and independent variables. The values of R^2 with different pre-treatment for both the varieties are presented in Table 4.2.

Table 4.2 Drying rate equations for solar tray dried Grand Naine and Robusta banana slices

S. No.	Variety	Pre-treatment	Drying rate equation	Coefficient of determination, R^2
1	Grand Naine	Control	$Y = 0.0038X^2 - 1.9764X + 348.1$	0.9346
2		Blanching	$Y = 0.0061X^2 - 2.605X + 403.2$	0.9556
3		Potassium meta bisulphite	$Y = 0.0036X^2 - 1.7748X + 312.18$	0.9137
4		Benzoic Acid	$Y = 0.0034X^2 - 1.9438X + 371.39$	0.9722
5	Robusta	Control	$Y = 0.0018X^2 - 0.9917X + 209.92$	0.7398
6		Blanching	$Y = 0.0014 X^2 - 0.8936 X + 228.7$	0.8315
7		Potassium meta bisulphite	$Y = 0.0019 X^2 - 1.0249 X + 222.63$	0.6849
8		Benzoic Acid	$Y = 0.0028 X^2 - 1.2481 X + 231.78$	0.6627

where, Y=Drying rate, g of water/100 g of dry matter/h

X= Time, min

4.2.3 Indirect Solar Cabinet Drying

The drying characteristics of banana slices of two varieties namely Grand Naine and Robusta under indirect solar cabinet drying at different pre-treatments are shown in Fig. 4.9 and 4.10. The observations collected under this method of drying are presented in Appendix VIII and Appendix IX.

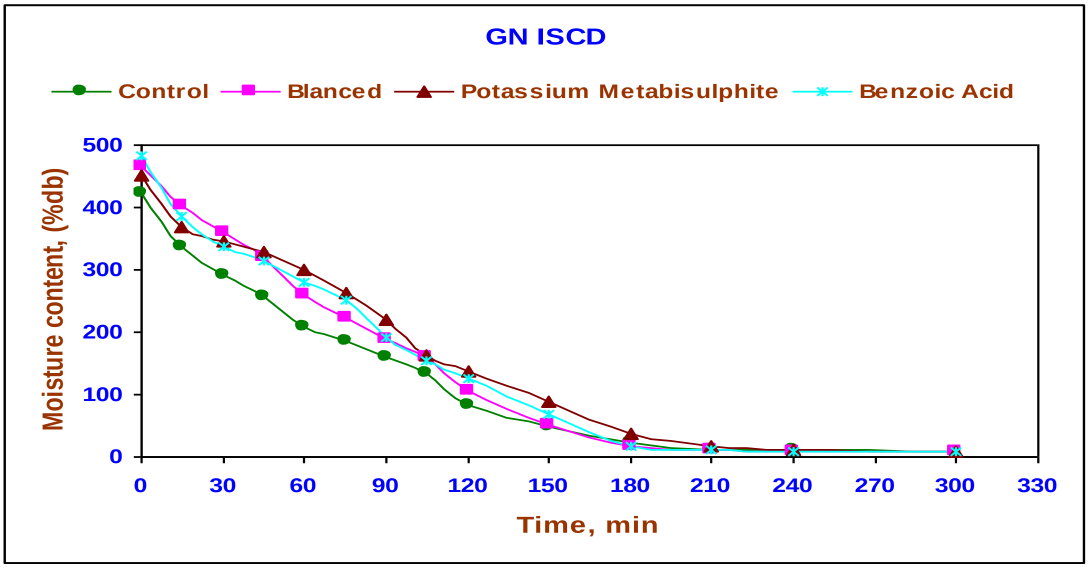

Fig. 4.9 Drying characteristics of Grand Naine banana slices under indirect solar cabinet drying at different pre-treatments

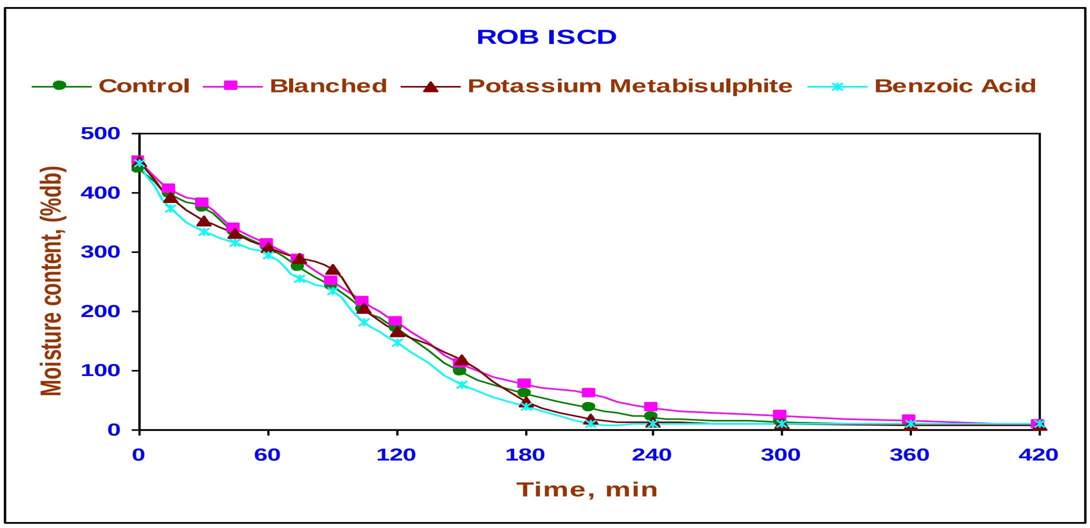

Fig. 4.10 Drying characteristics of banana slices (Robusta) under indirect solar cabinet drying at different pre-treatments

From Fig. 4.9 and Fig. 4.10 it can be seen that initially the moisture removal was higher in all treatments for both varieties. It was observed that control sample of Grand Naine variety banana shows rapid decrease in moisture content than the other pre-treatments in initial drying duration but final moisture content is more than other pretreated samples. Blanched slices shows uniform reduction in moisture content and final moisture content was found as 7.54 per cent (db). Corresponding values of final moisture content was observed as 9.20 and 8.94 per cent (db) for potassium meta bisulphite and benzoic acid treated samples. Similar observations were recorded for the slices prepared from Robusta variety of banana except the final moisture content and corresponding drying time. The final moisture content obtained were 8.65, 9.00, 9.36 and 9.17 per cent (db) and drying time was 420, 360, 300 and 420 min for the samples treated with blanching, potassium meta bisulphite, benzoic acid and control respectively. The higher rate of moisture evaporation was attributed to the more amount of moisture present in blanched samples.

The relationship between drying rate (g of water/100 g of dry matter/h) and drying time for indirect solar cabinet drying for both the varieties with different pre-treatments has been developed and is presented in Fig. 4.11 and 4.12. It is evident from the graph that in first one hour maximum drying rate was found. In general drying rate decreased as the drying duration progressed showing an inverse proportion between the drying rate and the drying time. The absence of constant rate period of drying suggests that there was no free water available on the surface of the slices. The drying rate was found higher value for potassium meta bisulphite treated banana slices and minimum for the slices which were pretreated with 1000 ppm of benzoic acid in case of Grand Naine variety. Whereas in case of Robusta variety, the drying rate was observed comparatively high for benzoic acid treated banana slices and was found minimum for the untreated slices.

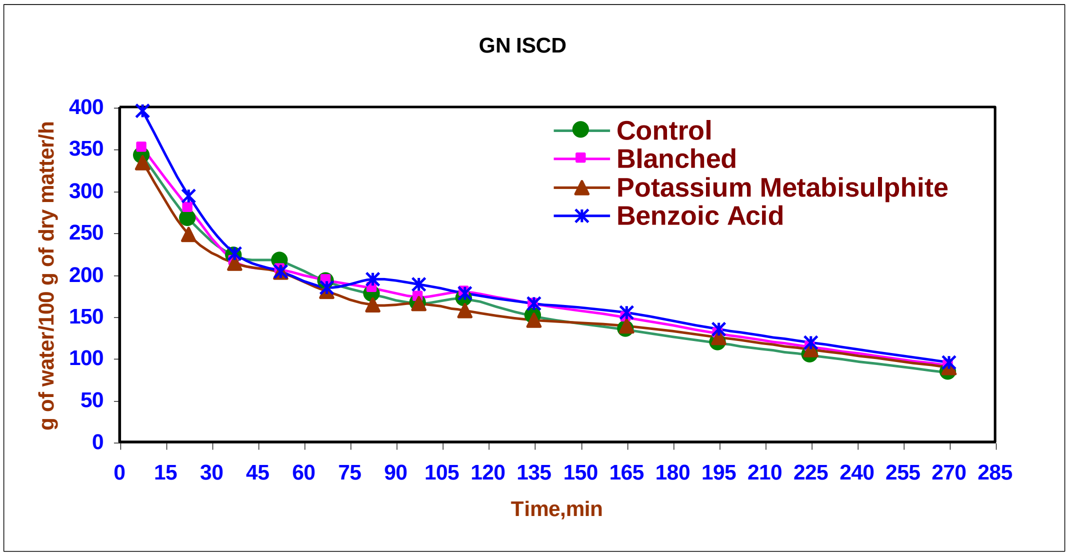

Fig. 4.11 Drying rate *versus* time curves for Grand Naine banana slices under indirect solar cabinet at different pre-treatments

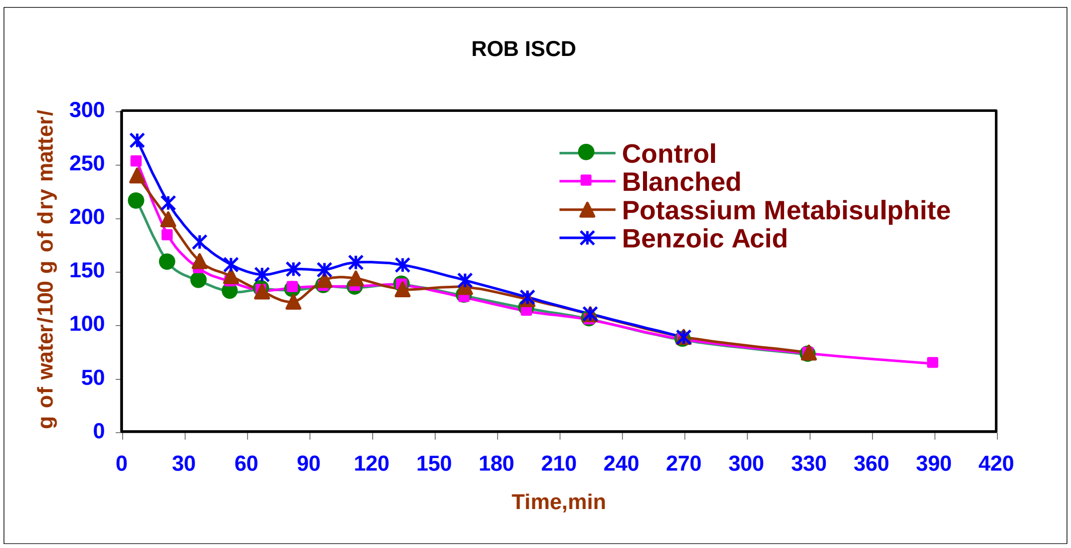

Fig. 4.12 Drying rate *versus* time curves for banana slices (Robusta) under indirect solar cabinet drying at different pre-treatments

The equations showing relationship between drying rate and drying time for slices of both varieties dried under different pre treatments are presented in Table 4.3.

Table 4.3 Drying rate equations for indirect solar cabinet dried banana slices (Grand Naine and Robusta)

S. No.		**Pre-treatment**	**Drying rate equation**	**Coefficient of determination, R^2**
1	Grand Naine	Control	$Y = 0.0032 X^2 - 1.677X + 317.63$	0.9173
2		Blanching	$Y = 0.003 X^2 - 1.598 X + 318.09$	0.8669
3		Potassium metabisulphite	$Y = 0.0031 X^2 - 1.5877 X + 301.77$	0.8774
4		Benzoic Acid	$Y = 0.0038 X^2 - 1.8903 X + 344.66$	0.8152
5	Robusta	Control	$Y = 0.0003X^2 - 0.3936X + 175.54$	0.748
6		Blanching	$Y = 0.0008 X^2 - 0.6272 X + 201.09$	0.779
7		Potassium metabisulphite	$Y = 0.0009 X^2 - 0.6439 X + 203.27$	0.7383
8		Benzoic Acid	$Y = 0.0016 X^2 - 0.9061 X + 235.46$	0.7513

where, Y=Drying rate, g of water/100 g of dry matter/h

X= Time, min

4.2.4 Hot air oven drying

Banana slices of both the varieties with different pre-treatments were dried in hot air oven at three different temperature levels viz. 65 ^{o}C, 55 ^{o}C and 45 ^{o}C. For ease of better description here parts were made for each temperature level.

4.2.4.1 At temperature level of 65 ^{O}C

The drying characteristics of banana slices of both the varieties under hot air drying at 65^{o}C for different pre-treatments are shown in Fig. 4.13 and Fig. 4.14.

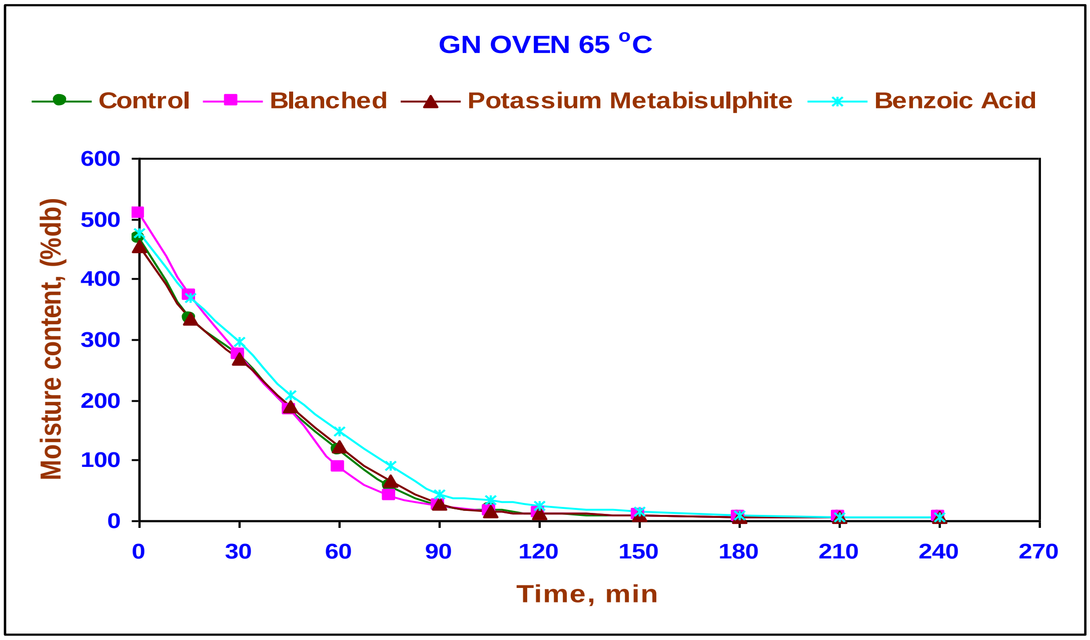

Fig. 4.13 Drying characteristics of Grand Naine banana slices dried in hot air oven at 65°C for different pre-treatments

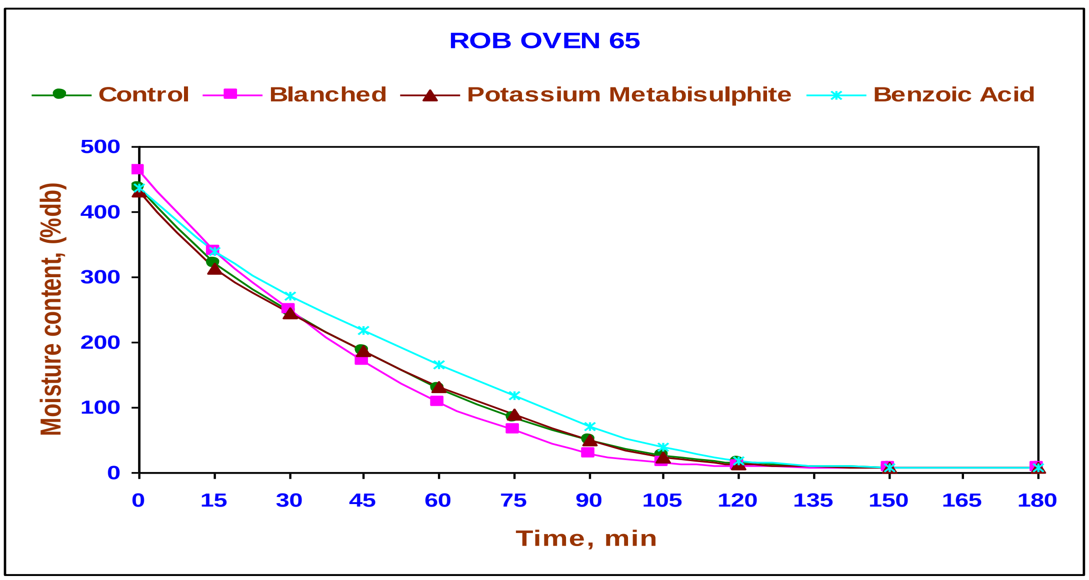

Fig. 4.14 Drying characteristics of banana slices (Robusta) under hot air oven at 65 °C for different pre-treatments

From Fig. 4.13 and Fig. 4.14 it can be seen that the amount of moisture removal at the initial period of drying was very high in all treatments. More than 80 per cent moisture loss was observed in first 75 min. The probable reason for this may be constant high temperature level through out the drying process. All the samples show rapid decrease in moisture content at initial stage of drying. In case of Grand Naine variety the final moisture content was observed as 5.48, 6.11, 6.14 and 6.23 per cent (db) in 210, 210, 240 and 180 min for blanched, potassium meta bisulphite, benzoic acid treated and control samples respectively. On the other hand for Robusta variety the corresponding values were found to be 6.57, 7.10,7.15 and 7.68 per cent (db) for blanched, potassium meta bisulphite, benzoic acid treated and control samples in 150 min of drying. This reduced drying time may be due to high and constant temperature.

For the same temperature level, the relationship between drying rate (g of water/100 g of dry matter/h) and drying time for different pre-treatments in hot air oven was plotted for both the varieties and presented in Fig. 4.15 and Fig. 4.16. From the figures it can be clear that in initial drying time maximum drying rate was found and inverse proportion between the drying rate and the drying time was observed as drying rate decreased with the drying time. The absence of constant rate period suggests that there was no free water available on the surface of the slices. The drying rate was found to be high for blanched banana slices and was found to be minimum for the slices, which were pretreated with 1000 ppm of benzoic acid for both the varieties. The probable reason for this may be availability of more free water in blanched slices and may be resistance offered by chemical treatment in benzoic acid treated sample.

Devlet and Turhan (2003) observed similar increase in drying rate as drying temperature increases up to 60 ^{o}C and decreased at 70 ^{o}C.

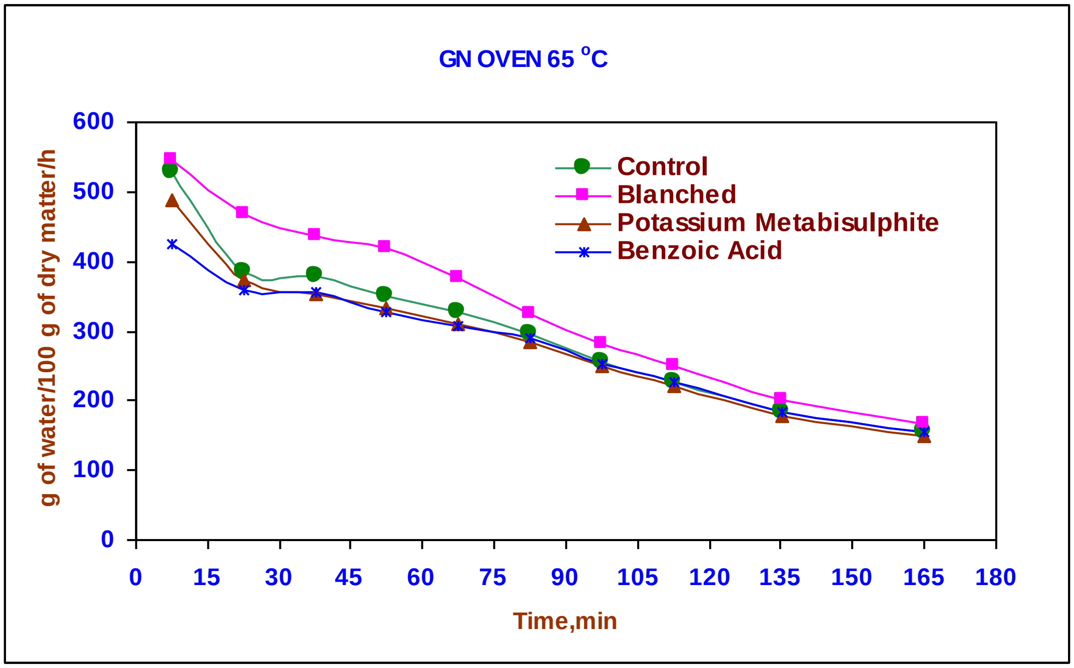

Fig. 4.15 Drying rate *versus* time curves for Grand Naine banana slices dried in hot air oven at 65 °C for different pre-treatments

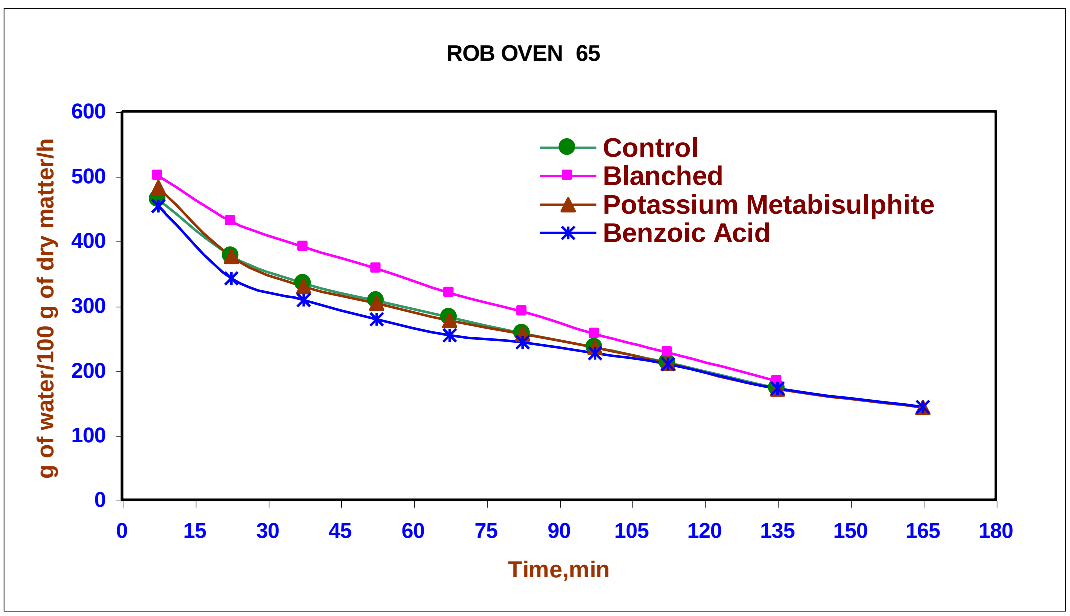

Fig. 4.16 Drying rate *versus* time curves for banana slices (Robusta) for different pre-treatments in case of hot air oven at 65 °C

Relationships between drying rate and drying time for slices of both varieties with different pre treatments have been developed and corresponding equations presented in Table 4.4. The value of R^2 was found very high for all the pre-treatments especially for blanched samples.

Table 4.4 Drying rate equations for hot air oven (65°C) dried banana slices (Grand Naine and Robusta)

S. No.	Variety	Pre-treatment	Drying rate equation	Coefficient of determination, R^2
1	Grand Naine	Control	$Y = 0.0078X^2 - 3.4941X + 533.95$	0.9513
2		Blanching	$Y = 0.0063 X^2 - 3.5015X + 587.67$	0.990
3		Potassium metabisulphite	$Y = 0.0065 X^2 - 3.0748X + 496.86$	0.9622
4		Benzoic Acid	$Y = 0.0024 X^2 - 2.0425X + 442.05$	0.9836
5	Robusta	Control	$Y = 0.0104X^2 - 3.6578X + 494.4$	0.9793
6		Blanching	$Y = 0.0081 X^2 - 3.5802 X + 541.4$	0.9961
7		Potassium metabisulphite	$Y = 0.0096 X^2 - 3.661 X + 499.63$	0.9666
8		Benzoic Acid	$Y = 0.0091 X^2 - 3.3327 X + 461.08$	0.9452

where, Y=Drying rate, g of water/100 g of dry matter/h

X= Time, min

4.2.4.2 At temperature level of 55 ^{O}C

The drying characteristics of banana slices for both the varieties under hot air drying at 55^{o}C for different pre-treatments are shown in Fig. 4.17 and Fig.4.18.

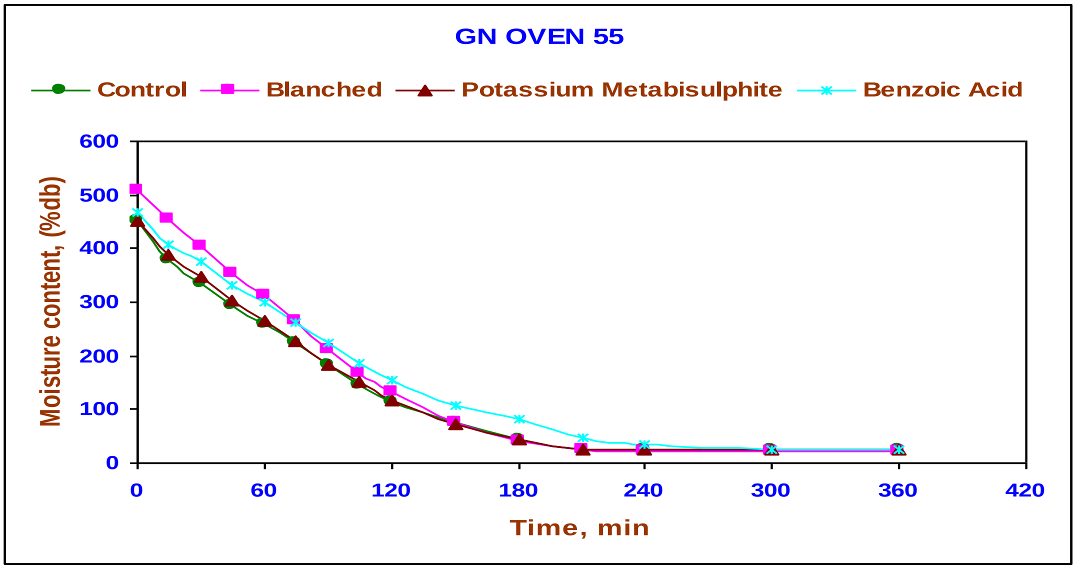

Fig. 4.17 Drying characteristics of banana slices (Grand Naine) under hot air oven at 55 ^{o}C for different pre-treatments

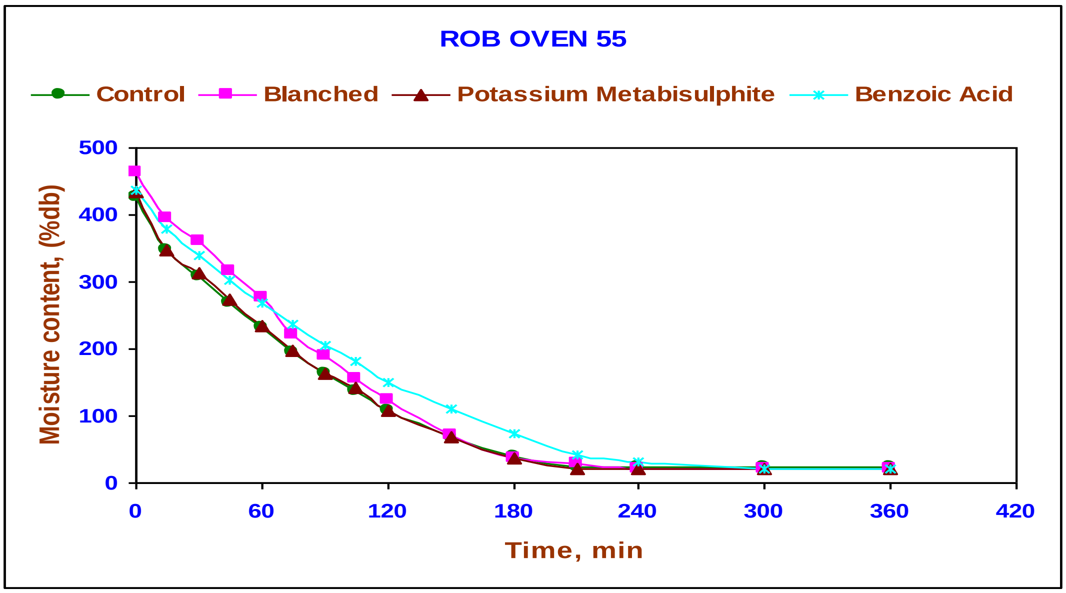

Fig 4.18 Drying characteristics of banana slices (Robusta) under hot air oven at 55 ^{o}C for different pre-treatments

The figures show that at initial stage of drying the rate of moisture removal was faster for all the samples. More than 80 per cent moisture loss takes place in first 2 hrs. The probable reason for this fact may be constant high temperature level. The final moisture content values were recorded as 21.69, 24.26, 24.90 and 24.95 for blanched, potassium meta bisulphate, benzoic acid treated and control samples of Grand Naine variety respectively and the corresponding time to attain the constant final moisture content level was recorded as 240, 300, 300 and 300 min for all the samples. This reduction in drying time was attributed to the more availability of free water in blanched samples. Similar observations have been recorded in case of Robusta variety except the final moisture content and drying time. The final moisture content values were recorded as 20.49, 21.38, 22.00 and 22.77 for blanched, potassium meta bisulphite treated, benzoic acid treated samples and control slices respectively and the corresponding time duration was recorded as 240, 210, 300 and 210 min.

The graphs showing the relationship between drying rate (g of water/100 g of dry matter/h) and drying time (min) was drawn (Fig. 4.19 and Fig. 4.20) and the equations were developed. The values of coefficient of determination are given in Table 4.5.

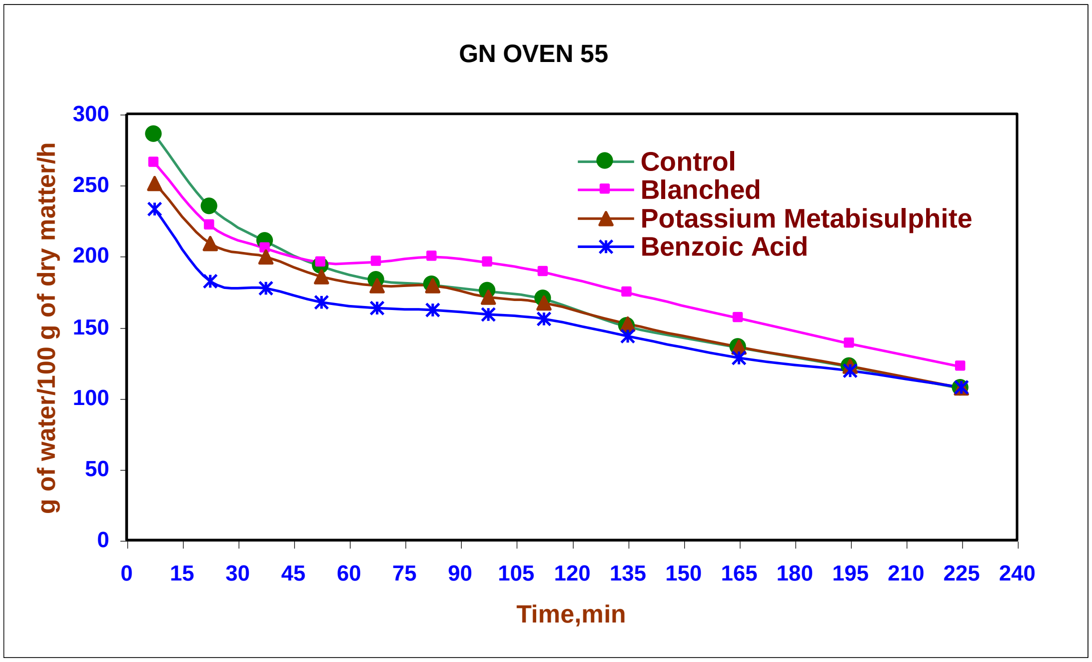

Fig. 4.19 Drying rate *versus* time curves for Grand Naine banana slices under hot air oven at 55 ^{o}C for different pre-treatments

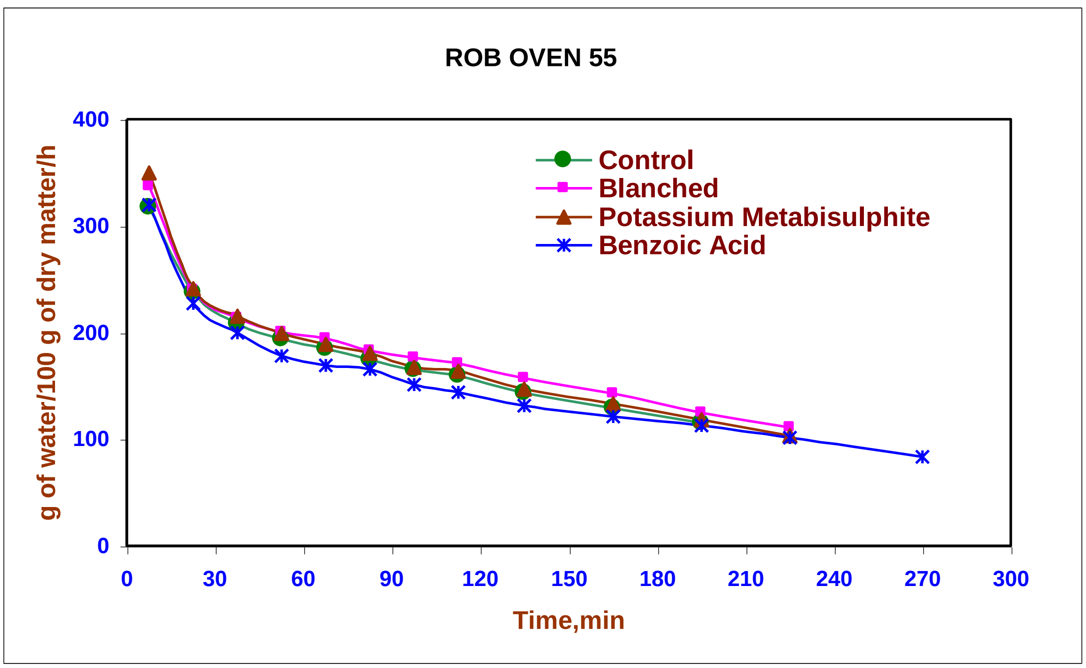

Fig. 4.20 Drying rate *versus* time curves for banana slices (Robusta) for different pre-treatments in case of hot air oven drying at 55 ^{o}C

The changes in drying rate (g of water/100 g of dry matter/h) with drying time under different pre-treatments are shown in Fig.4.19 and Fig.4.20. It is evident from these figures that the entire drying process followed the falling rate period of drying like all other biological materials. Further it can be seen that at the initial stages of drying the rate of drying was higher and gradually decreases with the progress of drying. The drying rate was found higher for blanched banana slices and lower for the slices, which were pretreated with 1000 ppm of benzoic acid irrespective of the variety. The probable reason for this may be availability of more free moisture in case of blanched slices and may be due to surface resistance of benzoic acid treated samples due to chemical treatment. Absence of constant rate period of drying suggests that there was no free water available on the surface of the slices.

Dandamrongrak *et al.* (2002) connected the trend of higher drying rate in blanched samples to the probable cell rapture having starch granules moving into the intercellular voids. Mowlah *et al.* (1983) also observed increase in drying rate of steam blanched bananas dried at 60 ^{o}C.

The values of R^2 for the relationship between drying rate and drying time for the Grand Naine and Robusta varieties was found very high ranges from 0.86 to 0.98.

Table 4.5 Drying rate equations for hot air oven (55^{o}C) dried banana slices (Grand Naine and Robusta varieties)

S. No.	Variety	Pre-treatment	Drying rate equation	Coefficient of determination, R^2
1	Grand Naine	Control	$Y = 0.0026X^2 - 1.2904X + 276.88$	0.9362
2		Blanching	$Y = -0.0014 X^2 - 0.0242X + 209.5$	0.9855
3		Potassium metabisulphite	$Y = 0.0012 X^2 - 0.8203X + 241.77$	0.9435
4		Benzoic Acid	$Y = 0.0012 X^2 - 0.7227X + 217.38$	0.8883
5	Robusta	Control	$Y = 0.0054x^2 - 2.0061X + 309.83$	0.9092
6		Blanching	Y = 0.0041x2 - 1.7453X + 311.12	0.8669
7		Potassium metabisulphite	Y = 0.0048x2 - 2.0077X + 323.23	0.8749
8		Benzoic Acid	Y = 0.0032x2 - 1.5654X + 285.65	0.8737

where, Y=Drying rate, g of water/100 g of dry matter/h

X= Time, min

4.2.4.3 At temperature level of 45 ^{O}C

Fig. 4.21 and Fig. 4.22 shows the drying characteristics of Grand Naine and Robusta banana slices treated with different pre-treatments, dried at 45^{o}C in hot air oven. This temperature level was lowest in all the experimental trials and corresponding results are presented here.

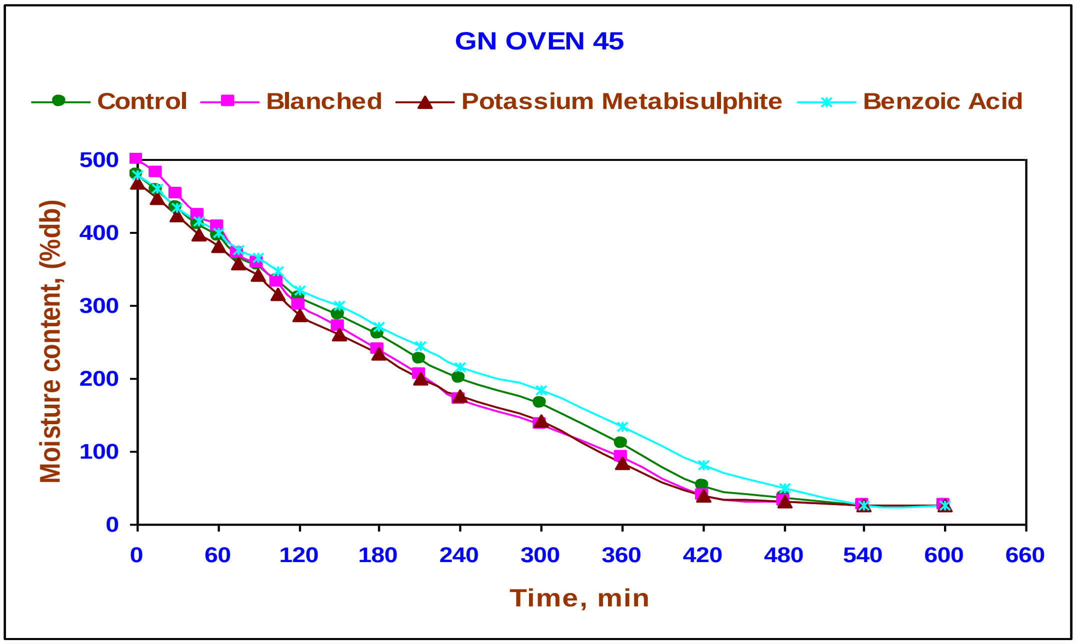

Fig. 4.21 Drying characteristics of Grand Naine banana slices dried in hot air oven at 45 ^oC for different pre-treatments

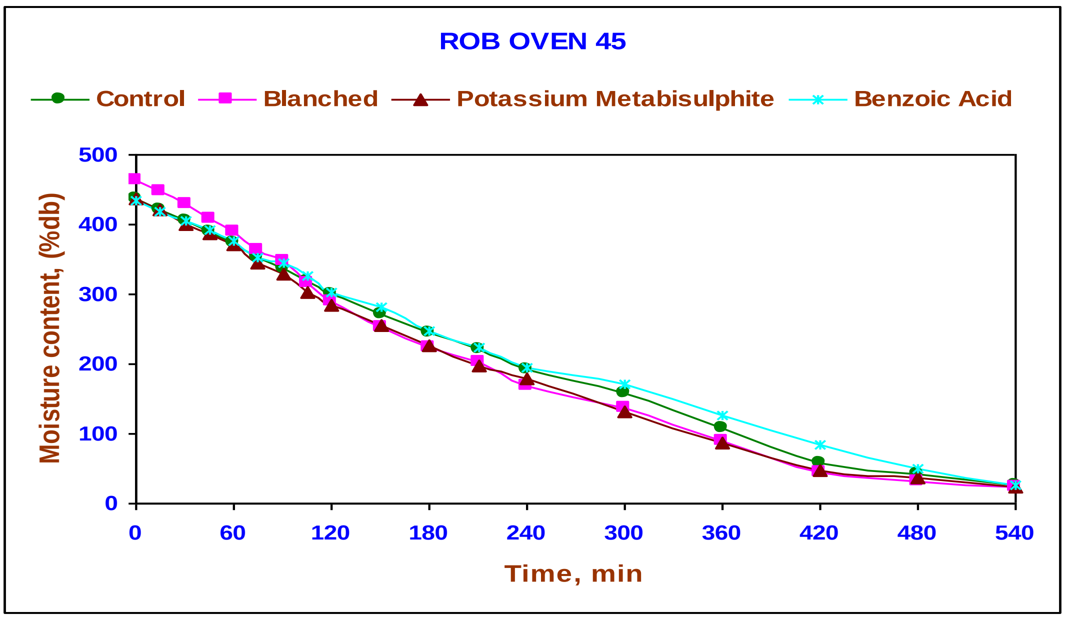

Fig. 4.22 Drying characteristics of banana slices (Robusta) under hot air oven at 45 ^oC for different pre-treatments

From the Fig. 4.21 and Fig. 4.22, it can be seen that for complete process of drying of banana slices requirement of long time duration was observed for all the pre-treatments. Unlike to the temperature level of 65^{o}C and 55^{o}C, there was no observation of rapid decrease in moisture content in initial drying time. For 45^{o}C temperature level the drying time was found to be 10 hrs for Grand Naine variety and 11 hour for Robusta variety and it is considered much higher as compared to another two temperature levels for hot air oven drying. A continuous and slow decrease in moisture content was observed and the drying time was found near to 8 and 9 hours to attain a nearby constant curve for Grand Naine and Robusta banana slices respectively. Though in all the samples slow moisture reduction was found, blanched slices show comparatively rapid decrease in moisture content than other pretreated and control samples in both the varieties. The final moisture content for blanched, potassium meta bisulphite, benzoic acid treated sand control samples was observed as 25.04, 25.75, 25.04 and 25.24 per cent (db) respectively for Grand Naine variety and 24.20, 24.52, 25.13 and 25.76 per cent (db) respectively for Robusta variety slices. Though satisfactory moisture content reached at the end of process but drying duration was more as the whole process takes as long as 10 hrs. This increased drying duration was probably attributed to the lower temperature level maintained inside a chamber throughout the drying process due to which slow moisture evaporation rate was occurred.

For the same temperature level, a graph was plotted between the drying rate (g of water/100 g of dry matter/h) and drying time for both the varieties for different pre-treatments and presented in Fig. 4.23 and Fig.4.24. It can be seen from these plots that amount of moisture evaporated per unit time was very less probably due to the selected lower temperature level. At the initial drying stage comparatively higher amount of moisture loss was observed. Like other case an inverse proportion between the drying rate and the drying time was observed, but the decrease in drying rate was slow as the drying process in progress. The drying rate was found to be comparatively high for blanched banana slices and was found to be minimum for the slices that were pretreated with 1000 ppm of benzoic acid in case of both the banana varieties. The probable reason for this may be the higher amount of moisture available in blanched slices.

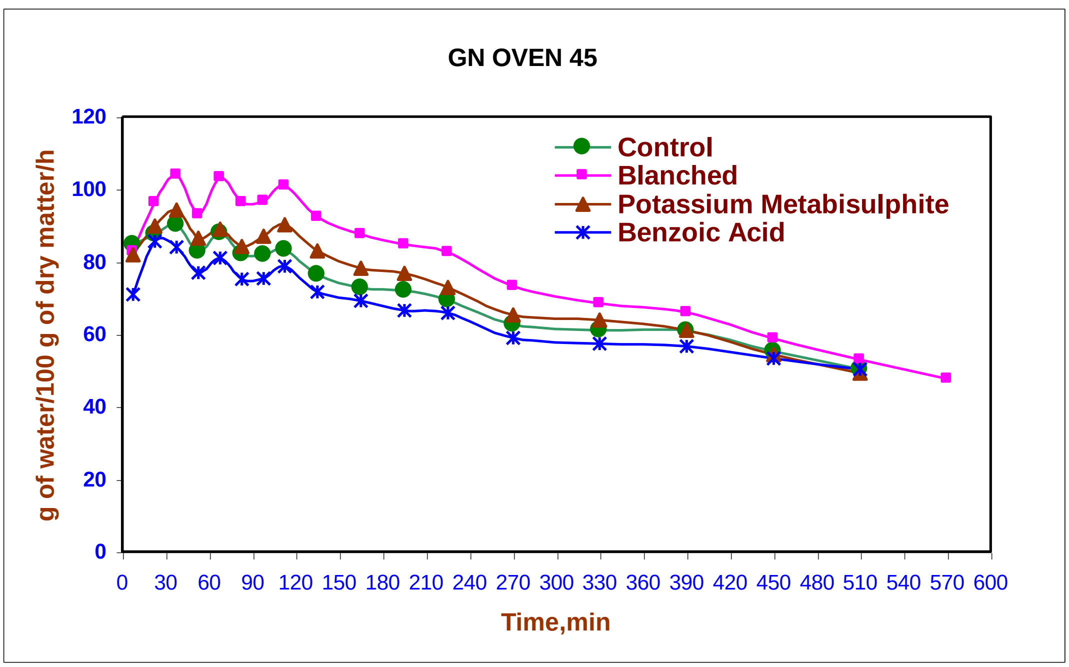

Fig.4.23 Drying rate *versus* time curves for all pretreated Grand Naine banana slices dried at 45 °C in hot air oven

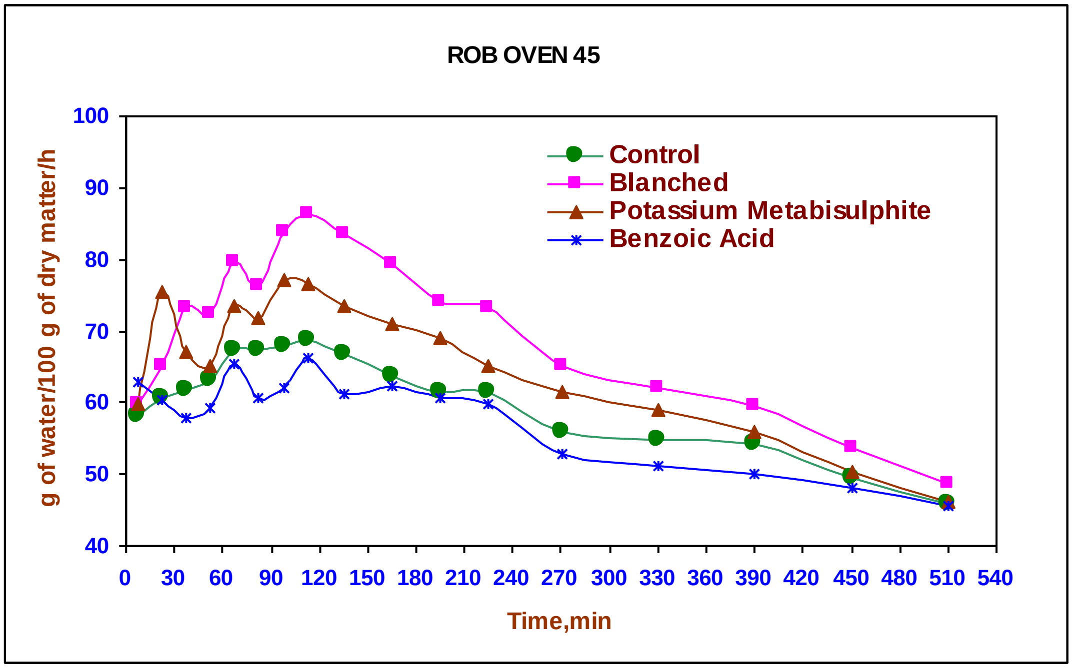

Fig.4.24 Drying rate *versus* time curves for banana slices (Robusta) in case of hot air oven at 45 °C for different pre-treatments

The decreasing drying rate in the banana slices since the very beginning of the process at a constant temperature indicated that the resistance controls the drying as pointed by others (Dandamrongrak et al. 2002, Queiroz and Nebra, 2001and Sankat et al. 1996).

Relationship between drying rate and drying time for all pretreated slices for both the varieties were developed in the form of equations and are presented in Table 4.6. The value of R^2 was found to be high for control samples viz. 0.96 followed by blanched samples i.e. 0.90 in case of Grand Naine variety and maximum for benzoic acid treated samples (0.83) and minimum for blanched samples (0.71) in case of Robusta banana slices.

Table 4.6 Drying rate equations for hot air oven (45°C) dried banana slices

S. No.	Variety	Pre-treatment	Drying rate equation	Coefficient of determination, R^2
1	Grand Naine	Control	$Y = 5E\text{-}05X^2 - 0.0975X + 90.802$	0.961
2		Blanching	$Y = -7E\text{-}05\ X^2 - 0.0501\ X + 99.43$	0.9007
3		Potassium Metabisulphite	$Y = -3E\text{-}05\ X^2 - 0.0621\ X + 91.571$	0.933
4		Benzoic Acid	$Y = 4E\text{-}05\ X^2 - 0.0807\ X + 83.107$	0.8833
5	Robusta	Control	$Y = -0.0001X^2 + 0.0265X + 62.655$	0.8131
6		Blanching	$Y = -0.0003\ X^2 + 0.0884X + 69.243$	0.7166
7		Potassium Metabisulphite	$Y = -0.0002\ X^2 + 0.0348X + 68.752$	0.7829
8		Benzoic Acid	$Y = -7E\text{-}05\ X^2 + 0.0023X + 61.955$	0.835

where, Y=Drying rate, g of water/100 g of dry matter/h

X= Time, min

4.4 Comparison of different drying methods

The comparative drying behaviour of banana slices of both the varieties under sun drying, solar tray drying, indirect solar cabinet drying and hot air oven drying is shown in Figs. 4.25 to 4.28. Two representative pre-treatments for each variety were selected for this comparison.

Fig. 4.25 shows the comparative performance of all the four drying methods used to dry Grand Naine banana slices treated with benzoic acid. It is very clear from this figure that hot air oven drying at 65°C shows high values of drying rate in entire drying period compared to rest of the drying methods. The performance of solar tray drying was observed next to oven drying at 65°C whereas the sun drying recorded lowest drying rate.

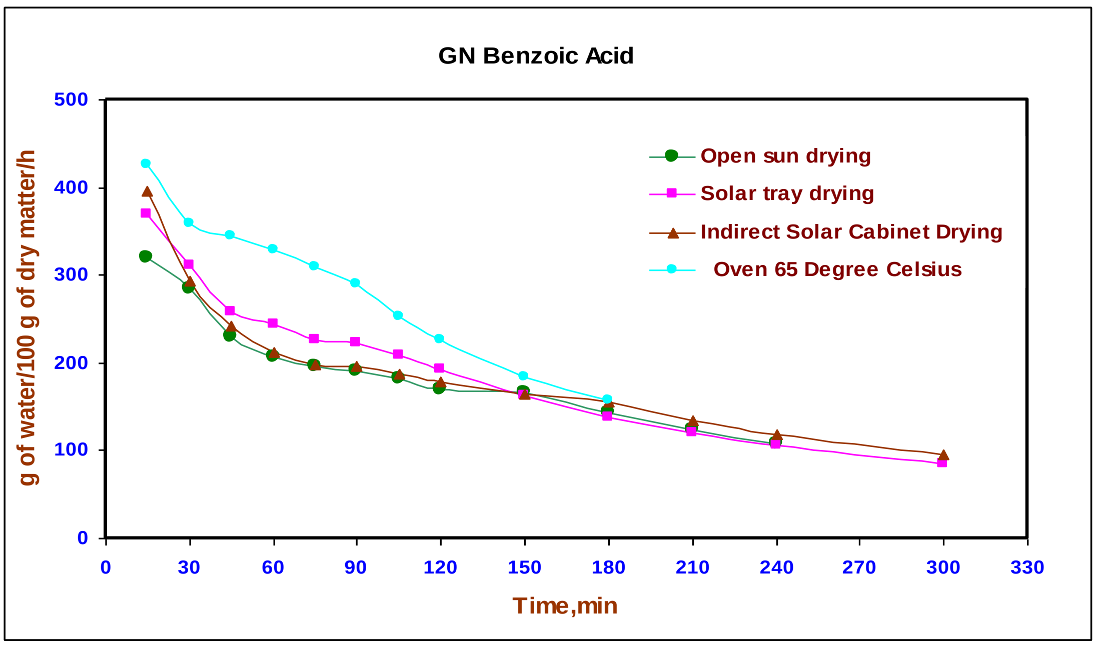

Fig. 4.25 Comparison of different drying methods for the drying of Grand Naine banana slices treated with benzoic acid

The probable reason for this variation in drying rate values for different drying methods may be the constant high temperature inside the hot air oven, varying high air temperature in solar tray dryer and indirect solar cabinet dryer and comparatively lower air temperature for open sun drying.

Similarly Fig. 4.26 shows the comparative performance of all the four drying methods applied to dry potassium meta bisulphite treated Grand Naine banana slices. It is evident from this figure that hot air oven drying at 65°C shows high values of drying rate throughout the drying period and drying process terminated within 3 hrs. The cause for this reduction in drying time may be due to constant high temperature inside the oven. The solar tray drying and indirect solar cabinet drying methods have shown the negligible variation in drying rate, however the drying rate for sun drying was found lowest for initial two hours. This may be due to lower temperature for morning two hours in case of open sun drying process.

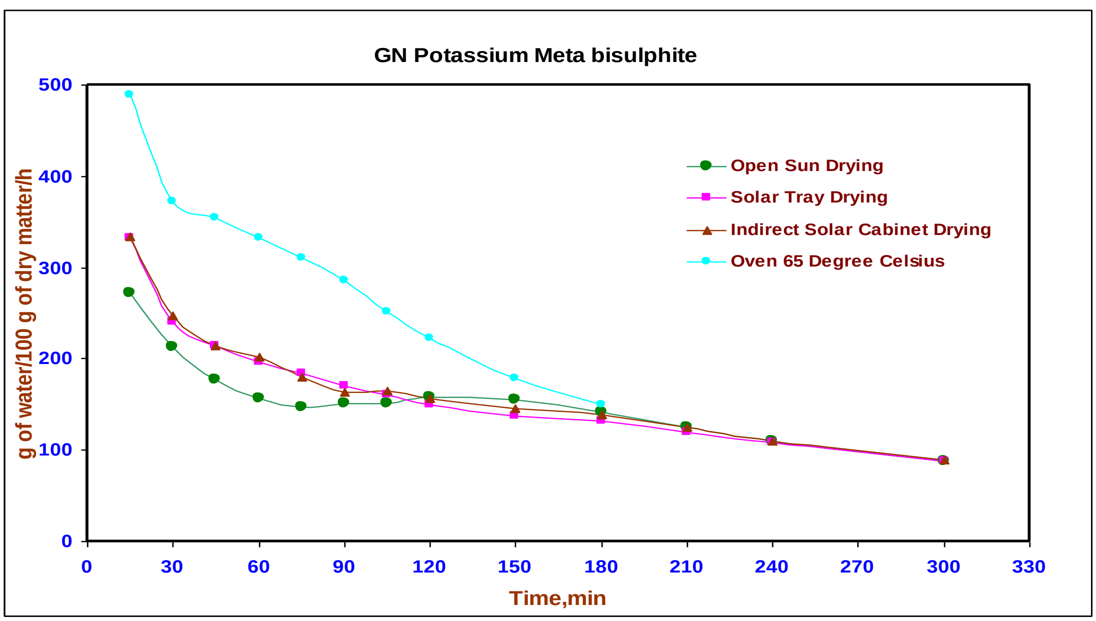

Fig. 4.26 Comparison of different drying methods for the drying of Grand Naine banana slices treated with potassium meta bisulphite.

In the same manner, the comparative performance of all the four drying methods applied to dry untreated (control) Robusta banana slices is presented in Fig. 4.27.

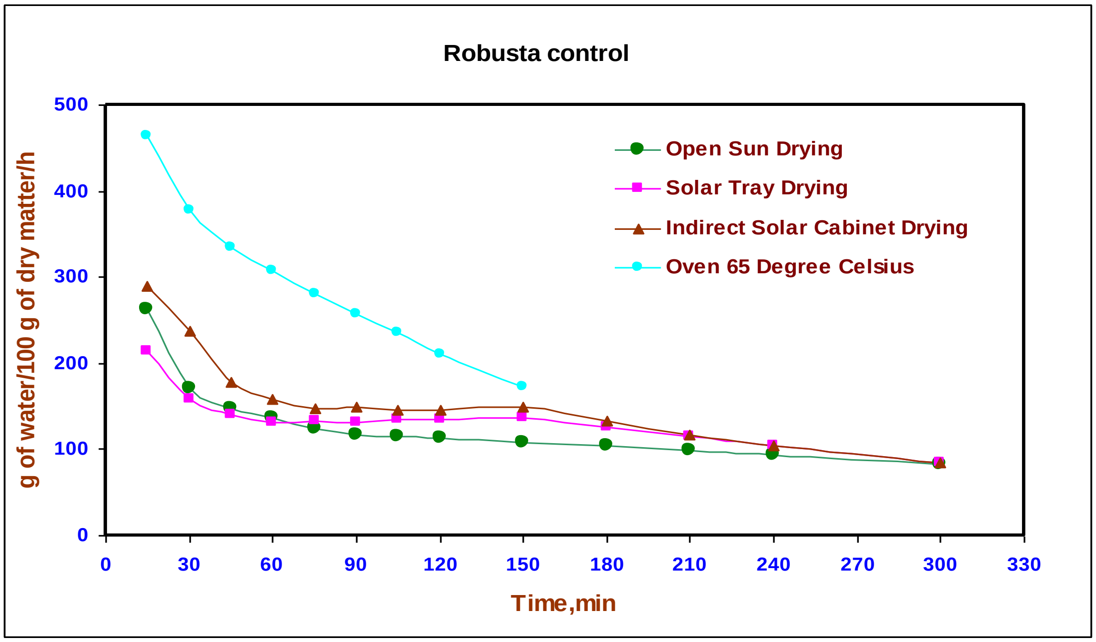

Fig. 4.27 Comparison of different drying methods for the drying of Grand Naine banana slices treated with potassium meta bisulphite

The plot illustrate the fact that hot air oven drying at 65^{o}C shows high values of drying rate in entire drying period and drying process was terminated in 150 minutes only. The strong reason for this reduced time was may be due to high and constant air temperature in hot air oven chamber. For the same sample, indirect solar cabinet drying shows comparatively high drying rate than the solar tray drying. However sun drying method shows comparatively lower drying rate values in all the four drying methods.

To dry blanched Robusta banana slices, the comparative performance of all the four drying methods is shown in Fig.4.28.

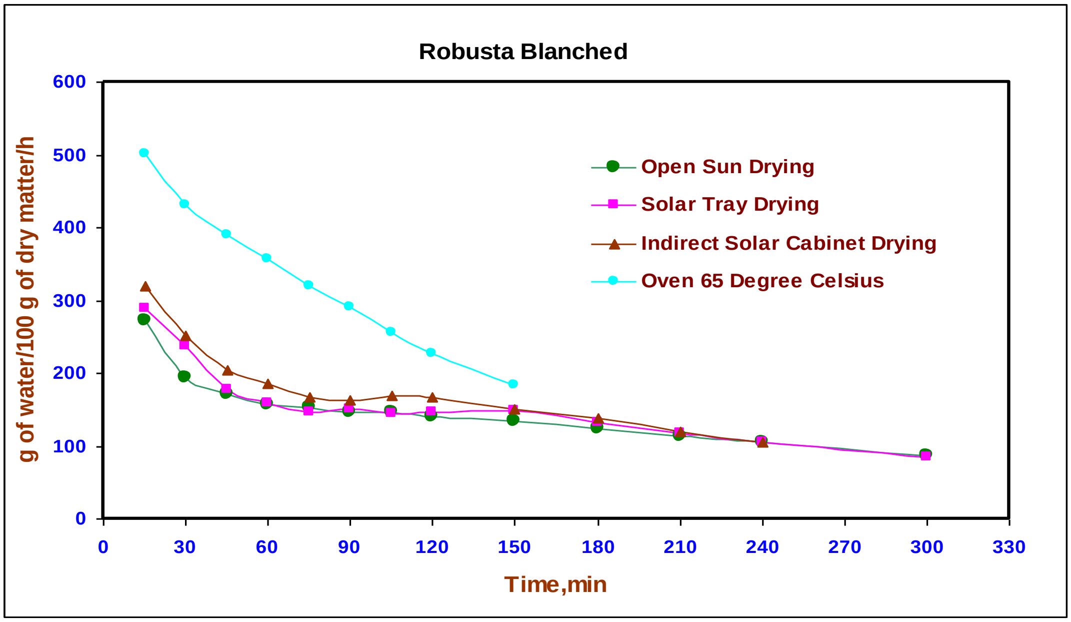

Fig. 4.28 Comparison of different drying methods for the drying of blanched Robusta banana slices.

This figure put the core fact for all the four drying methods, that hot air oven drying at 65^{o}C resulted in to high values of drying rate in entire drying period. Sun drying method shows the lower drying rate values in all the four drying methods, whereas solar tray drying and indirect solar cabinet drying shows intermediate drying rate between another two drying methods. The high drying rate values in hot air oven may be attributed to the constant high temperature inside the oven chamber, varying high air temperature in solar tray dryer and indirect solar cabinet dryer and comparatively lower air temperature for open sun drying.

Similarly final moisture content (%db) of untreated and pre-treated banana slices of both the varieties dried by different drying methods is presented in Fig. 4.29.

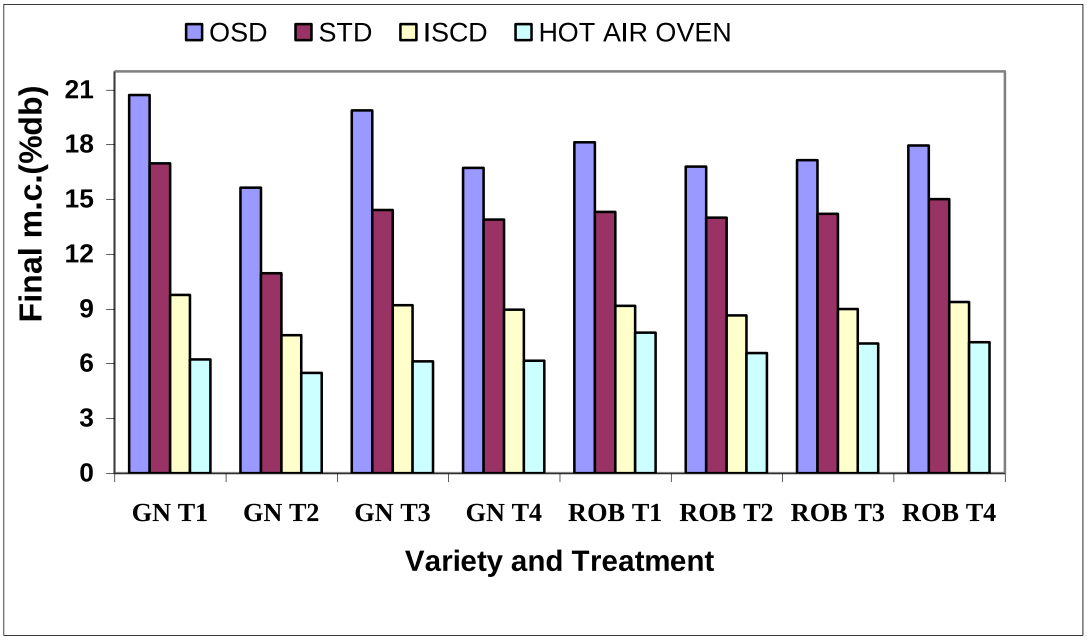

Fig. 4.29 Final moisture content of untreated and pre-treated Grand Naine and Robusta banana slices in all four drying methods.

In case of solar drying system, slices dried in indirect solar cabinet dryer shows comparatively lesser final moisture content than solar tray dryer. This may be due to the fact that indirect solar cabinet dryer has enough large air inlet space at front and exhaust chimney compared to inlet and exhaust holes available at bottom and backside in case of solar tray dryer. The values of final moisture content in case of open sun drying for both the varieties was on higher side compared to rest of the drying methods. The probable reason for this may be due to comparatively low air temperature than solar dryers and hot air oven. However, slices dried in hot air oven at 65^{o}C shows lowest final moisture content comparing to all other drying methods.

This may be because of high and constant air temperature throughout the drying period.

Besides the above comparison visual observations of colour of dried banana slices for both the varieties in case of all the four drying methods were recorded and are presented in table 4.7. Representative samples of solar dried and hot air oven dried banana slices are shown in fig.4.30.

Table 4.7 Visual observation of colour of dried banana slices

Parameters	**Open Sun Drying**	**Solar Tray Drying**	**Indirect Solar Cabinet Drying**	**Hot Air Oven (65^{o}C)**
Colour				
Control	Light brown	Cream with brown ting	Cream with brown ting	Pale white
Blanched	Brownish yellow	Dark yellow	Dark yellow	Attractive yellow
Potassium Metabisulphite	Cream with brown ting	Pale yellow	Pale yellow	White with creamy spots
Benzoic acid	Cream with brown ting	Pale yellow	Pale yellow	White with creamy spots
Flavour/smell				
	Good	Better	Better	Better +
Overall acceptibility				
	Acceptable	Acceptable +	Acceptable +	Acceptable +

Devlet and Turhan (2003) also observed decrease in discoloration with increase in temperature implying an enzymatic character of the browning. Under the same conditions, the pretreated slices exhibited less discoloration than the untreated

slices. Though temperature and pre-treatment decreased the discoloration, the colour of the untreated products was still acceptable.

Reports on the effect of pre-treatment on colour of dried banana is mixed probably due to use of different varieties, pre-treatment agents, concentration-time-temperature combination of pre-treatments, drying conditions *etc.*

However banana slices dried in hot air oven at 45^{o} C shows inferior quality in terms of colour and flavour and as final product shows sticky texture it put in the remark of rejectable in case of acceptability of end product.

4.5 Statistical Analysis

As per the plan, results were analyzed statistically following the standard methodology and ANOVA table is presented in Table 4.7. In the table factor A indicate varieties of banana, factor B is drying methods used in the experiment and factor C indicate the pre-treatments applied to banana slices. It was observed that there was no significant difference among the varieties of banana in respect of final moisture content. The effect of drying methods on final moisture content was also analyzed and the differences were significant. The interaction effect of variety and methods of drying was also found significant on the values final moisture content. The pre-treatments viz. blanching, potassium metabisulphite (100 ppm) and benzoic acid (1000 ppm) were also statistically compared and it was found that the effect of all pretreatments on final moisture content was significant for both the varieties. The interaction effect was also found significant. The combine effect of drying method, pretreatments and variety was also analyzed for final moisture content and this interaction has significant effect on final moisture content.

Table 4.8 ANOVA Table

K Value	Source	Degree of freedom	Sum of squares	Mean square	F Value	Probability
2	Factor A	1	1.114	1.114	2.2297	0.1403
4	Factor B	3	1834.704	611.568	1224.4063	0.0000*
6	AB	3	6.803	2.268	4.5397	0.0060*
8	Factor C	3	59.719	19.906	39.8539	0.0000*
10	AC	3	23.136	7.712	15.4403	0.0000*
12	BC	9	12.980	1.442	2.8874	0.0063*
14	ABC	9	21.310	2.368	4.7406	0.0001*
15	Error	64	31.967	0.499		
	Total	95	1991.733			

*Significant at 5% level

4.6 Cost economics of different drying methods

Cost economics of drying of banana slices in open sun drying, solar tray dryer, indirect solar cabinet dryer and hot air oven was estimated and is given in Appendix X. This cost economics shows that the cost of drying was maximum (Rs.189.65/kg) in case of oven followed by indirect solar cabinet dryer (Rs.117 /kg), Solar tray dryer (Rs.107.16/kg) and open sun drying (Rs.83.15/kg).

The net saving of Rs.76.85, Rs.43.00 and Rs.52.83 per kg of processed slices were recorded for open sun drying, indirect solar cabinet dryer and solar tray dryer respectively. This shows that under solar drying solar tray drying system is more profitable compared to indirect solar cabinet dryer. However hot air oven was found to be uneconomical for drying of 1 kg banana slices.

CHAPTER V
SUMMARY AND CONCLUSIONS

India is leading producer of banana with about 16.91 million tonnes, which is approximately 20% of the world banana production. Because of rich source of energy producing food, it is consumed in several varieties and forms. Though major share of banana production is consumed in the fresh form, small per cent of it is exported to Middle East, Gulf, Russia, Ukraine and other European countries. Being highly perishable in nature, there is a need to preserve this important fruit by processing it to produce banana pulp, banana chips, banana powder *etc.* to cater the needs of different sections of the society and thereby provides incentives to the growers.

Though there are varying views about the extent of losses in these commodities, it is roughly estimated that the losses are 20-30 per cent of highly perishable horticultural produce amounting to a loss of Rs. 30,000 crore per annum.This huge loss is strongly responsible to lesser financial gain to producers and higher price paid by consumers.

Though the total quantum of production of fruits and vegetables by the country is quite impressive, its share in the global processed food trade of horticultural produce is negligible. Horticultural produces are seasonal and perishable and often wasted. It is being increasingly realized that food processing capacity also needs to be increased to balance seasonal production factors, apart from adding value to the produce.

Looking to the lack of post harvest management and high production of banana (5155.25 tonnes) in Chhattisgarh the study on drying characteristics of banana slices was thought for value addition. In this study four drying methods were used for drying of banana slices.

The present study focused on drying characteristics of two commonly grown banana varieties in Chhattisgarh namely Grand Naine and Robusta. Slices of 2-3 mm thickness of both the varieties were dried using four different drying methods *viz.* open sun drying, solar tray drying, indirect solar cabinet drying and hot air oven (at temperature of 65^o,55^o and 45^{o}C) drying. Prior to drying, banana slices were pre-treated with four different kinds of pre-treatment *viz.* without treatment, blanched in hot water at 97^{o}C for 5 min, dipped in to 100 ppm of potassium meta bisulphate for 5 min and infiltration of 1000 ppm of benzoic acid for 5 min.The effect of these pre-treatments was studied on drying characteristics of slices. Several facts in the form of results on the basis of observations gained from experimental measures are as follows.

1) Both the varieties contain almost same amount of initial moisture content (79-83% wb). On the basis of size Grand Naine variety was found longer and has more weight than Robusta. The appearance of the slices of Grand Naine seems to be attractive because of their larger diameter than Robusta banana slices.
2) Solar tray drying and indirect solar cabinet drying were found better on the basis of rapid moisture reduction compared to sun drying. It facilitates the higher air temperature inside the drying chamber.

3) The open sun drying method was found comparable with others. However less air temperature was observed and fairly good quality of slices were achieved after a course of drying.

4) Out of selected four drying methods, hot air oven drying at 65^{o}C was proved to be most time saving and weather independent. However, it requires higher cost input. Hot air oven drying at temperature of 45 ^{o}C was found to be most time consuming method and the dried samples shows inferior quality than at other air temperatures by visual observations.

5) There was inverse proportion between drying rate and drying time as the drying time increased the drying rate decreased for all pre-treated samples. The banana slices dried under all the four different drying methods did not have any constant rate drying period and complete drying took place only in falling rate period.

6) In all drying methods, for all pre-treatments there was rapid moisture removal at the initial stage of drying. The slices without any pre-treatment were found dark in colour compared to pre-treated samples. However colour of these untreated slices was found within acceptable limit.

7) Blanched slices have attained an attractive yellow colour after the drying and the final moisture content was found less than that of other pre-treated samples. The potassium meta bisulphate and benzoic acid treated samples do not show much more variation in final moisture content, but they can be stored for longer time period than control samples as visually observed.

8) The highest net saving of Rs. 76.85 per kg of processed slices was recorded in open sun drying followed by solar tray dryer and indirect solar cabinet dryer. In case of hot air oven drying this value was observed as Rs. (–) 29.65 per kg.

From of this study the following conclusions can be made:

The higher drying rate in case of blanched banana slices was observed during initial period of drying and the reduction in final moisture content was higher compared to rest of pre-treatments in all types of drying.

Comparing the two types of solar dryers, the performance of indirect solar cabinet dryer was superior in terms of the lowest final moisture content followed by solar tray dryer. In case of hot air oven dryer higher the drying temp higher was the drying rate and lower was final moisture content.

The highest net saving of Rs. 52.83 per kg of processed slices was attainable in case of solar tray dryer. Net saving of Rs. 76.85 per kg of processed slices was recorded in open sun drying. On the other hand, the cost involvement was maximum in case of hot air oven drying, this value was calculated to be as high as Rs. (–) 29.65 per kg of processed slices.

SUGGESTIONS FOR FUTURE WORK

From the present experiment some suggestions were made based on practical observation and are given here for possible future studies.

1) Quality evaluation of processed banana chips may be studied.
2) The study may also be taken up on higher batch size along with slice thickness of more than 3 mm.
3) Value addition aspect of banana slices may be studied by frying it at intermediate moisture levels.
4) The storability of banana chips should also be evaluated.

“STUDIES ON DRYING CHARACTERISTICS OF BANANA SLICES”

ABSTRACT

By
Kalne Abhimannyu Arun

Banana is considered to be the fourth most important food crop in world just after to rice, wheat and milk products in terms of gross production. Proudly, India is a leading producer of banana among all the countries, with 16.91 million tonnes yearly productions. Within a country banana contributes 37 per cent to total fruit production. Horticultural produces are seasonal and perishable and often wasted. Looking to the huge post harvest losses in banana also, there is a need to preserve this important fruit by processing it to produce different value added products to cater the needs of different sections of the society. Looking to the lack of post harvest management and high production of banana (5155.25 tonnes) in Chhattisgarh the study on drying characteristics of banana slices was to be thought for value addition.

In the present study drying characteristics of two commonly grown banana varieties in Chhattisgarh namely Grand Naine and Robusta were studied. Four different drying methods *viz.*, open sun drying, solar tray drying, indirect solar cabinet drying and hot air oven drying (at temperature levels of 65^o, 55^o and 45^{o}C) were selected for the study. Prior to drying, pretreatments were given to banana slices *viz.*, without treatment, blanched in hot water at 97^{o}C for 5 min, dipped in to 100 ppm of potassium meta bisulphate for 5 min and impigmation of 1000 ppm of benzoic acid for 5 min. Effect of these pretreatments was studied on drying characteristics of slices. In all the pre-treatments, higher drying rate was observed during initial period of drying and the reduction in final moisture content was higher in blanched samples compared to rest of pre-treatments in all types of drying. Comparing the two types of solar dryers, the performance of indirect solar cabinet dryer was superior in terms of the lowest final moisture content followed by solar tray dryer. In case of hot air oven dryer higher the drying temperature, higher was the drying rate and lower was final moisture content for all the pre-treatments. Cost economics of all the drying methods reveals that the highest net saving of Rs. 52.83 per kg of processed slices was attainable in case of solar tray dryer. Net saving of Rs. 76.85 per kg of processed slices was recorded in open sun drying. On the other hand, the cost involvement was maximum in case of hot air oven drying, this value was calculated to be as high as Rs. (–) 29.65 per kg of processed slices.

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APPENDIX -I

Specifications of Solar Tray Dryer (STD)

Type of material used	MS Sheet
Area of MS sheet	$1.44 m^2$
Total height of dryer	590 mm
Total length of dryer	670 mm
Total width of dryer:	360 mm
Space from ground	140 mm
Inclined glass size	690 X 670 mm
No. of trays	3
Type of trays	Wire mesh trays
Area of each tray	300 mm X 600 mm

APPENDIX -II

Specifications of Indirect Solar Cabinet Dryer (ISCD)

Sr. No.	Component of the ISCD	Specifications of the component	Dimensions
1	ISCD	Length X Breadth X Height	920 X 385 X 450 mm
2	Chimney	Height Outer diameter Inner diameter	490 mm 450 mm 400 mm
3	Reflector	Length X Breadth 1st adjustment 2nd adjustment 3rd adjustment	870 X 380 mm 580 mm from the top 660 mm from the top 760 mm from the top
4	Tray	Length X breadth Mesh size	375 X 360 mm B.S.S. 200 approx. (75 microns)
5	Glass collector	Length X breadth X thickness	560 X 385 X 5 mm
6	Reflector glass		370 X 550 mm
7	Air inlet vent	Height	40 mm

APPENDIX -III

Specifications of Hot Air Oven

Type of Oven:	Lab Model of Static Hot Air Oven
Overall Size:	470 X 470
Drying Chamber Type:	Stainless Steel
Chamber Size:	455 X 455 X 605 mm
No. of Racks:	3
Electric Supply:	230 V, AC Single Phase, 50 Cycles
Temperature Controller:	Digital Recorded
Manufacturer:	Micro Tech. Pvt. Ltd. Ambala Cant

APPENDIX -IV

Variation of temperature and relative humidity in relation to time during open sun drying of Grand Naine banana slices

Time (hrs)	Drying Duration (min)	Temperature (^{o}C)	Relative Humidity
9.00	0	39	58
9.15	15	40	
9.30	30	43	
9.45	45	45	
10.00	60	44	55
10.15	75	47	
10.30	90	47	
10.45	105	49	
11.00	120	49	51
11.30	150	50	
12.00	180	55	46
12.30	210	55	
1.00	240	55	42
2.00	300	54	40
3.00	360	47	36
4.00	420	50	36
5.00	480	47	38

APPENDIX -V

Variation of temperature and relative humidity in relation to time during open sun drying of Robusta banana slices

Time (hrs)	Drying Duration (min)	Temperature (^oC)	Relative Humidity
9.00	0	39	57
9.15	15	40	
9.30	30	40	
9.45	45	42	
10.00	60	42	54
10.15	75	44	
10.30	90	45	
10.45	105	48	
11.00	120	49	50
11.30	150	48	
12.00	180	50	48
12.30	210	50	
1.00	240	51	44
2.00	300	47	42
3.00	360	47	37
4.00	420	45	38
5.00	480	41	40

APPENDIX -VI

Variation of temperature and relative humidity in relation to time during solar tray drying of Grand Naine banana slices

Time (hrs)	Drying Duration (min)	Temperature (^oC)	Relative Humidity
9.00	0	44	57
9.15	15	51	
9.30	30	52	
9.45	45	53	
10.00	60	53	59
10.15	75	56	
10.30	90	57	
10.45	105	59	
11.00	120	58	55
11.30	150	60	
12.00	180	62	49
12.30	210	68	
1.00	240	69	41
2.00	300	78	39
3.00	360	81	34
4.00	420	76	36
5.00	480	66	39

APPENDIX -VII

Variation of temperature and relative humidity in relation to time during solar tray drying of Robusta banana slices

Time (hrs)	Drying Duration (min)	Temperature (^oC)	Relative Humidity
9.00	0	42	57
9.15	15	44	
9.30	30	51	
9.45	45	52	
10.00	60	53	59
10.15	75	54	
10.30	90	54	
10.45	105	58	
11.00	120	59	55
11.30	150	61	
12.00	180	63	49
12.30	210	69	
1.00	240	71	41
2.00	300	75	39
3.00	360	73	34
4.00	420	67	36
5.00	480	61	39

APPENDIX -VIII

Variation of temperature and relative humidity in relation to time during indirect solar cabinet drying of Grand Naine banana slices

Time (hrs)	Drying Duration (min)	Temperature (^{o}C)	Relative Humidity
9.00	0	47	54
9.15	15	48	
9.30	30	50	
9.45	45	51	
10.00	60	53	55
10.15	75	53	
10.30	90	54	
10.45	105	51	
11.00	120	52	52
11.30	150	60	
12.00	180	61	44
12.30	210	64	
1.00	240	65	39
2.00	300	65	36
3.00	360	63	34
4.00	420	56	34
5.00	480	47	41

APPENDIX -IX

Variation of temperature and relative humidity in relation to time during indirect solar cabinet drying of Robusta banana slices

Time (hrs)	Drying Duration (min)	Temperature (^oC)	Relative Humidity
9.00	0	40	55
9.15	15	44	
9.30	30	45	
9.45	45	44	
10.00	60	45	56
10.15	75	46	
10.30	90	48	
10.45	105	52	
11.00	120	56	53
11.30	150	58	
12.00	180	60	50
12.30	210	61	
1.00	240	62	44
2.00	300	65	41
3.00	360	61	36
4.00	420	55	36
5.00	480	50	38

APPENDIX-X

Three Factor Completely Randomized Design

Data case no. 1 to 96.

Factorial ANOVA for the factors:

Replication (Variable 4: Replication) with values from 1 to 3

Factor A (Variable 1: Variety) with values from 1 to 2

Factor B (Variable 2: Drying method) with values from 1 to 4

Factor C (Variable 3: Pre treatment) with values from 1 to 4

Variable 5: Moisture content

Grand Mean = 11.825 Grand Sum = 1135.180 Total Count = 96

TABLE OF MEANS

4	1	2	3	5	Total
*	1	*	*	11.717	562.420
*	2	*	*	11.932	572.760
*	*	1	*	17.726	425.430
*	*	2	*	14.102	338.440
*	*	3	*	8.959	215.010
*	*	4	*	6.512	156.300
*	1	1	*	17.952	215.420
*	1	2	*	14.053	168.640
*	1	3	*	8.869	106.430
*	1	4	*	5.994	71.930
*	2	1	*	17.501	210.010
*	2	2	*	14.150	169.800
*	2	3	*	9.048	108.580
*	2	4	*	7.031	84.370
*	*	*	1	12.870	308.880
*	*	*	2	10.656	255.740
*	*	*	3	11.991	287.780
*	*	*	4	11.783	282.780
*	1	*	1	13.419	161.030
*	1	*	2	9.905	118.860
*	1	*	3	12.120	145.440

*	1	*	4	11.424	137.090
*	2	*	1	12.321	147.850
*	2	*	2	11.407	136.880
*	2	*	3	11.862	142.340
*	2	*	4	12.141	145.690

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*	*	1	1	19.410	116.460
*	*	1	2	16.215	97.290
*	*	1	3	17.937	107.620
*	*	1	4	17.343	104.060
*	*	2	1	15.635	93.810
*	*	2	2	12.477	74.860
*	*	2	3	14.313	85.880
*	*	2	4	13.982	83.890
*	*	3	1	9.473	56.840
*	*	3	2	8.100	48.600
*	*	3	3	9.105	54.630
*	*	3	4	9.157	54.940
*	*	4	1	6.962	41.770
*	*	4	2	5.832	34.990
*	*	4	3	6.608	39.650
*	*	4	4	6.648	39.890

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*	1	1	1	20.703	62.110
*	1	1	2	15.640	46.920
*	1	1	3	18.737	56.210
*	1	1	4	16.727	50.180
*	1	2	1	16.960	50.880
*	1	2	2	10.950	32.850
*	1	2	3	14.423	43.270
*	1	2	4	13.880	41.640
*	1	3	1	9.773	29.320
*	1	3	2	7.547	22.640
*	1	3	3	9.207	27.620
*	1	3	4	8.950	26.850
*	1	4	1	6.240	18.720
*	1	4	2	5.483	16.450
*	1	4	3	6.113	18.340
*	1	4	4	6.140	18.420
*	2	1	1	18.117	54.350
*	2	1	2	16.790	50.370
*	2	1	3	17.137	51.410
*	2	1	4	17.960	53.880
*	2	2	1	14.310	42.930
*	2	2	2	14.003	42.010
*	2	2	3	14.203	42.610
*	2	2	4	14.083	42.250
*	2	3	1	9.173	27.520

*	2	3	2		8.653	25.960
*	2	3	3		9.003	27.010
*	2	3	4		9.363	28.090
*	2	4	1		7.683	23.050
*	2	4	2		6.180	18.540
*	2	4	3		7.103	21.310
*	2	4	4		7.157	21.470

ANALYSIS OF VARIANCE TABLE

K Value	Source	Degree of freedom	Sum of squares	Mean square	F Value	Prob
2	Factor A	1	1.114	1.114	2.2297	0.1403
4	Factor B	3	1834.704	611.568	1224.4063	0.0000
6	AB	3	6.803	2.268	4.5397	0.0060
8	Factor C	3	59.719	19.906	39.8539	0.0000
10	AC	3	23.136	7.712	15.4403	0.0000
12	BC	9	12.980	1.442	2.8874	0.0063
14	ABC	9	21.310	2.368	4.7406	0.0001
-15	Error	64	31.967	0.499		
	Total	95	1991.733			

Coefficient of Variation: 5.98%

SE_m for means group 2: 0.1020 Number of Observations: 48

CD value : 0.2880

SE_m for means group 4: 0.1443 Number of Observations: 24

CD value : 0.4075

SE_m for means group 6: 0.2040 Number of Observations: 12

CD value : 0.5761

SE_m for means group 8: 0.1443 Number of Observations: 24

CD value : 0.4075

SE_m for means group 10: 0.2040 Number of Observations: 12

CD value : 0.5761

SE_m for means group 12: 0.2885 Number of Observations: 6

CD value : 0.8147

SE_m for means group 14: 0.4080 Number of Observations: 3

CD value : 1.1522

APPENDIX-XI

Cost Economics of Different Drying Methods

I. Open Sun drying

For open Sun drying 3 m^2 black polythene sheet @Rs. 10/m^2 is required to spread one kg of raw banana slices

Investment cost (P)	=	Rs. 30
Expected life (L)	=	1 years
Hourly use / year (N)	=	1920 h / year (8 h x 30 days x 8 months)
Salvage value (S)	=	10 % of the total investment cost
Interest (R)	=	@ 10 %

i) Fixed cost

a) $$\text{Depriciation} = \frac{P - S}{N \times L} = \frac{30 - 3}{1920 \times 1} = 0.014 \text{ Rs./h}$$

b) $$\text{Interest} = \left(\frac{P + S}{2}\right) x \left(\frac{R}{100}\right) x \left(\frac{1}{N}\right)$$

$$= \left(\frac{30 + 3}{2}\right) x \left(\frac{10}{100}\right) x \left(\frac{1}{1920}\right) = 0.00086 \text{ Rs./h}$$

c) Miscellaneous (Housing and insurance) = Rs. 0.08 /h

Total fixed cost = Rs. 0.014 + 0.00086 +0.08 / h

= Rs. 0.09486 X 8 h

= 0.76 Rs/Batch of one kg

ii) Variable cost

a) Labour charge @ Rs. 60 / day = Rs. 60 / 8 = Rs. 7.5 /h

Since total man hours required for drying and processing of one batch is only 0.25 h, the labour cost per 0.25 h is considered in calculation of cost of one batch.

So labour charges = Rs. 7.5/4 = Rs.1.875/ batch

Total operational cost /h = Total fixed cost + Variable cost

= Rs. 0.75888 + Rs. 1.875 =Rs. 2.63/ batch

iii) Material cost:

Batch size = 1 kg

Raw banana required: 1.5 kg @ Rs. 8/kg (Since pulp to peel ratio is 6:4)

Total material cost = Rs. 12.

Final recovery @ 20 per cent of raw slices = 1x (20/100) = 0.2 kg.

Processing Cost assumed @ Rs. 10/kg of dried slices (Oil, Flavouring agents, *etc.*)

So for 0.2 kg dried slices, processing cost is 0.2 X 10 = Rs. 2

Now, Total cost = fixed cost + variable cost + material cost + processing cost

= Rs.2.633+12+2

= Rs. 16.63

For 0.2 kg dried slices, cost required cost is Rs. 16.63, So for 1 kg dried slices the cost required is Rs. 16.63 X 5 = Rs.83.15

Average market cost of processed banana slices is Rs. 160 /kg.

So, net profit per kg of processed banana slices is Rs. 160 – Rs. 83.15 = Rs.76.85

II. Indirect solar cabinet dryer

Investment cost (P) = Rs. 3274

Expected life (L) = 10 years

Hourly use / year (N) = 1920 h / year (8 h x 30 days x 8 months)

Salvage value (S) = 10 % of the total investment cost

Interest (R) = @ 10 %

i) Fixed cost

a) $$\text{Depriciation} = \frac{\text{P - S}}{\text{N x L}} = \frac{3274 - 327.4}{1920\text{x}10} = 0.153\,\text{Rs./h}$$

b) $$\text{Interest} = \left(\frac{\text{P + S}}{2}\right)\text{x}\left(\frac{\text{R}}{100}\right)\text{x}\left(\frac{1}{\text{N}}\right)$$

$$= \left(\frac{3274 + 327.4}{2}\right)\text{x}\left(\frac{10}{100}\right)\text{x}\left(\frac{1}{1920}\right) = 0.09\ \text{Rs./h}$$

d) Miscellaneous (Housing and insurance) = Rs. 0.08 /h

Total fixed cost = Rs. 0.32 Rs/ h X 8 h

= Rs 2.56 per batch

ii) Variable cost

a) Labour charge @ Rs. 60 / day = Rs. 60 / 8 = Rs. 7.5 /h

Since total man hours required for drying and processing of one batch is only 0.25 h, the labour cost per 0.25 h is considered in calculation of cost of one batch.

So labour charges = Rs. 7.5/4 = Rs.1.875/ batch

b) Repair and maintenance cost @ 2 % of the initial cost

$$= \left(\frac{3274}{1920}\right) x \left(\frac{2}{100}\right) = 0.03 \text{ Rs./h } \text{ X } 8\text{h}$$

=Rs. 0.27 / batch

Total variable cost = Rs. 1.875 + Rs. 0.27

= Rs. 2.14 / batch

Total operational cost = Total fixed cost + Variable cost

= Rs. (2.56 + 2.14) = Rs 4.70 / Batch

iv) Material cost:

Batch size = 0.5 kg

Raw banana required: 0.75 kg @ Rs. 8/kg (Since pulp to peel ratio is 6:4)

Total material cost = Rs. 6

Final recovery @ 20 per cent of raw slices = 0.5x (20/100)= 0.1 kg.

Processing Cost assumed @ Rs. 10/kg of dried slices (Oil, Flavouring agents, *etc*)

So for 0.1 kg dried slices, processing cost is 0.1 X 10 = Rs. 1

Now, Total cost = (fixed cost + variable cost) + material cost + processing cost

= Rs. (4.70) +6+1

= Rs. 11.70 / batch of 0.1 kg processed banana slices

For 0.1 kg dried slices, cost required cost is Rs. 11.70, So for 1 kg dried slices the cost required is Rs. 11.70 X 10 = Rs.117

Average market cost of processed banana slices is Rs. 160 /kg.

So, net profit per kg of processed banana slices is Rs. 160 – Rs. 117 = Rs.43.00

III. Solar tray dryer

Investment cost (P) = Rs. 2840

Expected life (L) = 10 years

Hourly use / year (N) = 1920 h / year (8 h x 30 days x 8 months)

Salvage value (S) = 10 % of the total investment cost

Interest (R) = @ 10 %

i) Fixed cost

a) $$\text{Depriciation} = \frac{\text{P - S}}{\text{N x L}}$$

$$= \frac{2840 - 284}{1920 \text{ x } 10} = 0.133 \text{Rs./h}$$

b) $$\text{Interest} = \left(\frac{\text{P + S}}{2}\right) \text{x} \left(\frac{\text{R}}{100}\right) \text{x} \left(\frac{1}{\text{N}}\right)$$

$$= \left(\frac{2840 + 284}{2}\right) \text{x} \left(\frac{10}{100}\right) \text{x} \left(\frac{1}{1920}\right) = 0.081 \text{Rs./h}$$

c) Miscellaneous (Housing and insurance) = Rs. 0.08 /h

Total fixed cost = Rs. 0.294 /h

= Rs. 0.294 /h X 8

= Rs. 2.35/ batch of 0.6 kg batch size

ii) Variable cost

a) Labour charge @ Rs. 60 / day = Rs. 60 / 8 = Rs. 7.5 /h

Since total man hours required for drying and processing of one batch is only 0.25 h, the labour cost per 0.25 h is considered in calculation of cost of one batch.

So labour charges = Rs. 7.5/4 = Rs.1.875/ batch

b) Repair and maintenance cost @ 2 % of the initial cost

$$= \left(\frac{2840}{1920}\right) x \left(\frac{2}{100}\right) = 0.02 \text{ Rs./h}$$

= Rs.0.02/h X 8

= Rs. 0.23 / batch

Total variable cost = Rs. 1.875 + Rs.0.23 / h

= Rs. 2.11 / 0.6 kg batch

Total operational cost = Total fixed cost + Variable cost

= Rs. (2.35 + 2.11) = Rs 4.46 / Batch

v) Material cost:

Batch size = 0.6 kg

Raw banana required: 0.9 kg @ Rs. 8/kg (Since pulp to peel ratio is 6:4)

Total material cost = Rs. 7.20

Final recovery @ 20 per cent of raw slices = 0.6x (20/100) = 0.12 kg.

Processing Cost assumed @ Rs. 10/kg of dried slices (Oil, Flavouring agents, *etc.*)

So for 0.12 kg dried slices, processing cost is 0.12 X 10 = Rs. 1.2

Now, Total cost = (fixed cost + variable cost) + material cost + processing cost

= Rs. (4.46) +7.20 +1.2

= Rs. 12.86 / batch of 0.12 kg processed banana slices

For 0.12 kg dried slices, required cost is Rs. 12.86, So for 1 kg dried slices the cost required is Rs. 12.86 / 0.12 = Rs.107.16 per kg

Average market cost of processed banana slices is Rs. 160 /kg.

So, net profit per kg of processed banana slices is Rs. 160 – Rs. 107.16 = Rs.52.83

IV. Hot air oven

Investment cost (P) = Rs. 10,000

Expected life (L) = 10 years

Hourly use / year (N) = 1920 h / year (8 h x 30 days x 8 months)

Salvage value (S) = 10 % of the total investment cost

Interest (R) = @ 10 %

i) Fixed cost

a) $\text{Depriciation} = \dfrac{P - S}{N \times L}$

$$= \frac{10000 - 1000}{1920 \times 10} = 0.46 \text{ Rs./h}$$

b) Interest $= \left(\frac{P+S}{2}\right) x \left(\frac{R}{100}\right) x \left(\frac{1}{N}\right)$

$$= \left(\frac{10000 + 1000}{2}\right) x \left(\frac{10}{100}\right) x \left(\frac{1}{1920}\right) = 0.28 \text{ Rs./h}$$

c) Miscellaneous (Housing and insurance) = Rs. 0.08 /h

Total fixed cost = Rs. 0.82/ h

= 0.82 X 8

=Rs. 6.56/ batch

ii) Variable cost

a) Labour charge @ Rs. 60 / day = Rs. 60 / 8 = Rs. 7.5 /h

Since total man hours required for drying and processing of one batch is only 0.25 h, the labour cost per 0.25 h is considered in calculation of cost of one batch.

So labour charges = Rs. 7.5/4 = Rs.1.875/ batch

b) Electricity cost @Rs. 3 /unit = Rs. 3 /h

c) Repair and maintenance cost @ 2 % of the initial cost

$$= \left(\frac{10000}{1920}\right) x \left(\frac{2}{100}\right) = 0.10 \text{ Rs./h}$$

Total variable cost = Rs. 1.875 + (3 X 5) + (0.50)

= Rs. 17.37 / batch of 1 kg

Total operational cost = Total fixed cost + Variable cost

= Rs. (6.56 + 17.37) = Rs 23.93 / Batch

vi) Material cost:

Batch size = 1 kg

Raw banana required: 1.5 kg @ Rs. 8/kg (Since pulp to peel ratio is 6:4)

Total material cost = Rs. 12

Final recovery @ 20 per cent of raw slices = 1x (20/100) = 0.2 kg.

Processing Cost assumed @ Rs. 10/kg of dried slices (Oil, Flavouring agents, *etc.*)

So for 0.2 kg dried slices, processing cost is 0.2 X 10 = Rs. 2

Now, Total cost = (fixed cost + variable cost) + material cost + processing cost

= Rs. (23.93) +12+2

= Rs. 37.93 / batch of 0. 2 kg processed banana slices

For 0.2 kg dried slices, required cost is Rs. 37.93, So for 1 kg dried slices the cost required is Rs. 37.93 X 5 = Rs.189.65

Average market cost of processed banana slices is Rs. 160 /kg.

So, net profit per kg of processed banana slices is = Rs.189.65 – Rs. 160

= Rs. (-) 29.65


(A) Control (Untreated)


(B) Blanched


(C) Potassium meta bisulphate treated


(D) Benzoic acid treated


(E) Control (65°C)


(F) Benzoic acid treated (65°C)


(G) Control (45°C)


(H) Benzoic acid treated (45°C)

A to D – Pretreated and dried banana slices by solar tray dryer
E to H – Control and benzoic acid treated banana slices in hot air oven at 65 °C and at 45°C temperature

Fig. 4.30: A view of pretreated and dried banana slices by solar tray drying and hot air oven