Technical Bulletin No. 76

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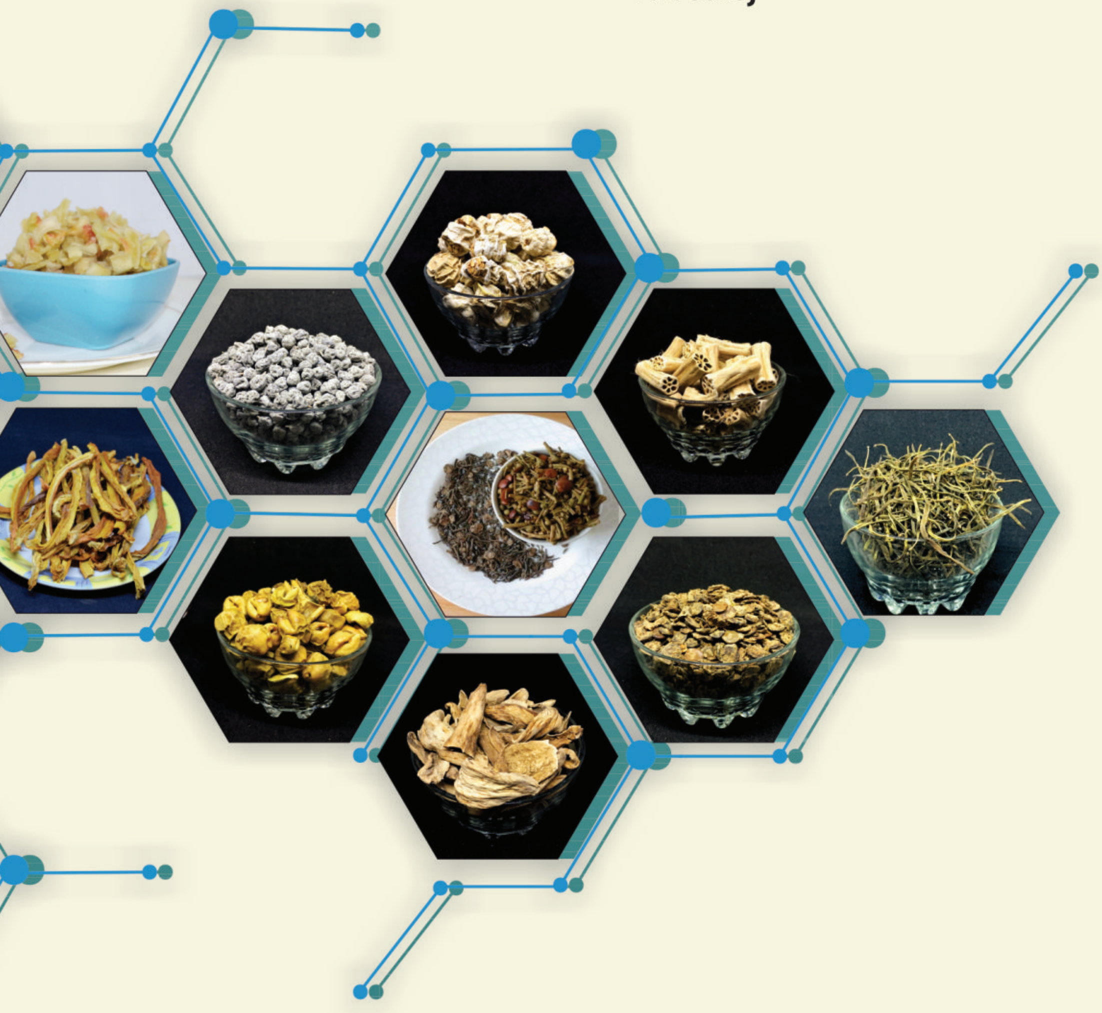

ICAR-CENTRAL INSTITUTE FOR ARID HORTICULTURE
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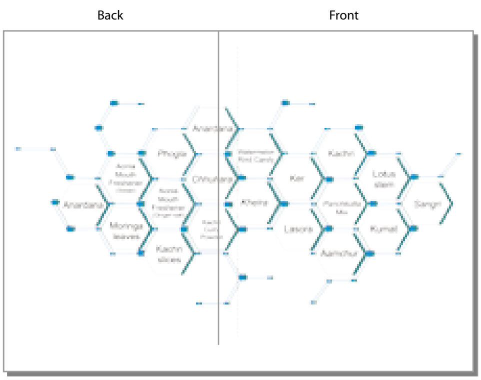
Cover page Introduction



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PREFACE

The arid regions of India are characterized by weather extremes *viz.* high temperatures, recurrent droughts, wind erosions, winter frosts, poor quality underground water, sandy soils etc. In spite of all these aberrations, these vast land resources are blessed with rich agro-biodiversity and has conducive climatic conditions for production of quality fruits, vegetables and seed spices viz. date palm, bael, aonla, pomegranate, fig, mulberry, jamun, ker, karonda, lasora, wood apple, ber, bordi, khejri, kachri, snap melon, drumstick, curry leaf, cluster bean, methi etc.. Other potential strengths of this region include high intense solar radiation and wind energy, sufficient working force of family labors coupled with developing infrastructure facilities and advanced technologies which are contributing for sustainable arid horticulture development. Of late the immense potential of the arid horticulture has been realized and the area under cultivation of these crops is increasing enormously.

With increased area under cultivation, the production also increases and there are more chances for creation of market glut with these arid horticultural crops. Most of these crops are highly perishable and couldn't be stored for longer periods due to uncongenial atmospheric conditions (high temperature and low relative humidity). However, the rural people of these arid regions preserve the surplus arid horticultural crops traditionally through sun drying and use them during the off-seasons/ round the year. These dried / dehydrated horticultural commodities form an essential part of regular diet of the desert dwellers and contributes a lot for their food and nutritional security. As the traditional drying is done under open sunny conditions, there is huge chance for settling of dust, dirt, infestation by insects, rodents etc. Hence, there is a great need for refining the traditional drying methods in order to improve the quality of the dehydrated arid horticultural produce. The clean and hygienic dehydrated food materials have more economic value and nutritional value compared to the open sun dried food material. Hence, research in this direction has progressed since decades and there is substantial improvement in the drying and dehydration technologies. Hence, an attempt was made to compile all the technical aspects related to dehydration of arid horticultural crops as the literature on this aspect was scanty.

August, 2018 Authors
Bikaner

CONTENTS

INTRODUCTION

Drying is one of the oldest and widely used method of food preservation. Though it is basically mimicked from nature but many features of this operation have been refined over the years. The natural sun drying of foods yields highly concentrated materials of enduring quality. For sun drying, the hottest days in summer are chosen so that the foods get dried very fast preventing them from getting spoiled due to souring. Souring/ turning acidic is mainly due to growth of microorganisms that convert carbohydrates in the food to acid while quick removal of moisture could prevent these microorganisms. Dehydration refers to artificial drying of food through application of artificial heat under controlled conditions of temperature, humidity and air flow, since drying is completely dependent on the elements of nature which is highly unpredictable. In this process, the food material is spread inside the dehydrator over trays in single layers of fruits/ vegetables, whole/ cut pieces or slices. Generally, the initial temperature of dehydrator is kept usually at 43°C, which gradually increases to 60-66°C for vegetables and to 66-71°C for fruit commodities.

Arid and semi-arid regions of the country are blessed with a variety of horticultural crops such as date palm, bael, aonla, pomegranate, fig, mulberry, jamun, ker, karonda, lasora, wood apple, ber, bordi, khejri, kachri, snap melon, drumstick, curry leaf, cluster bean, methi *etc.* Most of these crops are highly perishable and couldn't be stored for longer periods due to uncongenial atmospheric conditions (high temperature and low relative humidity). However, the rural people of the arid region preserve the surplus produce traditionally through sun drying and use them during the off-seasons/ round the year. These dried / dehydrated horticultural commodities form an essential part of regular diet of the desert dwellers and contributes a lot for their food and nutritional security.

Figure1. Marketing of traditionally sun dried arid crops

Need for dehydration of foods

Drying (dehydrating) is one of the easiest methods of food preservation, involving removal of water/ moisture from the food product, rendering them lighter and smaller for easy handling cum transportation. Dried and dehydrated foods are more concentrated forms compared to any other preserved form of food materials. Dehydrated foods are fairly ideal for backpacking, hiking, and camping as they weigh much less than their non-dried counterparts and do not require refrigeration. Dehydrated foods are relatively inexpensive to produce as they require minimum labour and equipment's. The storage requirements for dried and dehydrated products are minimum and distribution costs are also reduced compared to fresh commodities. Drying food is also a way of preserving seasonal foods for later use. Dehydration permits preservation of the dried produce through reduction in free water content available for microbial activity as well as spoilage.

Sun Drying Vs. Dehydration

Solar drying is climate dependent while dehydration possess control over the climatic conditions within a chamber or restricted microenvironment. The end products from a dehydration unit have better quality compared to their solar dried produce. The land requirement for solar drying is relatively high compared to dehydration process for drying of unit crop. Appropriate hygiene could be maintained in a dehydration unit while there are huge chances of contamination from dust, insects, birds, and rodents during solar drying in open fields. The yield or recovery of dried fruits from dehydrator is generally high as more sugar losses occur by continuous respiration during solar drying. When operated under optimum conditions, the colour of the solar dried produce is superior compared to the dehydrated produce. This is because colour development in certain immature fruits/ vegetables continuous to develop slowly during solar drying while this gets arrested during dehydration. The cooking quality of the dehydrated foods is superior to the sundried products. Eventually, the dehydration is an expensive process compared to sun drying, however the dehydrated food products possess more economic value compared to their solar dried produce due to high quality. Also, the sun drying couldn't be practiced widely due to unfavourable weather conditions in many areas where the agriculture is highly rewarding.

Factors affecting drying:

Dehydration of perishable horticultural crops is a complex process as it is involved with continuous exchange of heat and moisture. The time period taken for drying through conventional driers or dehydrators vary considerably based on the kind of food material, their initial moisture content coupled with drying temperature and relative humidity. Some foods require several hours while few others take more than a day for drying. Prolonging the drying period by lowering the drying temperatures or interruption of drying time might result in spoilage of the food material being dried. There are various factors that affect the drying of arid horticultural produce, which include:

(i) Nature and composition of the raw material.

(ii) Dimensions (size, shape and thickness) of the raw material and their stacking pattern.

(iii) Temperature, Relative Humidity (RH) and Velocity of air flow.

(i) Nature and Composition

This includes the type or kind of food material to be dried, their physical and chemical composition, moisture content *etc*. Certain crops possess large amount of water and such crops need more drying time. Also, the nature of water present in the commodity decides the drying efficiency, as free/ unbound water could be easily removed while the bound water couldn't be removed that easily.

(ii) Product dimensions

These include product size, length, thickness, shape *etc*. Small sized products dry faster compared to big sized products as the relative surface area for the small sized products is higher than that of bigger sized particles under equal weight. Another important thing is product thickness, as the product thickness increases, the distance from the centre of the product to the surface increases. With the increase in distance, the time taken by moisture to travel from centre to the surface also increases resulting in longer drying periods.

(iii) Temperature, RH and Air Velocity

The optimum drying temperature for most of the food materials is 50-55°C. The temperature should never go beyond 60°C, as it destroys their nutrients rendering loss of their dietary significance. In addition to the temperature used for drying, the relative humidity and velocity of the air under circulation are also important factors in drying. When the relative humidity is high and air velocity is low, the water on the surface cannot be removed. Only when the saturated air gets displaced by fresh unsaturated air, it could pick up more moisture from the food surface. As along as the air surrounding the product continuous to move, the drying process would continue at a satisfactory pace. At times, a thin layer of air clinging to the surface of food material, prevents efficient removal of moisture from the food material which is technically termed as 'stagnant boundary layer'. Hence, for efficient removal of the boundary layer an air velocity of 0.2 – 0.5 m/s is generally recommended for drying of food material. However, this could vary with the nature of food material being used and its dimensions.

DRYING KINETICS

It is the study of rate of drying using drying rate curves which depict the rate of moisture removal from the fruits or vegetables. This physical phenomenon could be expressed in three different ways *viz.* relationship among drying rate, drying time, and moisture content.

Drying time *Vs* Drying rate

During drying of food material, the removal of moisture doesn't occur at constant rate and the rate of moisture removal drops-off under any set of fixed conditions with the progression of drying process. In practice, though we could remove 90 per cent of moisture in 2 hours, it might take more than 2 hours for removal of remaining 10 per cent moisture. This becomes asymptotic so that zero moisture is never reached under practical operating conditions.

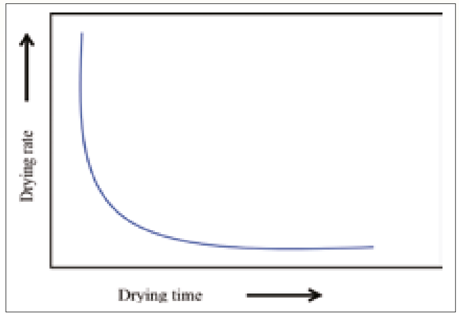

Figure 2. Drying curve with drying time vs. drying rate

Moisture content *Vs* Drying rate

In the initial stages of drying, the moisture is removed at a constant rate from the food material which is followed by an inflection in the drying curve leading to falling rate period of drying. However, the precise shape of normal drying curve varies with different food material, type of drier, and drying conditions. Most of the arid fruits and vegetables show constant and falling rate periods as shown in the fig. 03. With decrease in moisture content, drying rate changes from constant rate to falling rate and during falling rate period, rate of water movement from interior of food to surface falls below the rate at which it evaporates to the surrounding air.

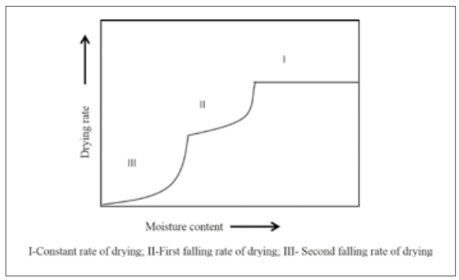

Figure 3: Drying curve with Moisture content vs. drying rate

Drying time *Vs* Moisture content

During drying/ dehydration, there is a drastic reduction of moisture in the initial phases and reduces to a minimum with the progression of drying process. With drying/ dehydration, the available moisture content in the commodity decreases and removal of water below 2 per cent without damaging the commodity is highly difficult.

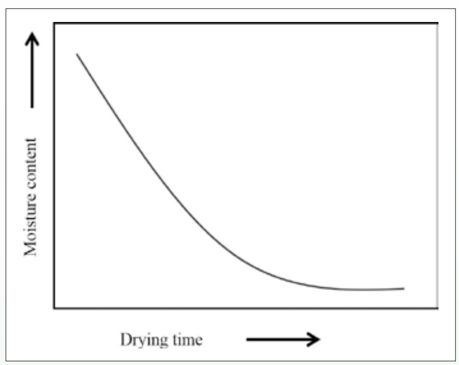

Figure 4. Drying curve with drying time vs. moisture content

PRE-TREATMENTS

Pre-treatments for drying and dehydration include raw material preparation, treatments for reducing nutrient losses, arresting enzymatic reactions, retention of natural colour pigments etc. for getting good quality end products.

Raw material preparation

It involves selection of fruits/ vegetables, sorting and grading, washing, peeling (kachri, pomegranate *etc.*), cutting/ slicing into appropriate form (aonla, kachri, kakdi/ snap melon *etc.*), blanching (date palm, sangri/ khejri, karonda, moringa leaf, curry leaf *etc.*). The arid fruits and vegetables for drying are selected/ sorted according to size, maturity and soundness. The selected fruits and vegetables are washed under running water for removal of dust, dirt, mould spores, other plant parts and any other foreign material that could contaminate/ affect the colour, aroma or flavour of fruit/ vegetable.

Blanching

Blanching is a special thermal process of dipping the fruits/ vegetables in hot/ boiling water prior to drying for preservation of natural colour, destroying the enzymatic activity, and protection from oxidative breakdown during drying process. This pre-treatment is very much essential for drying of most of the horticultural commodities because the temperatures associated with drying/ dehydration are insufficient for inactivation of enzymes present within the commodity and the enzyme activities are not controlled by reduced moisture content of the dried food material. This prevents discoloration, softening and off-flavour development during subsequent storage of dehydrated commodities. It also helps in cleaning and reducing the microbial load over the raw material. Additionally it also reduces the soaking and/ cooking time during reconstitution of the dehydrated products.

Commercial blanching processes include heating the vegetable as quickly as possible to the required temperature and then cools them rapidly to ambient temperature. Rapid heating and cooling minimises softening of tissue due to thermal damage. However, in certain fruits and vegetables, the blanching treatment is given with prolonged low temperatures for development of the desired textures. Some of the major factors influencing the blanching process are size, shape, and convective heat transfer coefficient which in turn gets influenced by heating medium as well as the duration. Based on the heat transfer medium used, blanching is broadly classified into two major types *i.e.* (i) Hot water blanching and (ii) Steam blanching. Some other novel blanching methods developed in recent times include vacuum steam blanching, In-can blanching, microwave blanching, and hot gas blanching.

The blanching time ranges from 1 minute to 10 minutes based on the nature and kind of the material being blanched. Over blanching should be avoided as it results in sticking of products together and flavour loss to certain extent. Sodium bicarbonate could be added to the blanching water for green vegetables such as sangri (Khejri), ker, and other green leafy vegetables. This compound raises the pH of blanching water and prevent the conversion of fresh green color into unattractive brownish- green compound pheophytin.

Figure 5. Blanching treatment for different arid horticultural crops

Dipping

Dipping is a pre-treatment used to prevent browning/ to improve the color and keeping quality of whole or sliced fruits during drying/ dehydration. Generally, the solution containing ascorbic acid, sulphur dioxide, citric acid, salt and sugar or fruit juices high in vitamin C *viz.* lemon, orange, pineapple, grape, *etc.* are used. However, the composition and strength of dipping solution vary with the type of fruit/vegetable being used. Dipping treatment occurs generally after blanching or when blanching is not required, after slicing. The container used for dipping treatment should be enamelled, plastic or stainless-steel as the normal metal containers get corroded with these solutions. The steps in dipping treatment include:

- Put enough preservative solution to cover the cloth bag into container/ pan.
- Dip the bag into preservative solution for specified time period.
- Remove the bag and place it over clean tray for draining of liquid. Care must be taken that the drained liquid should not go back into the original preservative solution as this might weaken the solution.
- Refill the container to original level with fresh preservative solution of correct strength.
- The dipping solution should be changed/ replaced after treating 5 batches of material.

For example, dipping sliced fruit pieces in a mixture of ascorbic acid crystals and water (1 teaspoon ascorbic acid crystals per 1 cup of water), or dipping directly in fruit juice for 3 to 5 minutes was found to prevent browning. Fruits may also be blanched as a means of treatment. Non-enzymatic browning in dry dates (*chhuhara*) could be significantly reduced by giving post-blanch dip treatment with ascorbic acid (1000 ppm) or Potassium Metabisulfate (KMS) 1500 ppm for 5 minutes prior to drying.

Sulphuring

This is the process of exposing the cut fruits/ vegetables to sulphur dioxide fumes. It is used for majority of the fruits due to its antioxidant and preservative effects. This pre-treatment preserved the color of the food material by preventing oxidation of the colouring matter. Being preservative in action, the sulphur fumes check the growth of moulds and thus prevent fermentation of fruits during prolonged drying under sun. Vitamins in the sulphured

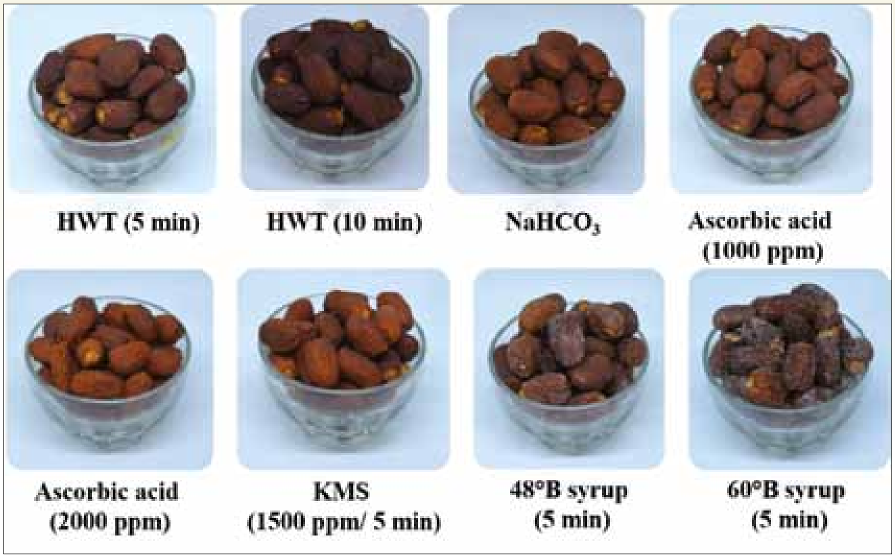

Figure 6. Dry dates prepared after exposing to various pre-treatments

commodities are protected compared to the unsulphured ones. Most commonly used for whole or minimally processed fruits and rarely with vegetables. The whole fruits, slices, or pieces are exposed to the fumes of burning sulphur inside a closed airtight chamber known as sulphur box for 30-60 minutes.

The sulphur box is a closed airtight chamber made up of glavanized iron sheet and fitted with wooden framework having runways on both sides for holding of trays. For small scale sulphuring, a box (90 x 60 x 90 cm) holding 11 trays each of size 80 x 60 x 5 cm is suitable. The box with a holding capacity of 10 trays requires 3 g sulphur for one charge.

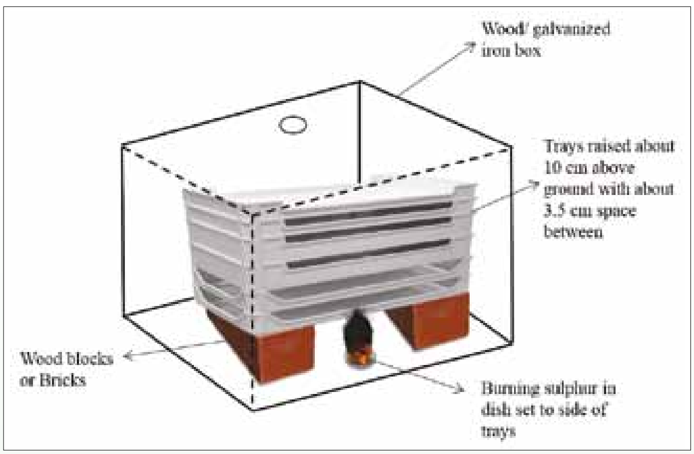

Figure 7. Schematic representation of sulphur box used for sulphuring pre-treatment

DRYING METHODS

Dehydrated fruits and vegetables could be produced by a variety of process which differ primarily by the type of drying method used. Over the decades various methods of drying have been developed in view of quality requirements, raw material characteristics, and economic factors. to meet varying needs of materials. All the drying processes could be broadly classified as (i) Sun and Solar drying (ii) Artificial atmospheric dehydration –Stationary/batch processes (kiln, oven and cabinet/tray driers); continuous processes (tunnel, fluidized bed, foam mat, spray, drum, and microwave assisted driers) and (iii) Sub-atmospheric dehydration (vacuum belt, drum and freeze driers). Some of the most common methods used for drying of arid horticultural crops include:

a. ***Sun drying:*** It is a traditional method of drying followed in most of the households. It is completely dependent on the weather, temperature, relative humidity of the outside atmosphere. This is highly successful in areas where solar radiation is abundant and atmospheric humidity is low. The major advantage is low investment on drying trays and netting for protection from insect pests. The major limitation is time, as this method takes 3-5 days in general for complete drying of majority of the food products while the other improved methods complete the job in 6-10 hours. In this method, the food material should be shifted to shade for finish once it reached 2/3 dry for avoidance of sun scorching.

Figure 8. Open sun drying of date fruits

b. ***Solar drying:*** This is a modified version of the sun drying where the solar radiation is collected in a specially designed unit with adequate ventilation for removal of saturated air. The drying time is relatively shorter compared to the sun drying as the temperature in this unit is 20-30 degrees higher. The major drawback in both these methods is lack of control over the weather parameters. This method utilizes black-painted trays, solar trays, collectors, and mirrors to accelerate the drying process through increased solar energy.

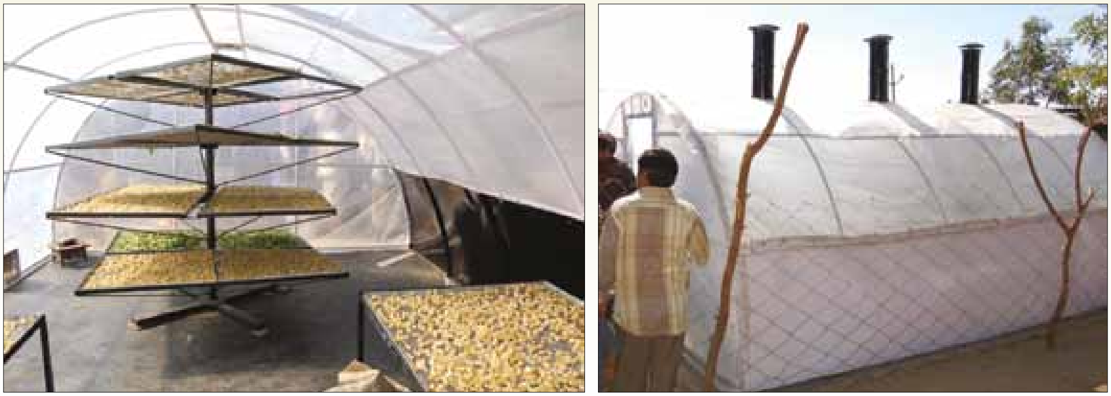

Figure 9. Locally made solar tunnel for drying arid horticultural crops

C. ***Oven drying:*** it is one of the most practical approach for experimentation with dehydration of food materials. The major advantage being lower investment, protection from dust and insect, and free from influence of weather parameters. However, continual use of oven for drying is not recommended as the oven are less energy efficient compared to the dehydrators and the energy costs tend to be relatively high. The products dried through oven are more susceptible to scorching towards the end of drying as it is very much difficult to maintain low temperatures in it. Other limitation include the final product tend to be darker, more brittle and less flavoured compared to the foods dried by dehydrator.

d. ***Osmotic dehydration:*** This is based on the principle of osmosis where a percent of moisture is removed from the fruit/ vegetable by placing it in concentrated solution of salt/ sugar/ both. The product weight is reduced by 50 per cent during osmotic dehydration. This method is a combination of two methods (i) osmosis; and (ii) drying processes such as solar drying, vacuum drying, freeze drying, cabinet drying *etc.* The sugar syrup protects the colour and flavour during osmotic dehydration. Also the final product retains a large percentage of flavour volatiles of fresh food. However, these are controlled by various factors such as kind of osmotic agent used (sugar/ salt/both), concentration, temperature, syrup agitation, product dimensions and fruit to syrup ratio. Suitable for preparation of Aonla candy.

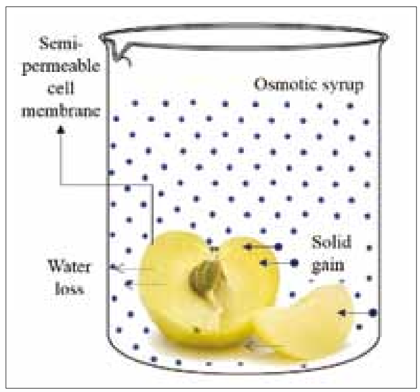

Figure 10. Principle of osmosis

e. **Cabinet/ Tray drying:** The food material is spread out in thin layers over the metal trays. Heating of food material occurs through hot air currents sweeping across the trays, by conduction from heated trays/ shelves over which the trays are placed or by irradiation from the heated surfaces. Generally hot air is circulated in the cabinet at 0.5-5.0 m/s per square meter tray area. The drier is also equipped with a system of ducts and baffles for directing the hot air over or through each tray for uniform distribution of hot air. It also has the provision for removal of saturated air from the product surface. They are used for small scale production processes up to 1-2 t/day or for pilot- scale projects. Though the capital and maintenance costs are low, the final product quality is non-uniform due to poor control over the drying factors. Applicable for drying of arid fruit crops such as date palm, kachri, aonla *etc.*

Figure 11. Air circulating tray drier

f. ***Tunnel drying:*** They are highly flexible, efficient, and used widely for commercial dehydration purposes. These are developments over the tray driers where in the trays placed over trolleys move through a tunnel where heat is applied and moisture is removed. The produce loaded trucks are moved through the tunnel at the rate required to maintain residence time for its dehydration. Produce could be moved either in the same direction or in opposite direction to the air flow which are thus called concurrent or counter current dehydration. This is highly recommended for commercial applications as it could dry large quantities (5000 kg) of food material in relatively short time period (5-16 hours). Suitable for drying of arid fruit crops such as ber, bordi, jharber, lasora, karonda *etc.*

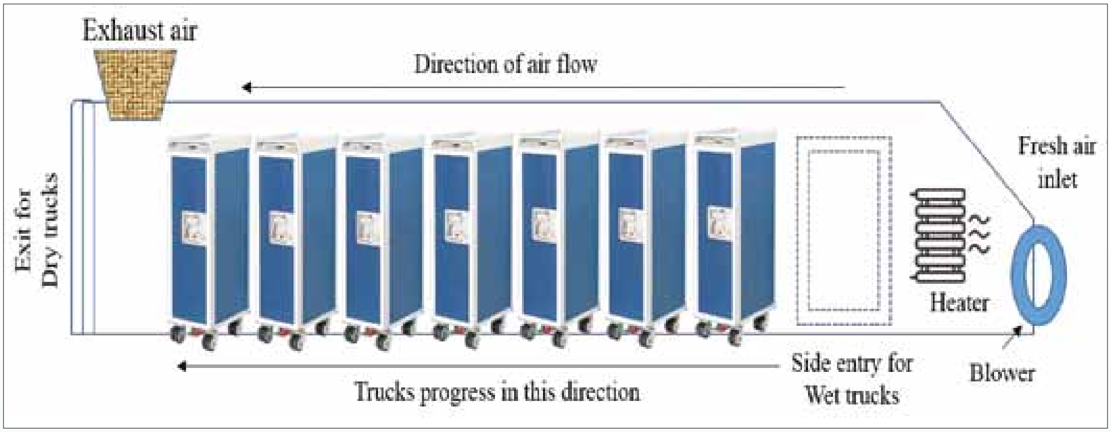

Figure 12. Schematic representation of tunnel drier (concurrent flow)

g. ***Conveyer/ Belt drying:*** These are continuous conveyer driers upto 20 m long and 3 m wide. Food material is spread over a perforated mesh belt 5-15 cm deep layers. Initially the hot air was blown upwards and downwards in the later stages to prevent dried food from blowing out of bed. At times 2-3 stage driers mix and repile partly dried shrunken food material into deeper beds of 15-25 cm and 250-900 cm, respectively. This results in uniformity of drying and later the dried material is transferred to bin driers for finishing. This is highly suitable for large scale drying of food material as it has good control over the drying conditions. In recent times, this has replaced the tunnel driers due to automation of loading and unloading facilities eliminating the need for manual labour. Majority of fruits and vegetables could be dried in 2-3.5 hrs at the rate of 5.5 t/hr. Commercially applicable for drying of arid vegetable crops such as kachri, sangri, ker, lasora, snap melon, *etc*.

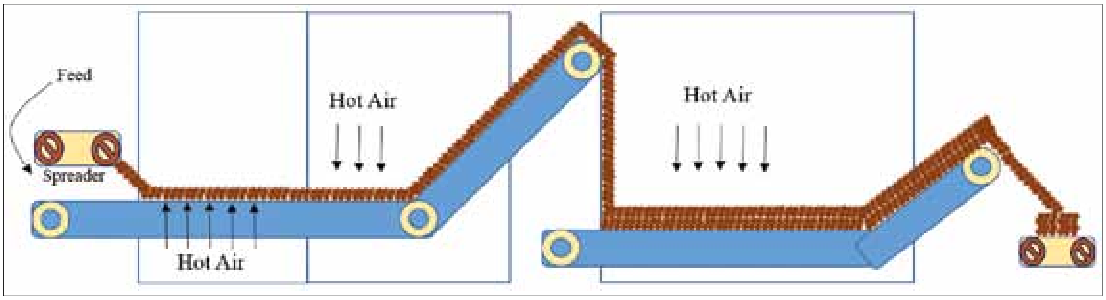

Figure 13. Schematic representation of typical two stage conveyer drier

h. ***Foam mat drying***: This is an application of conveyer driers applicable for drying of liquid and semi-solid food materials such as fruit juices/ pulp. Stabilizer such as xanthum gum, sorbitol, mannitol and alginic acid are added to fruit juices to convert them into stable foam with supplemented aeration using nitrogen gas/ air. Foam is spread over perforated belt to a thickness of 2-3 mm and dried rapidly in two stages through concurrent as well as counter current air flows. This method is three times faster than other methods of drying same thickness liquid. The thin porous mat of dried food material is ground to a free flowing powder with very good rehydration properties. The end product is of very high quality due to low product temperatures and rapid drying process. However, the capital costs are high due to requirement of large surface area. This method is applicable for production of fruit powders from arid fruit crops such as bael, phalsa, karonda *etc*.

i. ***Fluidized bed drying***: In this method, the food material is maintained in suspended form against gravity using upward flowing hot air stream. Useful for drying of small sized food particles/ products. Among various arid horticultural crops, this method is applicable during drying of pomegranate arils for preparation of anardana. As the hot air acts both as drying and fluidizing media, maximum surface area was available for drying rendering the product to be dried in limited time. The heat transfer from air to food material is generally through convection in this method. Being compact, these driers have good control over the drying conditions with relatively high thermal efficiencies and drying rates. Other arid crops suitable to be dried using this method include phogla (flower buds of phog), ker, jherber, kumat, lasora *etc*.

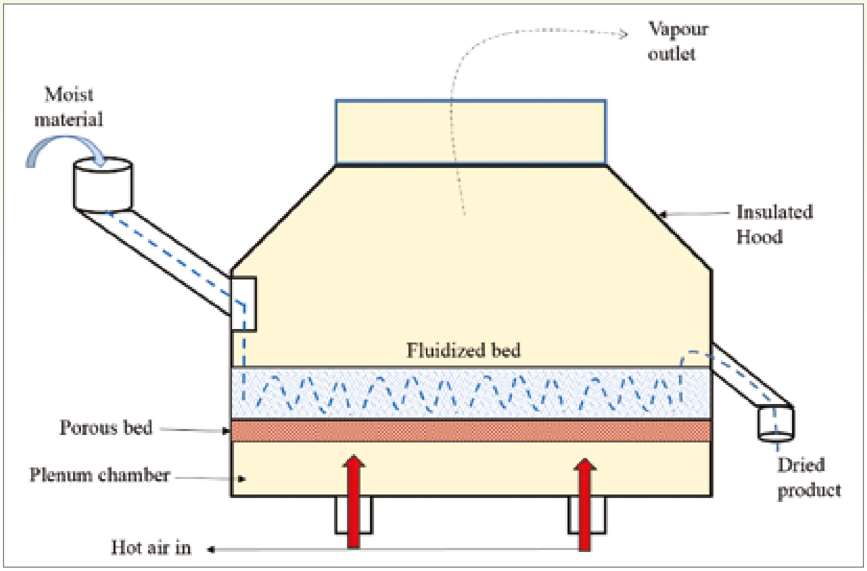

Figure 14. Schematic representation of fluidized bed drier

j. ***Roller/ Drum drying:*** These method of dryers are used for drying of liquid food material such as juices where the food is being applied to drum at one part of the cycle. Generally, steel drums are used which are heated internally by using pressurised steam (120-170°C). A thin layer of food material is coated over the drum surface by dipping/ spraying/spreading/through auxiliary feed rollers. The coated food material remain on the drum surface for a greater part of the rotation cycle during which the actual drying takes place, and then it is scraped off. Generally it takes 20 s to 3 minutes for completion of one rotation cycle. Single drum drying is most commonly used method as it has greater flexibility due to availability of larger proportion of drum area, ease of access for maintenance and lesser risk for crushing objects between drums. Most suitable for preparation of ready-to-reconstitute (RTR) fruit powders from arid fruit crops such as bael, phalsa, karonda, cactus pear, mulberry *etc*.

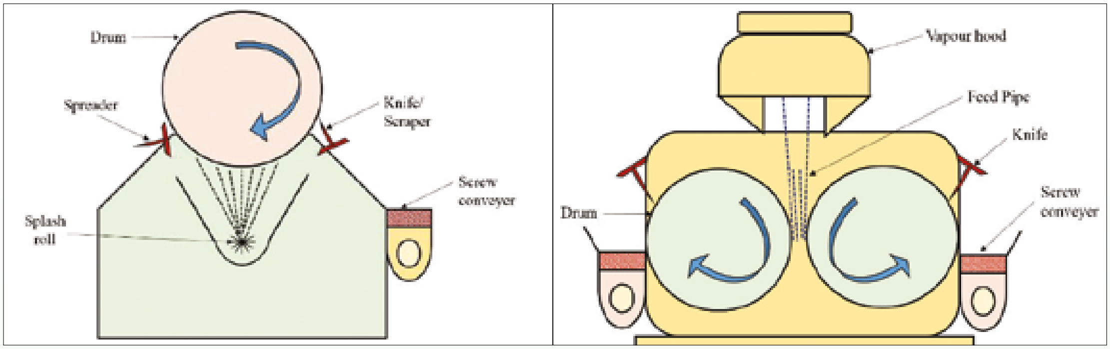

Figure 15. Schematic representation of Single and Double Drum drier

Figure 16. Laboratory scale spray drier

k. ***Spray drying:*** this method is useful for production of juice powders from arid horticultural crops where liquid or fine solid material could be sprayed or atomised in the form of fine droplets (10-200 μm) into heated (150-300°C) air currents. For successful drying of the fruit juices, complete and uniform atomisation are essential. Since drying occurs very rapidly, this is highly suitable for heat sensitive fruit juices. Commercial spray dryers could be very large to the order of 10 m diameter and 20 m height. Major advantage being rapid drying for large-scale continuous production, low labour costs with simple operation cum maintenance. However, it needs a high capital investment.

l. ***Pneumatic drying:*** These are used in combination with spray dryers in general where in the moisture content of the spray dried food material is further lowered by pneumatic drying. The solid food material are conveyed rapidly in airstream, with enough velocity and turbulence of stream for maintaining the particles under suspension. The heated air assists in drying while certain classifiers incorporated in it which separates the dried material and passes out as a product while the moist product is recirculated for further drying.

Figure 17. Microwave drying apparatus

m. ***Microwave drying:*** In this method of drying the heat is produced within the food molecules when the polar molecules oscillate around their axis. This heat removes the moisture from fruits and vegetables. The important advantage with this method of drying is its depth of penetration, uniform heating selective absorption of radiation and easy control. It is useful for drying of fruit juices, pulps, and fruit segments.

n. ***Vacuum drying:*** This method is very much similar to tray drying except that it operates under vacuum and heat transfer occurs mostly through conduction or by radiation. Here, the drying occurs at low air pressure enabling moisture removal below boing point under ambient conditions. This is highly suitable for heat sensitive crops which loose aroma volatiles and other bio-active components through oxidation when heated at elevated temperatures. Some of the crops suitable for vacuum drying include curry leaf, mint leaves *etc*.

o. ***Freeze drying:*** During freeze drying material is held on shelves/ belts placed under high vacuum and the raw material is frozen prior to loading in to it. The heat is being transferred to food material through conduction/ radiation and the vapours are removed by vacuum pump for condensation. The major advantage of freeze drying include high flavour retention, maximum retention of nutrients, minimal changes to the product structure, texture, shape and color. However, high capital investments and operating costs are the major limitation. The final product obtained with this method are highly hygroscopic and need special hermetic packaging to avoid oxidation as well as moisture gain.

Figure 18. Lab scale Freeze drier/ Lyophilizer

POST-DRYING TREATMENTS

After drying/ dehydration, the produce is subjected to various treatments such as sweating, screening, inspection, pasteurization *etc*. However, the type/ kind of treatment to be given depends on the nature of the fruit/ vegetable and their intended use thereafter.

Sweating/ Conditioning:

It is the process of holding the dehydrated produce in boxes/ bins for equalising the product moisture content. This is generally done for fruits after removing them from the dehydrator. The moisture retained in the dehydrated fruit pieces might not be equally distributed among all the pieces due to variation in their size and their location in the dehydrator. Conditioning is the process used to equalize the moisture content among the dehydrated fruits for reducing the risk of mold growth during storage.

For conditioning, the dried/ dehydrated fruits are cooled to room temperature and then packed loosely in plastic/ glass jars which are sealed air tight and kept standing for 7- 10 days. The excess moisture in some pieces will be absorbed by the drier pieces. The jars should be shaken daily to check the moisture condensation and to separate the dried fruit pieces from sticking to each other. If condensation is observed in the jar, the fruit pieces are returned to the dehydrator for more drying.

Screening:

It is the process of removal of dehydrated produce of unwanted size which are often referred to as 'fines'.

Inspection:

It is the process of checking the final dehydrated material just before packing for removal of foreign particles, discoloured pieces and other imperfections such as skin, carpel, or stem particles.

Pasteurization:

Foods exposed to insects before or during the drying process should be pasteurized to destroy insect eggs. This can be done in two ways as described below:

Heat pasteurization:

It is done in a pre-heated oven at 80°C where the dehydrated food material is spread loosely, not more than 1 inch deep, on trays. Only two trays are kept in the oven at one time. Heat brittle, dried vegetables for 10 minutes; and fruits for 15 minutes. Oven pasteurizing results in additional loss of vitamins, and may scorch food.

Cold pasteurization:

It is done by sealing dried food material in heavy freezer containers (bags or boxes) for about 48 hours to kill insects and insect eggs. Later, the sealed containers are removed and allowed to reach room temperature before packaging for permanent storage.

PACKING & STORAGE

Packaging has a great effect on the shelf-life of the dehydrated produce. The packing material should protect the dehydrated food commodities from external moisture, light, air, dust, micro-flora, foreign odour, insects and rodents. The packing material should also provide strength and stability to maintain the products original size, shape and appearance throughout its storage, handling and marketing. Also, in general it is recommended to pack the dehydrated foods in smaller packets as the packing once opened could lead to moisture absorption and quality deterioration. Traditionally, in the arid regions the dehydrated material is stored in large gunny bags and are marketed in loose without appropriate packaging. Hence there is a great need to standardise the type of packing material for each kind of dehydrated product for increasing their shelf-life as well as marketability.

Fruit that has been sulphured should not touch metal as the sulphur fumes react with the metal to cause colour changes in them. Hence, they are packed in polythene bags before storing in metal cans. Foods that are packaged seemingly "bone dry" can spoil if moisture is reabsorbed during storage. Hence, regular check during storage is necessary to see if they are still dry. Glass containers are excellent for storage as the moisture condensation could be easily seen from outside. Foods affected by moisture, but not spoiled, should be used immediately or redried and repackaged. Moldy foods should be discarded. Vacuum packaging is also a good option as it increases the shelf-life of the dehydrated food material through exclusion of oxidative deterioration of dehydrated food material.

Packaging tips

- The material should be water proof. Eg. Tin boxes/ drums (for long term bulk storage) and cartons lined with metallic sheet/ polythene (for small retail packages).
- Maintain product moisture is not only the requirement, we should also reduce the inner moisture using desiccants placed into hermetically sealed packing material.
- Dehydrated products undergoing oxidative degradation are sensitive to atmospheric oxygen and need to be packed under vacuum or in inert gases.
- Opaque packing material protects the dehydrated food material from sun/ artificial light which render them discoloured in general.

All safe packaging material must be food grade. Approved by FDA as not containing or transferring chemicals hazardous to human health into food, food grade materials are clearly labelled for food use. These include glass canning jars, ceramic containers, plastic freezer bags, plastic freezer containers with tight lids, and freezer wraps of plastic, paper, or foil. Examples of containers not approved for food contact include trash bags and plastic or fibreboard containers that have previously held non-food materials. It is important to package and seal dried foods properly to avoid insect infestation and moisture reabsorption. First, make sure the food has completely cooled and conditioned as packing warm food could result in sweating which might provide enough moisture for mold growth.

Storage

Exposure of dehydrated food material to humidity, light and air decreases their shelf-life hence, they need to be stored in a cool, dark and dry areas such as basement/ cellars. Storage temperature also plays an important role as it determines the rate of physico-chemical, biochemical and microbiological processes. Thus, lower the storage temperature, greater will be the shelf-life of the product.

The storage temperature for dehydrated products should be below 25°C. Dehydrated foods stored at temperatures less than 15°C keep approximately for a year while those stored at 27-32°C begin deterioration within few months. In general, the storage life of dehydrated fruits and vegetables doubles with every 10°C drop in storage temperatures. Lower storage temperatures (0-10°C) help maintain taste, colour and rehydration ratio along with vitamin c content to certain extent.

REHYDRATION/ RECONSTITUTION

This is the process of soaking the dried food material in water in order to restore it to the condition similar to when it was fresh. This enables the food product to be cooked as that of fresh fruits/ vegetables. There are certain factors which influence the rehydration process of dried/ dehydrated food material such as time, temperature, air displacement, and pH. Time for reconstituting will depend on the size and shape of the food and the food itself. Most dried fruits can be reconstituted within 8 hours, whereas most dried vegetables take only 2 hours. Rehydration rate could be accelerated by ultrasonic treatment of the dehydrated product to be rehydrated. Gamma radiation increases the rehydration rate of freeze dried products. To prevent growth of microorganisms, dried fruits and vegetables should be reconstituted in the refrigerator. One cup of dried fruit will yield approximately 1½ cups of reconstituted fruit. One cup of dried vegetable will yield approximately 2 cups of reconstituted vegetable. Reconstituted fruits and vegetables should be cooked in the water in which they were soaking. The level of reconstitution/ rehydration is evaluated by rehydration coefficient and rehydration ratio.

$$\textbf{Rehydration ratio} = \frac{[(\text{Wt. of drained rehydrated sample (g)}]}{[\text{Wt. of dehydrated sample (g)}]}$$

Rehydration coeffecient

$$= \frac{\text{Drained Wt.of rehydrated sample (g)} \times [\text{100-moisture content of sample before drying}]}{[\text{Wt.of dried sample (g)-moisture content in dried sample}] \times 100}$$

PRODUCT QUALITY

Nutritive value

The nutritional composition of the food material is greatly influenced by the drying/ dehydration process. There is a huge variation in the nutritive values of the dehydrated products due to variations in the preparation procedures, drying temperature, time, and storage conditions. However, the nutrient losses during preparation of fruits and vegetables exceeds the losses caused by the actual drying process. Vitamins like ascorbic acid and β-carotene are largely destroyed by heat and air. Though sulphite treatment could prevent loss of certain vitamins, it causes deterioration of thiamine. Major loss occurs during blanching treatment of arid vegetables where in the water soluble vitamins such as vitamin C and B-complex get leached out. However, losses of vitamins such as β-carotene, vitamin C and thiamine during dehydration and storage is reduced by blanching process.

Fat soluble vitamins (A, D, E and K) are mostly contained within the dry matter of the food material and gets concentrated during drying. Water being a solvent for heavy metal catalysts promote oxidation of unsaturated nutrients. With dehydration, the water gets removed from the food material rendering the catalysts more reactive and thus accelerating the rate of oxidation. The fat soluble vitamins are lost to a certain extent by reacting with the peroxides produced through lipid oxidation. The storage losses could be reduced with low oxygen concentration coupled with exclusion of light and low storage temperatures. However, the total calories provided by dehydrated food material is relatively high compared to their fresh counter parts as the nutrients get concentrated during drying.

Texture

Textural changes of the dehydrated solid food material is one of the major quality deterioration process. The textural changes of the dehydrated material is largely dependent on the nature and extent of pre-treatments, type and extent of size reduction, peeling, etc. which directly affect the texture of dehydrated arid fruits and vegetables. For the commodities which are blanched before drying, the textural loss occurs through gelatinisation of starch, crystallisation of cellulose and localised variations in the moisture content during dehydration. These results in development of internal stresses resulting in compression and rupture of rigid cell walls that distort permanently giving a shrunken shrivelled appearance to the dehydrated food material. During rehydration, the product absorbs water more slowly and couldn't regain the firm texture as that of the fresh material.

Rate of drying as well as temperature have considerable effect on the texture of dehydrated foods. In general, rapid drying at high temperatures results in greater textural changes compared to moderate rate of drying at low temperatures. While drying powders, the textural properties are related to their bulk densities and the ease of their rehydration. However, these properties are determined by the composition of the food material, method of drying, and particle size of product. The fruit juices from arid fruits such as bael, phalsa, mulberry etc. could be readily formed into free flowing powders compared to high fat food products such as whole milk.

Flavour and Aroma

The heat applied for drying/ dehydration not only vaporizes internal moisture content but also cause loss of volatile components of the food material. However, the extent of loss depends mainly on the temperature, solid concentration of food material, vapour pressure of the volatiles and their solubility in the water vapour released from the food material. Volatiles with relatively greater volatility and diffusivity are lost in the early stages of drying while few volatile components are lost in the later stages. Thus there should be control of drying conditions during each stage for minimising the volatile losses.

Another major cause for loss off flavour is oxidation of pigments, vitamins and lipids during storage. The dried food material has open porous structure which allows free movement of oxygen into the product. The rate of deterioration is dependent to a large extent over the storage temperature as well as water activity of the dehydrated food material. However, the flavour changes due to oxidative / hydrolytic enzymes are prevented in the fruits through application of sulphur dioxide/ ascorbic acid/ citric acid, in fruit juices through pasteurisation and in vegetables through blanching.

Innovative methods for flavour retention

- Recovery of volatiles and their addition during drying.
- Adding granulated volatiles formed by mixing recovered volatiles with flavour fixing compounds to the dried product.
- Supplementation of enzymes/ activation of naturally occurring enzymes for producing flavour from their precursors present already in the dehydrated food material

Colour

During drying, the surface textural characteristics of food material changes resulting in an altered reflectivity as well as color. Various structural changes occur in the carotenoid as well as chlorophyll molecules due to the heat and oxidation occurring during drying. This is clearly visible during drying of arid leafy vegetables such as methi, coriander, moringa, curry leaf etc. In general, longer drying time and higher temperatures results in greater pigment losses. Oxidation reactions coupled with residual enzyme activity results in browning of dehydrated produce during storage. This kind of non-enzymatic browning was observed in dry dates (*chhuhara*) during storage. However, these enzymatic and non-enzymatic browning could be successfully prevented to certain extent with improved blanching techniques as well as treatment with ascorbic acid/ sulphur dioxide.

DEHYDRATED PRODUCTS

Aonla Candy

Fully mature fruits are thoroughly washed after sorting and grading. The fruits are blanched/ cooked for short time for facilitating easy separation of segments. The fruit segments are immersed in a thin sugar syrup for 24 hours at room temperature. Later the segments are removed from the syrup, and the syrup concentration increased to 70 °Brix by addition of additional sugar and re immerse the aonla segments in the thick syrup for 24 hours. After removal from the syrup, the segments are well drained and dipped in hot water (40-50°C) for 3-5 seconds to remove the surface coated sugar and dried in an air circulating tray drier at 60°C till the moisture content is reduced to 12 to 15 per cent. Best quality candy is prepared from bold sized fruits of cultivars Krishna, Chakkayya, and NA-7.

Figure 19. Freshly harvested mature aonla fruits and processed aonla candy

Aonla mouth freshener

Aonla is one of the imprtant arid fruit crop with commercial significance. It is under culitvation in India since time immemorial and is highly valued for it nutritional value especially its rich content of vitamin C (400-600 mg/100 g). The fruits also posess significant amounts of tannins that protect the ascorbic acid form oxidation. Traditionally the aonla fruits are used for making preserve (*Murabba*), pickle, candy, jam, jelly, squashes etc. With the changing life style of consumers there is a great need for developent of novel food products with incorporation of healthy and natural food components. Thus at ICAR-CIAH, we have develoeped two kinds of mouth freshener *i.e.* sweetened and salted. The major components used in developing sweet version include grated aonla pulp, crushed beet root, fennel and sugar candy. While the salted version was prepared using ginger extract, salt and black pepper powder. Aonla being the base material serves as a nutrient base, Beet root/ turmeric extract acts as a source of natural food colorant, Sugar candy acts as a sweetening agent and Fennel / Ginger extract gives the required flavor and aroma for the product. The developed products are shelf stable and could be stored for about 12 months at room temperature when packed hermetically.

Figure 20. Aonla based mouth freshener (i) sweet type, (ii) non-sweet type

Anardana

Anardana is an acidulant spice used in the Indian cuisines for giving sour-sweet taste. It is prepared from the dried seeds of pomegranate fruits wherein the seeds are dried along with adhering pulp. They can be consumed as such or in grounded form. Their sweetish astringency makes them a popular acidulant for Indian dishes where they serve as an alternative to amchur (mango powder)/ tamarind. At ICAR-CIAH, a pomegranate variety namely Goma Khatta was released specifically for the anardana purpose. It is known to have medicinal and smoothening effects on the stomach, as well as good for the heart.

Figure 21. 'Anardana' preparation from sour genotypes of pomegranate

Cluster bean *(Cyamopsis tetragonaloba)*

Cluster bean/ gaur bean is an annual legume rich in soluble fibre content. Beans are very nutritious and consumed after heat treatment like blanching to destroy the trypsin inhibitor and other anti-nutritional factors. They have several health benefits as it was known to lower the blood cholesterols. They are consumed both as vegetable and powdered form. The fruits are blanched (80°C) for 10 minutes and then dried under sun or in an air circulating tray drier till the fruits become brittle. The dehydrated cluster bean can be stored for one year with appropriate clean packing and storage. These fruits could be rehydrated prior to use as a cooking vegetable.


Figure 22. Different grades of dehydrated cluster bean pods

Dry dates *(Chhuhara)*

Chhuhara is prepared from doka/ khalal staged fruits. The freshly harvested fruits are stripped from the strands and washed under running water for removal of dust and dirt. Later the fruits were dipped in boiling water (80 ± 2 °C) for 5-8 minutes and cooled immediately by placing in normal water to avoid over cooking. Later they were dried in air circulating tray drier at a temperature of 70°C for 30 to 35 hours. The recovery of dry dates/ chhuhara for the cv. Medjool was in the range of 55 to 56 per cent.


Figure 23. Dry dates prepared from cv. Medjool (i) No pre-treatment, (ii) Pre-treated with Ascorbic acid

During sorting, grading and packaging of fresh dates the bruised, and partially damaged fruits are culled out which could be cut into small pieces of uniform size either manually or through any shredder and dried in an air circulating drier till the pieces become brittle and crunchy. These dry date bits could be used as a tasty cum healthy snack alone or together with the morning breakfast cereals like oats and corn flakes.

Figure 24. Dehydrated date bits prepared from culled date

Green Leafy vegetables

Green leafy vegetables are multi-cultural components used ubiquitously in Indian cuisine. They are rich sources of calcium, iron, β-carotene, vitamin C, dietary fiber and many other trace minerals. A large number of leaves from different sources *viz.* perennial trees (moringa, curry leaf) and annuals such as methi, coriander *etc.* are consumed on regular basis in the arid rural areas. These vegetables are an economic source to ensure the micronutrient intake. Annual green leafy vegetables are seasonal and also highly perishable due to their high water content. There are heavy losses due to non-availability of sufficient storage, transport and proper processing facilities at the production point. Thus there is a great need to preserve these nutrient rich vegetables through simplest means of preservation like drying and dehydration. Solar radiation being abundantly available in the arid regions could be efficiently used for cost-effective processing of green leafy vegetables, especially when they are abundantly available.

Dehydration of leafy vegetables not only preserves the perishable raw commodity against deterioration, but also reduces the cost of packaging, handling, transport and storage. Reduced water activity not only retards the microbial activates but also prevent various undesirable reactions during storage. In recent years, exhaustive efforts have been made for an improvement in the nutrient retention of dried products by altering processing methods and/or through pre-treatments. Blanching is a major prerequisite for preservation of green leafy vegetables as it prevents the formation of off-flavors, odors and colors. However, it may cause partial destruction of some nutrients like ascorbic acid. The optimum conditions of blanching, time and temperature, are necessary and need to be standardised to achieve the desired quality of end products. Pre-treatment of green leafy vegetables with potassium metabisulphite was found to reduce the extent of vitamin loss especially Vitamin C during drying/ dehydration process. While addition of alkalizing agents like magnesium carbonate during blanching was found to prevent the degree of chlorophyll degradation through subsequent formation of pheophytin. For effective drying of fenugreek, the water blanching should be followed by a dip in potassium metabisulphite and drying in a low temperature drier (Negi and Roy, 2000).


Figure 25. Dehydrated moringa and fenugreek leaves

Karonda *(Carissa congesta)*

Karonda is a hardy underutilized fruit crop of the arid regions with high nutritional value. The fruits are the richest source of Iron (Fe) among all the fruit crops and hence recommended for treating anaemia. They are also good in calcium and vitamin C content. The unripe fruits are sour and astringent in taste, hence used as vegetable, or in preparation of chutney and pickles locally. The storage life of karonda is very short because of its soft flesh and high moisture content. Karonda remains unexploited commercially owing to lack of standardized postharvest and value addition technology. The fruits can be dehydrated with or without seeds. Among various treatments tried, small size unripe fruits (2.0 to 2.5 g) as whole blanched for 3 minute and treated with sodium benzoate (0.1 %) was found to be superior for dehydration of karonda. These dehydrated fruit can be used as mouth freshener, chutney, vegetable and powder making. Dehydrated karonda powder was found to be good in organoleptic taste for tartness and masala mixture due to their typical sour taste.

Figure 26. Dehydration of mature karonda fruits

Kachri (*Cucumis callosus*)

Kachri is a drought hardy cucurbit growing naturally or cultivated under rain fed conditions by rural people for their food security. The fruits are rich in protein and are widely used as vegetable in arid regions of India. Mature fruits are generally used in various culinary preparations, pickles, chutneys and as garnishing vegetables/ salad. Mature kachri fruits are often dehydrated with or without peel for off-season use. This fruit also has great significance in the socio, cultural and religious occasions of desert inhabitants. Mature fruits are traditionally peeled and dried as such or after making into slices that can be stored for longer periods. The dehydrated fruits have greater potential for commercial exploitation either as such or in powdered form due to their nutritional significance.

Figure 27. Dehydrated kachri

Kachri RTU curry powder

Dried kachri powder has a distinct tangy taste which gives special flavour to the cooked food. It is used as a souring agent in various traditional cuisines of north-west India. The proteolytic enzymes present in it are very much useful for digestion of proteins aiding in repair of our body along with reduction of harmful acids. It is known to exert cooling effect, improve appetite, easy bowl syndrome, relives stomach pain, vomiting and constipation. Dry kachri powder is being blended with various Indian spices to produce masala products, meat tenderizers *etc.* Hence, an attempt was made to develop a ready-to- use curry powder using kachri powder as the base raw material. Other major ingredients include snap melon (*khelra*) powder, moringa leaf and curry leaf powders, coriander powder, cinnamon, black pepper *etc.*

Figure 28. Kachri based curry powder with its ingredients

Kachra/Snap melon (*Cucumis melo*)

The fruits of snap melon are rich in carbohydrates, vitamins, minerals, antioxidants and dietary fiber content while the keeping quality is very low due to high pulp and moisture content. The fruits are generally consumed as a table fruit for salad in the household of elite classes and restaurants during hot months of the year. During peak season, the fruits are sold at throw away prices which could be effectively processed using dehydration for off-season consumption. The dried/ dehydrated snap melon fruits are called as *khelra* locally in the western Rajasthan. The dehydrated slices of snap melon are used to prepare vegetable (pure or mixed), fried chutney, or as a food seasoning agent round the year.

Figure 29. Fresh and dehydrated snap melon

Khejri (*Prosopis cineraria*)

The fruits/ pods get ready for harvest within 20 days of fruit set. The green tender pods at papery soft seed stage are harvested for '*sangri*' purpose while fully ripe pods are collected for preparation of cookies. For dehydration purpose, immature soft seeded green pods with low tannin and fiber content are found to be highly suitable. The immature green pods are harvested manually while the mature ripe pods (*khokha*) could be collected from ground also. Sorting of green pods after harvest for removal of unwanted intact plant parts, and for discarding mature cum infected pods is essential for getting good quality final product. The pods are graded into different stages based on their size and maturity for further processing. The tender green pods are blanched in 2 per cent salt solution with 0.1 per cent KMS (Potassium Metabisulfate) for 5 minutes before drying under sun for 12-14 hours. The recovery percentage was about 24-28 per cent without significant loss in quality and appearance.

Figure 30. Different grades of dehydrated *sangri* (Khejri)

The ripe pods (*khokha*) with fully mature seeds are rich in proteins and are used as a potential animal feed. The dried ripe pods are powdered and used for preparation of bakery items such as biscuits or cookies. The *khokha* powder (Dry ripe pod flour with seed) replacing 15 per cent of the traditional maida in biscuits was standardised to be the best treatment for fortification using dried khejri pods.

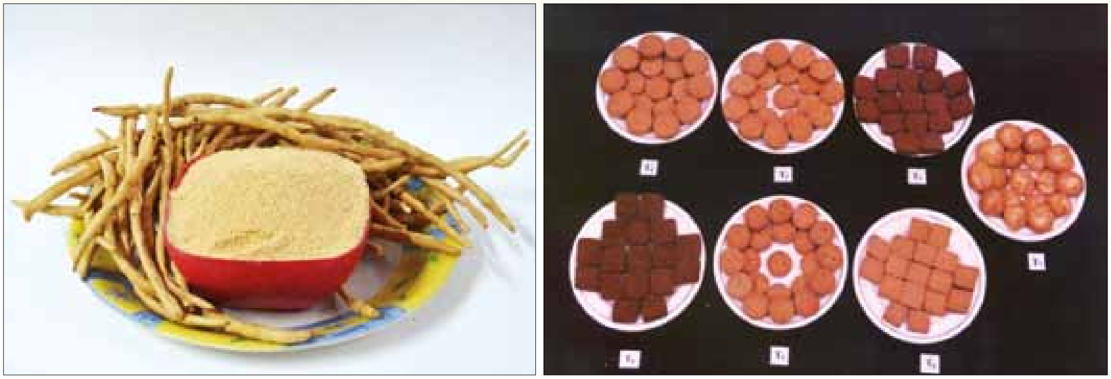

Figure 31. Dried ripe Khejri pods (*Khokha*) and cookies prepared from khokha powder

Ker (*Capparis decidua*)

The fruits are consumed as vegetable or pickles only after processing as the mature unripe fruits are unpalatable due to higher concentration of glucosinolates. They are rich sources of protein and β-carotene in fresh as well as processed forms such as blanched, dried and roasted. The furits are dried/ dehydrated for off-season utilization by the desert dwellers. The recovery percentage after drying the fresh mature unripe fruits is about 25 per cent *i.e.* one kg of fresh immature fruit yields about 200-240 g of processed dried fruit. The dried ker fruits are graded into three classes based on their size *i.e.* big, medium and small which depends on their stage of maturity at the time of harvest. The processed dried fruits could be stored in flexible polythene bags for one year without any spoilage and quality deterioration.

Figure 32. Dehydrated ker fruits

Kumat (*Acacia senegal*)

Though kumut is primarily grown for gum extraction, the pods are rich source of protein and hence used as vegetable by the tribal people of western Rajasthan. They constitute one of the major component of the traditional desert dish *i.e. Panchkutta*. The fruits (pods) ripe during September to November under Indian conditions and at maturity some pods split while the color changes from green to yellowish to brown. Seed are extracted from pods and dried for off-season use. The seeds are blanched with salt water for 6 minutes before drying. The quality of the dried kumut seeds was best when they are blanched in 3 per cent slat solution and dried in a solar drier. When the dried seeds are packed in 250 guage polybags they could be safely stored for about 6 months at room temperature.

Figure 33. Mature fresh and Dehydrated kumut

Lasora/Gonda (*Cordia dichomata*)

The tender fruits are mostly consumed as vegetable while they are also dried for off-season consumption. The tender fruits can't be stored for longer periods at room temperature as they turn yellow and ripe rendering unfit for use as vegetable/ for pickling. Blanching of tender unripe fruits is essential before dehydration process. For getting good quality end product, the tender unripe fruits are blanched in solution containing salt and sugar (1:1) at 80°C for 8-10 minutes followed by sudden cooling in tap water and dipping in 0.2 per cent KMS for 30 minutes. Destoning is also done before dehydration. The destoned pulpy halves could be dehydrated directly under sun or with mechanical driers. The dried pieces are packed in polycontainers and could be used for various culinary preparations after rehydration.

Figure 34. Dehydrated lasora (i) Blanched & destoned (ii) Unblanched, (iii) Blanched

Panchkutta

Panchkutta is a traditional prestigious dish of the western Rajasthan, which is prepared from five food crops grown in the great Indian Thar Desert *viz*. sangri (*Prosopis cineraria*), ker (*Capparis decidua*), kumat (*Acacia senegal*), kachri (*Cucumis callosus*) and gonda (*Cordia myxa*). The proportion of these components used for this delicious dish include 50 g sangri, 35 g ker, 50 g kumat, 25 g gonda and 10 pieces of kachri which were all soaked overnight before cooking with salt and turmeric powder for 10 minutes. In certain regions, the kachri and gonda are being replaced with kamal dandi (lotus stem) and aamchur (dried mature mango) based on the local availability and preferences.

Figure 35. '*Panchkutta*' dish and its ingredients

Phogla (*Calligonum polygonoids*)

Phogla is prepared from the unopened flower buds of phog plant. Phog is an evergreen xerophyte of arid Rajasthan used for feeding animals during extreme drought. For phogla preparation, the twigs are clipped when the flowers are in unopened bud stage and shade dried for 4-5 days. As the moisture loss occurs, the flower buds get dried and with slight threshing all the flower buds get separated from the phog twigs. These dry flower buds of phog are popularly known as phogla which are generally consumed with curd based preparations *viz*. raitha.

Figure 36. Phog flower buds (i) Freshly harvested, (ii) Dried

PROBLEMS ENCOUNTERED

Enzymatic reactions, which are not completely understood, but which are very slow at low a_w values, due to lack of mobility of the substrate to diffuse to the active site of the enzyme.

Non-enzymatic browning (NEB), a water-dependent reaction with maximum reaction rates around $a_w = 0.6–0.7$.Water is also a reaction product. Too much water inhibits the reaction by dilution, too little gives inadequate mobility.

Lipid oxidation, a reaction that is fast at both low and high values of a_w, slow at intermediate values.

Loss of nutrients, for example vitamin B or C losses due to breakdown at high temperatures.

Loss of volatiles, for example flavors and aromas, from the product.

Release of structural water, which changes food texture. Softening of texture at high moisture, hardening at low moisture (water acts as a plasticizer of the food material).

Differential shrinkage: Outer layers shrink more relative to inner layers, leading to either surface cracks or radial cracks.

Surface wetting effects: Moisture works on the product surface to expand pores and capillaries.

Case hardening: A hydrophobic layer may be formed in oil-rich or proteinaceous products during rapid drying of outer layers, which traps moisture inside the product.

Cell collapse: Cells may collapse if internal moisture is removed, leading to the product shrinking and the surface becoming wrinkled, for example in prunes or sultanas.

GLOSSARY

Free moisture: Moisture content in excess of the equilibrium moisture content (hence free to be removed) at a given air humidity and temperature.

Bound moisture: Liquid physically and/or chemically bound to solid matrix so as to exert a vapour pressure lower than that of pure liquid at same temperature.

Psychrometry: Psychrometry is the science of studying the thermodynamic properties of moist air and the use of these properties to analyze conditions and processes involving moist air. Moist air is a mixture of dry air and water vapour. In atmospheric air, water vapour content varies from 0 to 3% by mass.

Water activity: Ratio of vapour pressure exerted by water in solid to that of pure water at the same temperature.

Critical moisture content: Moisture content at which the drying rate first begins to drop (under constant drying conditions)

Equilibrium moisture content: The moisture level at which a product is in equilibrium with the moisture of its surrounding air.

Falling rate period: Drying period under constant drying conditions during which the rate falls continuously with time.

Sorption Isotherm: It is the graphical representation of relationship between water content and equilibrium humidity of any material at equilibrium.

Adiabatic saturation temperature: Equilibrium gas temperature reached by unsaturated gas and vaporising liquid under adiabatic conditions. Only for air/ water system, it is equal to wet bulb temperature.

Constant rate drying period: Under constant drying conditions, drying period when evaporation rate per unit drying area is constant (when surface moisture is removed)

Dew Point: Temperature at which a given unsaturated air-vapor mixture becomes saturated

Dry bulb temperature: Temperature measured by a (dry) thermometer immersed in vapour-gas mixture

Wet bulb temperature: Liquid temperature obtained when large amount of air-vapor mixture is contacted with the surface. In purely convective drying, drying surface reaches wet bulb temperature during constant rate period.

Humid heat: Heat required to raise the temperature of unit mass of dry air and its associated vapour through one degree ($J\ kg^{-1}\ K^{-1}$)

Absolute Humidity: Mass of water vapour per unit mass of dry air

Relative Humidity: Ratio of partial pressure of water vapour in gas-vapour mixture to equilibrium vapour-pressure at the same temperature.

Desorption: The process of movement of water molecules outside the product through diffusion to its outer surface in order to evaporate to an air boundary layer for being carried away by the air stream is known as desorption.

Adsorption: The reverse process of desorption, where in the water condenses over the surface is known as adsorption

Absorption: the process of movement of water into the product from the surface is known as absorption.

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