STUDIES ON DRYING OF FISH USING A BARC- TYPE SOLAR DRYER

by

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THESIS

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Dedicated to

My father

With

Love and gratitude

DECLARATION

I hereby declare that this thesis entitled **"STUDIES ON DRYING OF FISH USING A BARC- TYPE SOLAR DRYER"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, or other similar title, of any other university or Society.

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INTRODUCTION

1. INTRODUCTION

Drying has been in practice since time immemorial for preserving foods including fish. Sun drying, salting, smoking, etc., are considered as traditional methods of preserving fish. Dried or cured fish forms an important part of the diet of a large section of world's population.

Drying and salting were once the most important means of fish preservation. However, with the advent of modern techniques of preservation such as freezing and canning, the importance of older methods were reduced, but not totally lost. Even today drying and salting are widely practiced particularly in the developing countries. According to one report, about 8 million tons of fish, accounting for 20-30 % of the world catches, are being dried, salted or treated by a combination of the two (Kamruzzaman, 1992).

However, the gap between demand and supply of fish is widening on account of increase in population, poor post harvest handling, lack of processing and storage facilities, etc. It is estimated that about 21 % of the harvest is still being lost due to inadequate post harvest processing.

In India the extent of utilization of dried and salted fish comes next to fresh fish. Since past few years there has been a decline in the export of dried and cured fish products from India possibly on account of low quality of the products (Sugumar, *et al.,* 1995).

The major reason for the popularity of methods such as drying is that the cost of production and preservation IS rather low; sun drying hardly involves any expenditure as sun's radiation is plentifully available free of cost. However, sun drying does have several drawbacks.

- It is dependent on weather conditions
- Drying cannot be carried out after sun set.
- Chances of contamination with sand, filth, maggots, microorganisms, etc., are high

- Factors that influence drying cannot be properly controlled
- The process is slow, requiring long periods for drying

These together with improper packing and storage conditions make the products of inferior quality. Several market surveys have been conducted in India for various dried and cured products. Some of their important findings are:

- higher contamination with microorganisms, maggots, dirt and sand,
- improper drying- either inadequate drying or over drying- resulting in poor reconstitution properties, breakages, putrefaction, etc.,
- improper packaging- in gunny bags, baskets, etc.,
- unhygienic conditions of storage,
- foul odour and discolouration on account of bacterial and fungal growth and rancidity development, and
- use of stale fish for processing.

To overcome these difficulties several types of mechanical dryers have been designed. Products with superior quality could be produced as it is possible to control many of the parameters that influence quality and drying rate such as temperature, humidity and air velocity. Drying period and extent of contamination could be substantially reduced. Further, dryers can be operated on all days irrespective of weather conditions and time of the day.

However, the major difficulties with mechanical dryers are the high investment and operational costs. Unless drying is done on a fairly large scale, operation of such equipments may not be viable. Therefore mechanical dryers are not very popular amongst the small scale entrepreneurs. It must be noted that in a country like India majority of those involved in drying or salting of fish belong to the low income group.

With the intension of improving sun drying methods, but at a low cost, several kinds of solar dryers have been designed. Many of them are being used commercially in several parts of the world. Solar dryers make use of sun's radiation as fuel. The investment and maintenance cost are minimal and hence affordable even by the poor fishermen. However, solar dryers do have some of the problems associated with conventional sun drying. Drying rate parameters can only be partially controlled in most of the cases. The equipment is inoperable during night or rainy days. Research is underway in further improving upon the design and functioning of the solar dryer.

A solar dryer designed by Nair *et al.,* (2009) at Bhabha Atomic Research Centre (BARC), Trombay, has been found suitable for drying various agricultural produces. The equipment is simple in construction, compact and efficient.

In the present study the possibility of adopting the BARC model for drying seafood was looked into. The equipment was suitably modified in order to obtain proper drying conditions. The efficiency of the equipment was studied in comparison with conventional sun drying. Quality variations of two products, viz., dried prawn and dry salted fish were also subjected to study. The observations are expected to help in optimizing the conditions for drying fish products in the shortest time with minimum effect on product quality. The dryer can then be popularized for commercial drying of fish particularly amongst the small scale entrepreneurs.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 Drying:

Fish drying can be found in the ancient civilizations of every country, and some of the traditional methods are still in use. Reduction in the water content or its complete removal will proportionately retard or totally stop all microbial and autolytic activities, thus preventing spoilage and resulting in preservation (Janson, 1956).

The most basic practice of leaving fish to dry on the beaches or rocks in hot sun can still be seen in parts of Asia and South America (Cutting, 1956). Traditionally, sun drying is carried out in the open air using the solar energy to evaporate water in fish by natural currents (Burgess *et al.*, 1965). Sun drying depends upon air velocity, temperature and relative humidity. Fish may be used as whole, split opened or filleted so that water in the liquid phase will diffuse from the fish flesh to its surface, and evaporate into the surrounding air (Janson, 1965).

According to Waterman (1976), air movement at ground level is comparatively slow and sun drying can be improved considerably by raising the fish off the ground on wooden frames. This, in addition, reduces contamination from dust and sand. The method, however, suffers from the vagaries of the weather, contamination from wind blown dirt and dust, insect attack, pilfering by birds, rodent and domestic animals, and chemical contaminants such as insecticides.

In tropical regions large quantities of small fish are often dried using traditional methods. However they suffer from great problems with insect infestation, sand and silt both during and after drying.

Williams (1977) reported that mechanical dryer provide the best control of quality, but is expensive. The equipment is generally composed of a fan, heater, air inlet, exhaust, and a chamber in which the fish are either hung or supported on mesh trays. The air moves around a closed cabin and out through the exhaust vent. The Torry kiln developed at the Torry Research Station, Aberdeen, has been widely accepted in the industrialised countries (Doe *et al.*, 1977). The disadvantage is the requirement of high operational cost.

Controlled solar drying, however may overcome many problems of conventional sun drying. It operates above 45°C at which fly maggots cannot survive, the rate of drying is high, etc. (Anon., 1977). Even so, air drying is a lengthy process. When drying is carried out in natural conditions, the quality may be rather variable. As reported by Connell (1980) some slight fermentation producing cheesy flavors during drying may be acceptable or even desired by connoisseurs, but adverse weather conditions can lead to loss because of putrefaction during the early stage of drying. According to a study conducted by Harendar *et al.* (2005) it takes 10 days to bring down the moisture content down to 9.9% by the conventional sun drying and in addition, the odour is not retained. Karthikeyen *et al.* (2007) reported that the moisture content of seven species of dried fish varied from 6.8 to 19.9% and the protein content from 52.7 to 60.5%.

2.2 Solar dryer:

Doe *et al.* (1972) designed a tent dryer that was found suitable for fish. A maximum temperature of 48°C was obtained inside while the ambient temperature remained at 27°C. A type of solar dryer designed specially for the Bangladesh fishing industry is in the form of a plastic tent with clear polythene sheeting (Doe *et al.*, 1977).

Peters and Newton (1980) described a tunnel dryer suitable for drying salted fish. The dryer, 1m long by 1.6m wide by 1.8m height, provided for control of both temperature and humidity. Air velocity was variable up to 4.5m / s. Baird *et al.* (1981) described a fish dryer provided with separate solar collector that is being used commercially in Florida. Although drying air may be heated by solar collectors in most areas, economic feasibility has not been determined for most locations.

Wheaton and Lawson (1985) recommended an air velocity of 1-2 m / s for economic drying of fish. According to them most spoilage bacteria cease to grow below a moisture content of 25% (wet weight basis), while moulds rarely grow below 15%. However normal spoilage moulds and bacteria cease to grow below 35-45% moisture in the presence of salt.

A comprehensive study of solar dryers, including dryer selection and design has been published by the Commonwealth Scientific Council (Brenndorfer *et al.*, 1985). There is a particular difficulty with agro-waste dryers in obtaining a suitable air flow without raising the air temperature to such a degree that the fish is not cooked. Provision of fans, and a suitable heat exchanger could overcome this problem (National Acadeamy, 1988).

Balachandran *et al.* (1989) observed that drying fish on cement platform was slightly quicker than that in tent dryer due to the effect of high velocity wind. No significant variation in the bacterial count and total volatile base nitrogen content were noticed between the samples dried either way.

Mukherjee *et al.* (1990) designed a greenhouse type solar dryer of dimensions 3 m height and 2.5 m breadth for fish drying that could reduce the moisture content sufficiently within 2-3 days of drying. Nair *et al.* (1994) thermally treated fish products in solar tent dryer that was maintained at 55°C and then stored at room temperature. They obtained a shelf life of 1-2 months for control (unheated) and four months for heated.

Moorjani (1998) dried Bombay duck in a solar dryer to a moisture content of 16-17% in 14 h. The material was then roller pressed and further dried to a moisture content of 14% at which the product could be well preserved.

According to Doe (2002) an increase in temperature from 30 to 35°C in a solar dryer will reduce the relative humidity of air from 85% to less than 65% which is sufficient to prevent the growth of most moulds. In 2007 he proposed a mathematical model that established partial differential equations for fish weight, air temperature and humidity.

Krishnakumar *et al.* (2004) designed a solar dryer of approximately 15-20kg capacity per load that was found to be 100% more efficient than conventional sun drying in terms of the time taken for drying.

Das and Tiwari (2008) observed that convection heat transfer coefficient was higher for forced convection than for natural convection during greenhouse drying of prawn (*Macrobrachium lamaarrei).* Reza *et al.* (2008) used a Hohenheim type solar tunnel dryer for drying five species of fish. Moisture content reached 16% after drying for 36 hours. Drying was carried out at two temperatures, viz., 45-50°C and 50-55°C, the former giving better quality products.

Tiwari *et al.* (2009) worked out an energy analysis for prawn surface temperature, greenhouse room air temperature and moisture evaporated during greenhouse drying of prawn under natural and forced conditions. They observed that drying was faster in forced convection. Sengari *et al.* (2009) developed a rotary solar dryer that required 8 hours for salted fish and 15 hours for unsalted fish to be properly dried.

Nair *et al.* (2009) of Bhabha Atomic Research Centre (BARC), Trombay, designed a foldable solar dryer for drying various agricultural produces. The drying process was found to be faster by up to five times than that of the normal sun drying. Chandak *et al.* (2010) compared a newly designed solar dryer with conventional solar dryer. It delivered almost three times more output if used round the clock.

2.3 Salting:

Storm (1950) reported that salted fish produced for export to warm climates are often dried to final water content below 50%. Salted fish may have water activities between 0.6 and 0.8. However, great proportion of the water has to be removed from any food before subjecting to a long-term storage (Labuza, 1970). Wolf et al. (1971) has described a typical sorption isotherm for fish (Fig.1). Water in zone A is firmly bound by the structural components of the food, or is otherwise unavailable for reaction. In Zone B, the water is loosely bound to the food structures where changes in water content have a profound effect on the water activity. In zone C water is said to exist in solution with food solutes and in capillaries formed by the food structure.

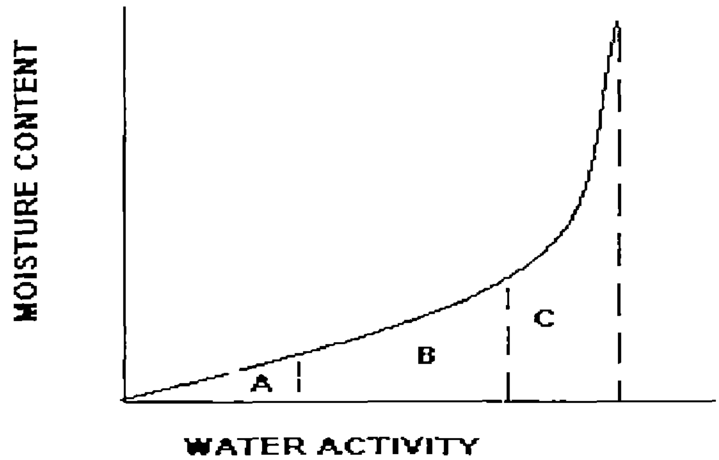


Fig.1: Typical sorption isotherm

Peters (1971), in his definitive work on the subject of mass transfer of solvent and solutes in fish muscle, has demonstrated that water in excess of that necessary to dissolve the salt present diffuses in exactly the same manner as it does in the absence of salt.

In stack salting, only 3-4 kg of s for 10-15 kg fish are used initially (Tanikawa, 1971). The stack salted fish became more popular than the hard salted ones. The size and oil content of fish are the factors governing the technology of salt preservation. Small sized fish and thin flat fish may be salted whole. According to Connell (1980) larger sized fish will have to be eviscerated, split, or opened before salting, the salt otherwise does not penetrate fast enough to prevent spoilage in the centre part of thick whole fish. For oily fishes contact with air should be avoided to prevent oxidative rancidity during and after salting.

According to Llobreda *et al.* (1980), the food borne pathogen, *Staphylococcus,* is able to grow at a_w as low as 0.8. Enzymes of wide spread occurrence such as peroxidases are completely inactivated at a a_w of 0.85 or less. Some hydrolases and lipases are active at a_w as low as 0.3 or 0.1 (Loncin *et al.,* 1980).

Duckworth (1980) reported that the principal effect of NaCl on microorganisms is due to the lowering of a_w, though NaCl itself in higher concentrations may be lethal for some bacteria and yeasts due to osmotic effects. Surprisingly, even sensitive bacteria such as *Salmonella* which contaminate a dried product, may persist as such for some time (Connell, 1980). The water activity of saturated sodium chloride solution is 0.75, which is insufficiently low in itself to inhibit the growth of microorganisms completely (Wood, 1981). Further reduction in a_w can be obtained by air drying and the water content of the fish will be reduced to around 15% (Grantham, G.J.1981).

2.4 Drying rate:

According to Pearson (1982) at a particular stage in the drying process water can no longer diffuse to the surface as rapidly as it is evaporated and therefore, the surface no longer remains wet. The moisture content at this stage is called the "critical moisture content". The rate of drying then will depend on the rate of movement of moisture from inside which decreases as drying progresses and therefore drying rate falls progressively.

Fennema (1982) reported that the rate of drying is controlled by the rate of diffusion of moisture which is influenced by several factors such as composition of fish, thickness of fish, temperature of fish, moisture content and amount of salt added. However, the drying rate at this phase does not depend on the humidity of the air, provided air is not saturated. The drying rate also does not depend on the speed of the air passing over the fish. This phase of drying is called the falling rate period. A typical drying rate curve is shown in Fig.2.

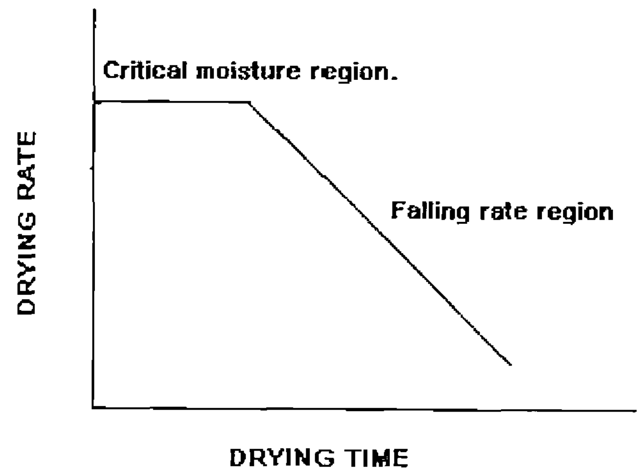


Fig. 2: Typical drying rate curve.

Doe *et al.* (1982) showed how the isotherms of the unsalted fish muscle can be compared with that of salt solutions of different molarities to give what they called sorption isotherm for dry salted fish. The effect is that the water activity is reduced close to 0.75 over a wide range of moisture contents. This will prevent the growth of all pathogenic and spoilage bacteria. Oxidation of lipid is maximized at very low water activity probably because of the concentration of metal catalysts. The reaction of the oxidized lipids with amino acids and protein lead to damage of four limiting amino acids, viz., cysteine, methionine, tryptophan and lysine as reported by Olley *et al.*, (1988).

Salting and drying are effective between bacterial growth and water activity reduction. Doe and Heruwati (1988) modeled this process for sun drying of tropical fish in Indonesia. They showed that different bacteria dominate under certain combinations of temperature and water activity. At high levels of water activity such as > 0.95, bacterial growth is largely determined by temperature. Non-enzymic browning is strongly dependent on a_w that reaches a maximum rate at a water activity range of 0.6-0.7, as in the case of intermediate moisture foods. In the intermediate range of a_w the reactants are all dissolved and that further increase in moisture content leads to dilution of the reactants (Deman, 1990).

During drying the concentration of moisture in the outer layers is less than that in the interior since the outer layer necessarily lose moisture before the interior. This results in surface shrinkage, case hardening, cracking and warping. This type of shrinkage causes moisture gradient and resistance near the surface (Achanta and Okaos, 1996). The shrinkage and drop in diffusivity may combine to give a skin practically impervious to moisture which encloses the inner portion, preventing further removal of moisture. This phenomenon is called case hardening or crust formation (Xiao Dong Chen, 2008).

2.5 Rehydration:

Rehydration is the process of moistening dry material. Mostly it is done by abundant amounts of water. Huss (1988) reported that in most cases dried food is soaked in water before cooking or consumption and thus rehydration is one of the important quality criteria. In practice, most of the changes during drying are irreversible and rehydration cannot be considered simply as a reverse process to dehydration (Lewicki, 1998).

Rahman and Perera (1998) have observed that cooked prawn rehydrate better than raw prawn. The low rate of rehydration is attributed to the irregular changes that generally take place during drying. These include protein denaturation and several damages suffered by the cellular structure. Prolonged soaking of dried prawn before cooking is undesirable as it can be a potential bacteriological hazard.

2.6 Quality changes during drying:

According Basu and De (1938) higher biological values are seen in the case of sun drying than in the case of steam drying. Long storage or excessive heating, particularly when the product is exposed to air, may decrease the physiological availability of the amino acids of fish proteins. This is primarily the result of the formation of enzyme resistant linkages rather than amino acid destruction.

The behavior of drying oils towards atmospheric oxygen is well known, and oxidation is a serious problem for commercial drying of fatty fish and seafood. The flesh of some fatty fish, such as herring, contain a fat pro-oxidant that is not wholly inactivated by heat (Banks, 1950).

According to the observations of Tappel (1955), the nutritive value and the available lysine decreased slightly in dried fish. Particularly important would be the reduction of lysine due to its key role of supplementation effect to fish and fishery products (Reinuis, 1956). Stansby (1957) reported that a carbonyl amine reaction has only a minor part in Maillard reaction. These findings supported the previous theory that the browning discoloration is coupled with off flavors and appearance is associated with changes in the muscle extractives (Jones, 1956).

Protein denaturation of fish meat occurred by the falling of solubility of myofibrillar proteins, disappearance of contraction of muscle fibre by ATP, and lowering of myosin ATPase activity (Connell, 1975). According to Connell (1980), when myofibrillar protein molecule aggregates or dissociates, viscosity or Flow birefringence in the protein solution decreases because of the decrease of particle axis ratio. Flow birefringence is often employed for measuring protein denaturation. The viscosity decreases markedly after rigor in mackerel and yellow tail, but showed no change in sea bass and sea bream even at the post-rigor stage. Peroxides, hydroperoxides, aldehydes, ketones, etc, are the types of products produced by oxidation of fatty acids. Protein-oxidized lipid interactions and their impact on nutritional quality of the protein have been exclusively reviewed by Devadasan (1981).

According to Coxon (1987), determination of hydroperoxides is most suitable to measure low levels of oxidation during storage. The primary products of lipid oxidation are generally not considered to have a flavour impact. Lipid degradation proceeds also by enzymatic hydrolysis. Heating is believed to cause the denaturation of the muscle proteins, even below 60^0C (Sebranek, 1988).

Phospholipids are hydrolyzed most readily followed by triacylglycerols, to produce free fatty acids (Sikorsky *et al.,* 1990). Oxidative rancidity developed in fish is determined by the estimation of peroxide value (PV). At a peroxide value above 20 most fish will smell rancid. For a good fish the PV value should be well below 10.

Lipid oxidation is an autocatalytic chain reaction, which takes place through four main stages: initiation, propagation, chain branching and termination (Hultin, 1992). Fish lipids undergo two main types of changes during storage of fish, viz., hydrolytic changes and oxidative changes. Both these if left unchecked lead to rancidity that will reduce the organoleptic quality and shelf life (Devadasan, 1993). The peroxide values of different dried meat samples were determined by Rahman *et al.* (1999). They observed that the values varied significantly with the methods of drying.

2.7 Quality changes during storage:

TVBN content is a measure of ammonia, trimethylamine, dimethylamine, etc., and would be a useful indicator of decomposition of dried fish products as according to Horie *et al.* (1954). Microbial spoilage takes place when the water activity of the substrate is favourable for the multiplication and metabolic activities of the microorganisms involved.

Organisms are present in slime and gills and may later find entry into the flesh of fish. Meat may become contaminated with heavy bacterial load. The major factors that cause spoilage in dried fish products are bacteria and fungi (Iyer and Joseph, 1966). Apart from organisms in raw meat it may pick up bacteria from surrounding during different stages of preservation and processing. Herschodefer (1968) reported that the important classes of spoilage organisms found in tropical dried fishes and prawns are *Pseudomonas, Flavobacter, Acinetobacter, Aeromonas* and *Moraxella.* The spoilage bacteria are characterised by their ability to produce H_2S, reduce trimethylamine oxide (TMAO) to trimethylamine (TMA) and convert urea to ammonia. Many volatile sulphur compounds are also produced by *Pseudomonas* (Toller and Christian, 1978).

Spoilage organisms convert many nitrogen compounds into off smelling volatile bases. Non protein compounds present in fish are good substrate for spoilage organisms. According to Connell (1980) ammonia is the major component in the total volatile nitrogen (TVN) fraction which is often used as a quality indicator of fresh fish as well as in dried fish. Urea present in elasmobranches such as sharks and rays is degraded to ammonia by bacterial action during drying (Malcm Love, 1980). Thus, high level of ammonia in these species is an indication of spoilage.

Subrata *et al.* (1985) reported that packed samples of dried fishes showed gradual increase in TVBN values. East African sun dried fish infested with *Dermestes maculates* were exposed to solar treatment for more than 6-8h was found highly effective for a split opened fish (Grestad, 1989). According to Prasad *et al.* (1994) within two months of storage 97.7% of dried fish samples were affected with red colouration. The colored surfaces contained high levels of total volatile base nitrogen and red halophiles.

If a product is handled carelessly during processing, there may be a chance of high multiplication of pathogenic organism, that results in food poisoning (Varma *et al.*, 1991). *Aspergillus fumigatus*, *Aspergillus niger* and *Mucor* were the common fungi in salted and dried fish at Kakinada coast. Growth of fungi was noticed in different seasons but rapid growth was seen in the rainy season (Chakrabarti *et al.*, 1997). Venugopal *et al.* (1999) have recognized that the major carriers of food borne pathogens were *Salmonella, Staphylococcus aureus, Vibrio cholera, Vibrio parahaemolyticus, Yersinia enterocolitica, Listeria monocytogenes, Campylobacter jejumi, and Escherichia coli.*

Water activity values are used extensively to predict the stability of food stuffs with respect to microbial growth and enzymatic, chemical and physical changes that can lead to food degradation during storage (Christian, 2000). The water activity of food system indicates how tightly water is bound structurally in the food matrix (Scott, 1957; Labuza, 1974). In other words, the water activity of the food describes the energy status of water in a food system, and hence, its availability to act as a solvent and participate in chemical or biochemical reactions (Labuza, 1977). The ability of water to act as a solvent medium or reactant decreases as water activity is reduced.

For transport in porous media, there is also the idea of surface diffusion as molecules can move from side to side (Rigby, 2005). Since the food material surfaces are in general hygroscopic (interactive with the water molecules), surface diffusion is possible.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 Fabrication of solar dryer:

A scaled down version of the BARC type solar dryer (Chandak *et al.*, 2009) of dimensions 120 × 80× 80 cm was initially fabricated. This was further modified and used for the present study. The design of the equipment is given in Figs 3 and 4. The framework of the equipment was formed of angle aluminum of width 2.5 cm and thickness 0.2 cm. The dryer consisted essentially of two parts, viz., a base and a hood. The base was in the form of a box of dimensions 120 × 80 × 26 cm. The sides and bottom were covered over with aluminum sheet of thickness 0.15 cm. Air inlet holes of diameter 0.6 cm where drilled in the aluminum sheet at a height of 3 cm from the bottom of the base and at 3.5 cm intervals. A foam tape was attached to the rim of the base over which the hood was placed. The sides of the hood were triangular shaped, tapering upwards with a square shaped hole of 20 cm side at the top. The corners of the hood had an angle of 40° to the horizontal. The bottom portion of the hood was also covered over with aluminum sheet to a height of 20 cm and the rest of it was covered over with transparent polyvinylchloride (PVC) sheet of thickness 200 µ. The outer surface of the aluminum sheet was painted black with matt finish. The aluminum sheet at one side of the hood served as a door. The total height of the equipment was 80 cm. An exhaust fan (Crompton Greaves make, 2300rpm, 40 watts, 6 inches sweep) was fixed to the hole at the top. The fan was provided with a speed regulator. Two trays of dimensions 115 × 25 cm were placed on supports at the top of the base. The trays were made of angle aluminum frame with high density polyethylene (HDPE) netting at the bottom. Plastic supports were provided at the four corners at the bottom.

3.2 Arrangement of dryer and instruments:

The dryer was placed on the ground directly under the sun with the longer side facing east - west direction as shown in Fig. 4. Two hygrometers of wet and dry bulb type (Jennson make), were suspended inside the dryer at the appropriate position. The bulb of one of the hygrometers was positioned 2 cm below the tray and those of the other were located 2cm above the fish in the tray (Fig. 3). The hygrometers were placed inside thermocole boxes provided with spaces for air flow. Thermocouple probes of a temperature measuring unit were also suspended with their sensing tip 2 cm above the tray.

For running the control, a square shaped wooden platform of 75 cm side was placed near the dryer at the same height as that of the dryer trays, from the ground. A windshield of paperboard, 20 cm high, was attached to the sides of the platform as shown in the Fig.5. Cotton thread netting of mesh size 10 cm was spread over the platform supported by the wind shield. Hygrometers and thermocouple probes were also placed outside the dryer in the open air.

3.3 Processing of prawn and fish:

Fresh flower tail prawn *Metapenaeus dobsoni* (Miers) and Malabar tongue sole *Cynoglossus macrostomu* (Norman), that were iced immediately after catching, were purchased from the Fishing Harbour, Kochi, and transported in an insulated box in iced condition to the laboratory within six hours.

3.3.1 Prawn:

Prawns were washed in freshwater and then subjected to beheading. Ice was used during the entire processing. The material was divided into two lots - one lot was spread on trays and placed in the dryer and the other lot was spread on the wooden platform. Samples were drawn periodically till the end of the drying for conducting various tests. The dried material was then subjected to storage studies.

3.3.2 Fish:

Fresh fish was washed and dressed. Scales, fins and viscera were removed. The material was split open from the ventral side. After washing, table salt was applied in the ratio 1:3 (salt: fish) by weight. A part of the salt was used for rubbing over the fish and the fish were packed in a perforated vessel in layers alternating with layers of salt. A plastic slab was placed over the stack with a weight on it. Salting was carried out for a period of 18 h. The fish was then taken out, given a quick dip in freshwater, and drained. The material was divided into two lots- one lot was spread in trays, skin down and loaded into the dryer, and the other lot was spread similarly on the platform. Samples were drawn periodically for conducting various tests. The dried material was then subjected to storage studies.

3.4 Tests:

The samples were drawn periodically during drying of prawn / fish. Around 10 g of sample was drawn for every sampling from the dryer (test) as well as from the platform (control) and subjected to various tests. All tests were done in triplicate. All the chemicals used were of either Analar or Guaranteed reagent. The table salt used for salting was of food grade.

3.4.1 Moisture content

The moisture content was determined by the method of AOAC (1975). Dried prawn/ fish sample of about 10 g was weighed in a pre-weighed, tared petridish. The dish was placed in a hot air oven at a temperature of 105°C for a period of 6 h, cooled in a desiccator and weighed. Drying was continued until a constant weight was obtained and the moisture content was calculated as percentage loss of weight.

3.4.2 Crude protein content

Crude protein content was estimated by the micro Kjeldahl method (AOAC, 1984). About one g of the dried prawn/ fish sample was weighed and transferred to a kjeldahl flask of 100 ml capacity. A few glass beads, a pinch of digestion mixture (K_2SO_4 and $CuSO_4$ = 8:1) and 10 ml 0f concentrated sulphuric acid were also added. It was digested in a digestion unit (Pelican instruments, Chennai) until the solution turned colourless. To the digested and cooled solutions distilled water was added in small quantities with intermittent shaking and cooling until the addition of water did not generate heat. It was transferred quantitatively to a 100 ml standard flask and made upto the volume. Two ml of the solution was pipetted out into the reaction chamber of the micro kjeldahl distillation apparatus. Ten ml of 40% (w/v) sodium hydroxide solution was added to the sample. Distillation was carried out for a period of two minutes and the ammonia liberated was absorbed into 2% boric acid solution taken in a conical flask containing 1-2 drops of Tachiro's indicator. The amount of ammonia liberated was determined by titrating with $N/_{70}$ standard sulphuric acid. Crude protein content was calculated as follows.

$$\text{Crude protein (\%)} = \frac{V \times 14 \times 100 \times 100}{1000 \times 70 \times 2 \times W} \times 6.25,$$

Where, V = volume of standard sulphuric acid required for titration in ml, and

W = weight of sample taken in g

3.4.3 Crude fat content

The method of Radin (1981) was followed for determining crude fat content. About one g of dried prawn/ fish sample was weighed, transferred to a mortar and homogenised with 18 ml of the extraction solvent (hexane: isopropanol :: 3:2, v/v). It was then filtered into a pre-weighed beaker. The residue was washed two or three times with minimum volume of solvent mixture. The solvent was evaporated off on boiling water bath, then cooled to room temperature in a desiccator, and weighed. The fat content was calculated as percentage of the sample weight.

3.4.4 Ash content

The method of AOAC (1984) was followed for ash content estimation. About 2 g of the dried prawn/ fish sample was weighed and transferred to a pre-weighed silica crucible. The sample was carbonized by burning at low red heat and was placed in a muffle furnace at a temperature of 550°C for about 4 h until a white ash was obtained. Crucibles were weighed after cooling in a desiccator. The weight of the ash was expressed as a percentage of the initial sample weight.

3.4.5 Acid insoluble ash:

The method of AOAC (1984) was followed for acid insoluble ash content estimation. About 5g of the dried material was weighed in a tared silica dish. It was ignited using an electric burner for one hour. The ignition was completed by keeping in a muffule furnace at 600 $\pm 20^0$C until gray ash resulted. The ash was cooled and to this 35ml of dilute hydrochloric acid was added. It was covered with a watch glass, heated on a water bath for 10 minutes, cooled and filtered through Whatman No.42 filter paper. The residue was washed with hot water until the washings were free from chlorides as tested using silver nitrate solution. The filter paper was then returned with the residue to the dish. The dish with the filter paper was kept in a muffle furnace at 600 $\pm 20^0$C for one hour. It was then cooled in desiccator and weighed. The dish was again ignited for 30 minutes, cooled and weighed. This process was repeated till the difference between two successive weighings was less than one mg and the lowest mass were noted.

$$\text{Acid insoluble ash, on moisture free basis, (percent by mass)} = \frac{100\times(M_2\text{-W})}{M_1\text{-W}},$$

where,

M_2 = the lowest mass in g of the dish with the acid insoluble ash,

M_1 = mass in g of the empty dish, and

W = mass in g of the dish with the dried material taken for the test.

3.4.6 Total plate count (TPC)

All media and diluents were sterilized by autoclaving at a temperature of 121°C for 15 min and all glasswares at 160°C in hot air oven for 2 h. Total plate count was determined according to the method of Surendran *et al.* (2006). A sample of 10 g dried prawn/ fish was aseptically transferred to a sterile blender and homogenized with 90 ml sterile diluent (physiological saline of 0.85% NaCl). Appropriate serial decimal dilutions of the homogenate were made using the diluent. Dilutions of 10^{-1}, 10^{-2} and 10^{-3} were plated by pour plate technique in triplicate. The medium used was Nutrient Agar of SRL make (composition in g/ l: beef extract- 10, peptone- 10, NaCl- 5 and agar- 12). The plates after solidification were inverted and incubated at a temperature of 37°C for 24 h. Plates showing 30 to 300 colonies were used for counting the colonies. TPC was calculated using the formula:

$$\text{TPC} = \frac{\text{Average number of colonies x dilution factor}}{\text{Weight of the sample taken}}$$

The count was expressed as number of colony forming units (cfu) / g sample.

3.4.7 Total fungal count (TFC):

Fungal count was determined according to the method of Detroit (1971). The homogenate dilutions prepared for TPC determination were used for determining the fungal count also. Appropriate dilutions were plated, in duplicate, by pour plate technique using Potato Dextrose Agar containing 10% tartaric acid, and incubated at a temperature of 20-25°C for 5 days. Plates showing colonies ranging from 30 to 300 were counted for determining fungal count. TFC was calculated in the same manner as TPC.

3.4.8 Total volatile base nitrogen (TVBN) content:

TVBN content was determined by Conway's micro diffusion method (Conway, 1947). About 5g of dried prawn/ fish sample was weighed out, to which 5 ml 10% trichloric acetic acid (TCA) was added and ground for 10 min and filtered using Whatman filter paper No.1 and the filtrate was made up to 25 ml using 10 % TCA. 1 ml of boric acid was pipetted out into the inner chamber of Conway's micro diffusion apparatus. 1 ml of sample and 1 ml of saturated sodium carbonate solution were added to the outer chamber and the Conway unit closed immediately. The solution in the outer chamber was mixed by slow rotation of the apparatus. The dishes were incubated at 37°C for 90 min. The solution in the inner chamber was titrated to a pink colour using standard 0.02 N H_2SO_4 solution. A blank was run using 1 ml of 4 % TCA instead of the sample extract.

$$\text{TVBN content (mg \%)} = \frac{(A-B)\times 0.28\times 50\times 100}{W}$$

where,

A = volume of H_2SO_4 solution required for blank,

B = volume of H_2SO_4 solution required for test and

W = weight of the sample.

3.4.9 Peroxide value (PV)

The method of Connell (1975) was adopted for peroxide value determination. A sample of 10g of dried fish/ prawn meat was blended thoroughly with anhydrous sodium sulphate in a mortar. The blend was shaken with chloroform for 5 minutes and filtered using Whatman No: 42 filter paper. 20ml of glacial acetic acid and a pinch of potassium iodide were added. After closing the flask the reagents were mixed carefully and incubated for 30 min in the dark at room temperature. Then the sides of the flask were washed with distilled water. A few ml of starch solution were added and titrated against standard 0.002 N sodium thiosulphate solution till the blue colour disappeard. PV was expressed as number of ml of 0.002 N sodium thiosulphate required per gramme of sample.

3.4.10 Temperature:

Temperature of air, both inside and outside the dryer, were directly read out from the digital display unit of the thermocouples.

3.4.11 Relative humidity:

Temperature of the dry bulb and wet bulb thermometers of the hygrometers were noted. The percentage relative humidity corresponding to the difference in the temperature was obtained from the hygrometric table.

3.4.12 Air velocity:

Velocity of air flowing through the dryer was measured using an anemometer (Lutron make) in m/ s.

3.4.13 Water activity:

Water activity of samples was determined using a water activity meter (Hygropalm make). A sample of approximately 10g dried prawn/ fish was taken in containers provided with the equipment and placed in the cup of the probe. The water activity value was directly read out from the display unit of the instrument.

3.4.14 Sodium chloride:

The method of AOAC (1970) was followed for sodium chloride estimation. About 2 g of dried prawn/ fish was weighed out in a 250 ml Ehrlenmeyer flask. 20ml of standard 0.1N sliver nitrate solution was added to precipitate all the chloride as silver chloride and then 20ml of dilute nitric acid was also added. The flask was heated on a sand bath until the solids, except silver chloride, dissolved. 50ml of water and 5ml of ferric alum indicator solution were added after cooling. The contents were titrated against standard 0.1 N potassium thiocyanate solutions until a permanent brick red colour appeared.

$$\text{Sodium chloride, (percent by mass)} = \frac{5.85(V_1N_1 - V_2N_2)}{W}$$

where,

W = weight of the sample taken,

V_1 = volume of silver nitrate taken,

N_1 = normality of silver nitrate,

V_2 = volume of potassium thiosulphate taken and

N_2 = normality of potassium thiosulphate taken.

3.4.15 Sensory evaluation:

A taste panel consisting of 12 judges carried out sensory evaluation of the dried samples. The quality characteristics assessed were colour, odour, taste and texture on the basis of a 5 - point scale according to the method of Amerine *et al.*, (1965). The format of the sensory evaluation score sheets are given in Appendix. I

Material of dried fish/ prawn were divided into 30g/ pack and packed in poly propylene - polyamide bags. The material of the bag had a water vapour transmission rate (WVTR) of 0.01 g/ m^2/ day. The samples were kept for storage studies and stored at room temperature for a period of 80 days. Samples were drawn on the 0 day, 40^{th} day and 80^{th} day for conducting various tests. For determination of moisture content and water activity the samples were drawn at fortnight intervals. TPC, TFC, TVBN and PV were determined as mentioned in the Section 3.

3.5.16 Statistical analysis:

Data obtained were analyzed using two way Analysis of Variance (ANOVA) technique (Snedecor and Cochran, 1968). The analysis was carried out using SPSS package ver. 15. In order to find the significant difference between periods Duncan's multiple range test was applied. For total plate count (TPC) and total fungal count (TFC), ANOVA was performed after applying lograthemic transformation to the data. Arcsine transformation was done for moisture content and water activity data before applying ANOVA. Comparison of treatments was done at 5% significant level of significance. Mann- Whitney test for the ordinal data was applied for organoleptic data (Zar, 2003).

RESULTS

4. RESULTS

4.1 Solar dryer:

The solar dryer designed could attain a temperature of 50°C and RH of 67 % on sunny days with the outside air temperature ranging between 27.6 and 53.3°C and RH ranging between 65 % and 85 %. The temperature and RH values attained within the dryer were 40- 45°C and 72- 76 %, respectively, on cloudy days when the outside air temperature was 37- 40°C and RH was 67- 85 %. A velocity of 0.08 m/ s was the maximum achieved for air flow at the level of fish in the dryer with the fan at full speed.

4.2 Drying of prawn:

4.2.1 Proximate composition:

Proximate composition of prawn before and after drying of prawn under various atmospheric conditions is presented in Table 1. Moisture content was found to decrease from 78.6 to 12.5% upon drying. Crude protein, crude fat, ash and acid insoluble ash contents increased during drying from 17.2 to 75.0 %, 0.1 to 1.4 %, 1.3 to 6.4%, and 0.02 to 0.6%, respectively.

4.2.2 Air conditions:

The temperature of air inside dryer and that of outside during drying of prawn at different times are given in Fig. 6. The temperature varied between 37.5 and 52°C inside and between 27.6 and 42.5°C outside.

Relative humidity of the air inside the dryer and outside during drying at different times are given in Fig. 6. Relative humidity varied between 65 and 85 % below the level of prawn and 67 to 85% above prawn in the drier. Outside, the relative humidity varied between 72 and 84 %.

Table 1: Proximate composition of fresh prawn and prawn dried in solar dryer and by sun drying under three atmospheric conditions (wet weight basis)

Atmospheric conditions		Moisture (%)	Crude Protein (%)	Crud e Fat (%)	Ash (%)	Acid insoluble ash (%)
A - Air temperature: 27.6-53°C, RH: 65-85%	Fresh	78.6	17.2	0.1	1.3	0.02
	Solar dryer	12.9	72.25	1.2	3.4	0.2
	Sun	13.1	73.5	1.4	5.0	0.5
B- Air temperature: 27.6- 53°C, RH: 65-85%	Fresh	78.4	17.2	0.1	1.3	0.02
	Solar dryer	12.5	74.5	1.2	3.4	0.2
	Sun	12.6	75.0	1.4	5.0	0.4
C- Air temperature: 37-46°C, RH: 67-85%	Fresh	78.6	17.5	0.1	1.3	0.02
	Solar dryer	12.6	74.5	1.2	3.4	0.2
	Sun	12.6	74.2	1.4	6.4	0.6

Average of three replications

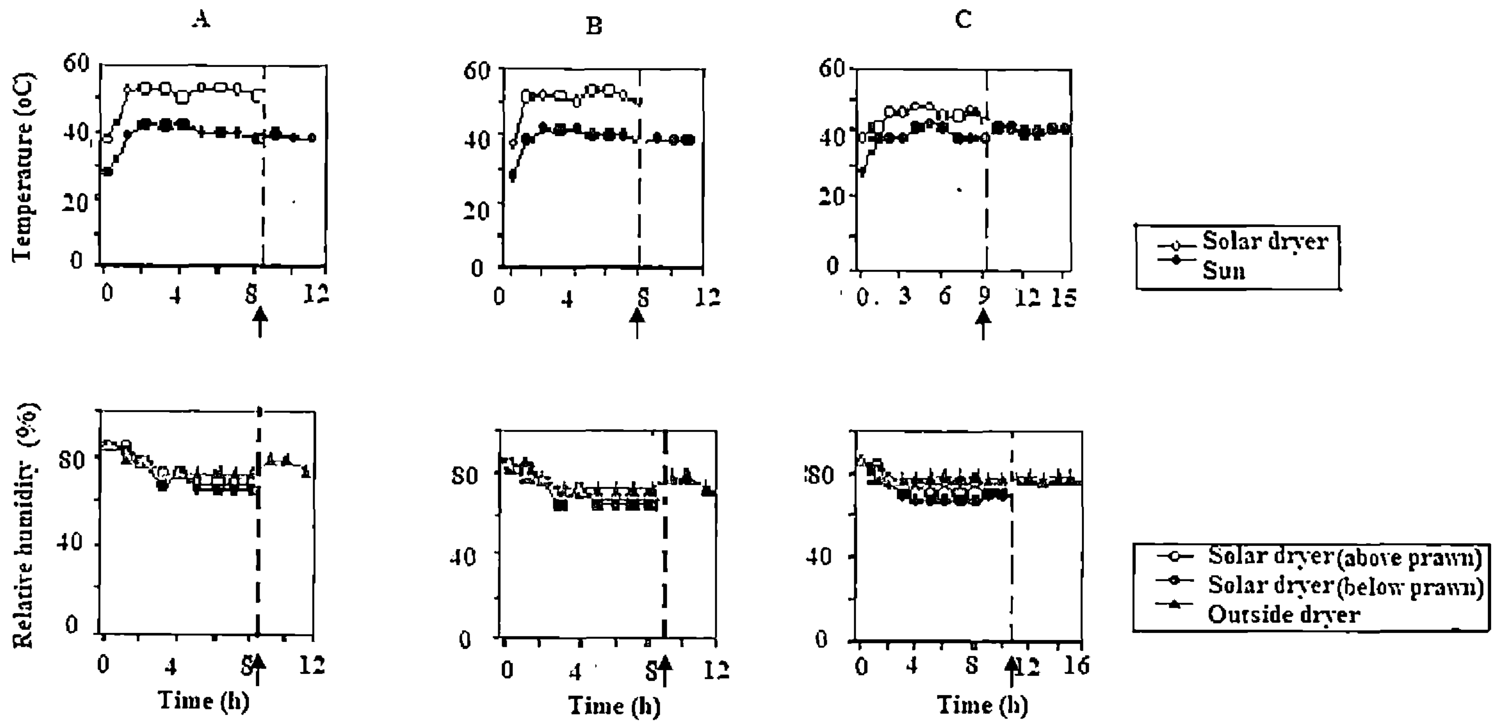


Fig. 6: Variation in air temperature and relative humidity during drying of prawn in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6-53°C, RH: 65-85%; B-Air temperature: 27.6-53°C, RH:65-85%; C- Air temperature: 37-46°C, RH: 67-85%)

↑ Continuation of drying next day

4.2.3 Water activity:

Water activity was found to decrease from 0.98 to 0.65 in prawn during drying at different atmospheric conditions as shown in Fig. 7. The drying time was 9 h in the case of solar dryer and 12 h in the case of sun drying. Significant difference was noted between test and control samples (Table 2).

4.2.4 Sorption isotherm:

Desorption isotherms of prawn during drying in dryer and under sun are shown in Fig. 8. Water activity ranged between 0.98 and 0.65 whereas moisture content varied between 78.4 and 12.6 %.

4.2.5 Microbial and chemical parameters:

Table 3 gives the data obtained for TPC, TFC, TVBN content and PV during drying of prawn either in dryer or outside in three different periods. Total plate count (TPC) increased from 3.0×10^2/ g to 8.2×10^2/ g and 3.0×10^2/ g to 1.6×10^3/ g in solar dryer- dried prawn and sun dried prawn, respectively. Total fungal count (TFC) decreased from 3.7×10^1/ g to 1.0×10^1/ g in the former and was more or less the same at around 3.0×10^1/ g in the latter. TVBN content varied from 30 to 130 mg % in test and from 30 to 140 mg % in the control, whereas PV increased from 1 to 3.4 milli equivalents O_2/ kg fat in the former and1 to 5.0 milli equivalents O_2/ kg of fat in the latter.

The data were analyzed by the two way classification with three observations per cell. Duncan's multiple range tests was carried out for periods. ANOVA for TPC, TFC, TVBN, and PV for prawn during drying are given in Tables 4 and 5. For TPC and TFC, after applying logarithmic transformation, two way analysis with three observations was carried out. The test (solar dryer-dried) and control (sun dried) of prawn are found to be significantly different. Periods and interactions are also significantly different.

4.2.6 Sensory parameters:

Sensory evaluation scores for freshly dried prawn are given in Table 9. Colour, odour, texture and taste were scored considerably higher for prawn dried in solar dryer compared to that by sun drying.

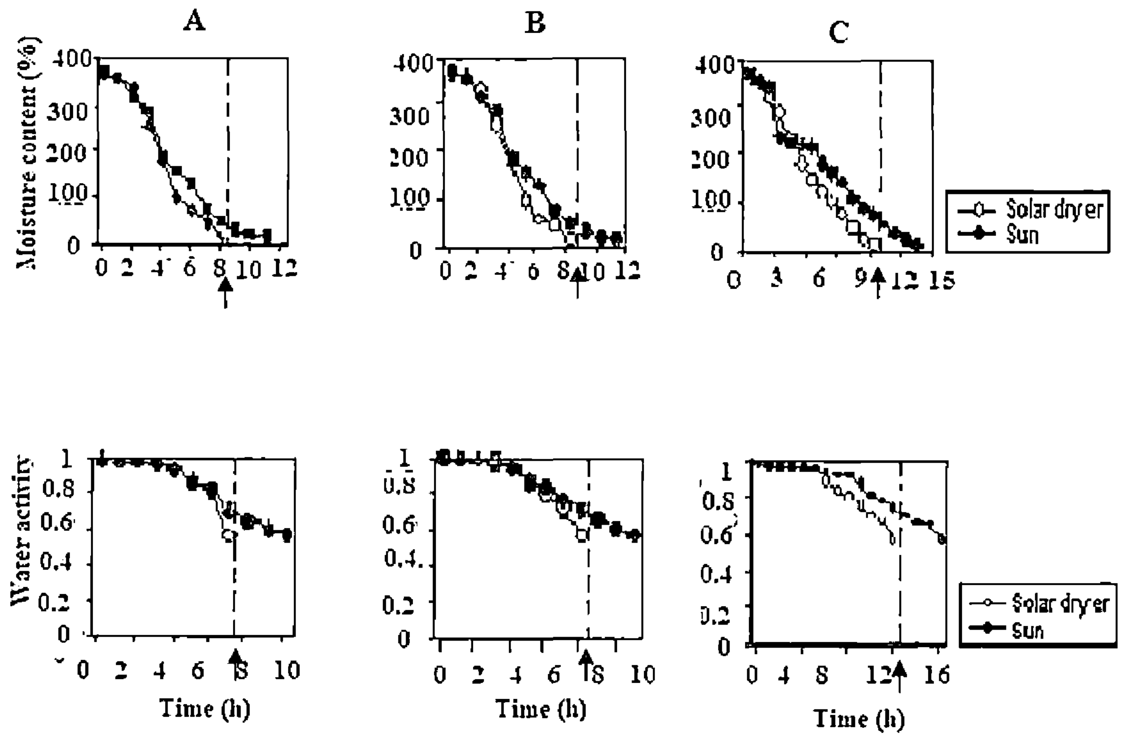


Fig. 7: Variations in moisture content and water activity of prawn dried in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6-53°C, RH: 65-85%; B-Air temperature: 27.6-53°C, RH: 65-85%; C- Air temperature: 37-46°C, RH: 67-85%).

↑ Continuation of drying next day

Table 2: ANOVA for variations in moisture content and water activity of prawn dried in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6- 53°C, RH: 65- 85 %; B-Air temperature: 27.6- 53°C, RH:65- 85%; C- Air temperature: 37- 46°C, RH: 67- 85 %).

Moisture content

	A				B				C		
Periods	F= 167950.56*				F= 189951.71*				F= 1976853.93*		
Treatment	F= 36789.088*				F= 26781.8*				F= 27671.00*		
Periods		0	1	2	3	4	5	6	7	8	9
Retransformed means:	A	44.6^a	74.4^b	85.4^b	120.^{c}	177.1^d	250^e	330.6^f	354^g	-	-
	B	44.6^a	75.4^b	83.4^b	123^c	177.1^d	251^e	335.5^f	359.^{g}	-	-
	C	49.6^a	78.4^b	85.4^b	135^c	180^d	256^e	334.5^f	354.2^g	366^g	367^g
Treatment	Solar dryer		Sun		Solar dryer		Sun		Solar dryer	Sun	
Retransformed means:	24.9		47.05		25.1		48.15		0.88	0.91	

Water activity

	A				B				C		
Periods	F= 167950.56*				F= 189951.71*				F= 1976853.93*		
Treatment	F= 36789.088*				F= 26781.8*				F= 27671.00*		
Periods		0	1	2	3	4	5	6	7	8	9
Retransformed means:	A	0.66^a	0.73^b	0.82^c	0.85^d	0.87^e	0.93^f	0.95^g	0.98^h	-	-
	B	0.66^a	0.73^b	0.82^c	0.85^d	0.87^e	0.93^f	0.95^g	0.98^h	-	-
	C	0.66^a	0.72^b	0.77^c	0.82^d	0.85^e	0.90^f	0.93^g	0.97^h	0.98^h	0.98^h
Treatment	Solar dryer		Sun		Solar dryer		Sun		Solar dryer	Sun	
Retransformed means:	0.75		0.85		0.74		0.82		0.78	0.87	

* Significant at 5% level; ^{a,b,c,d,e,f,g,h} - Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups

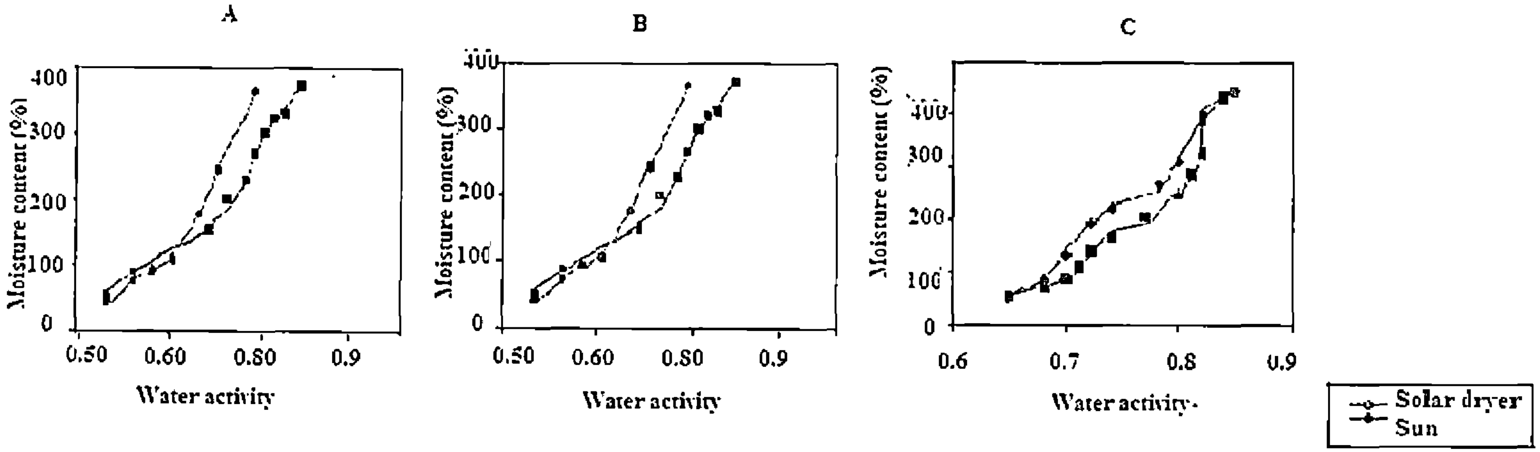


Fig. 8: Sorption isotherms of prawn dried in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6-53°C, RH: 65-85%; B-Air temperature: 27.6-53°C, RH: 65-85%; C- Air temperature: 37-46°C, RH: 67- 85%).

Table 3: **Total plate count (TPC), total fungal count (TPC), total volatile base nitrogen (TVBN) content and peroxide value (PV) of prawn during various stages of drying in solar dryer and under sun under three atmospheric conditions.**

Atmospheric conditions	**Drying time (hours)**	**TPC (count/ g)**		**TFC (count/ g)**		**TVBN (mg %)**		**PV (milli equivalent O_2/ kg of fat)**	
		Solar dryer	**Sun**	**Solar dryer**	**Sun**	**Solar dryer**	**Sun**	**Solar dryer**	**Sun**
A	0	3.0×10^2	3.0×10^2	3.7×10^1	3.7×10^1	30	30	1.01	1.02
Air temperature: 27.6-53°C, RH: 65-85%	5	6.0×10^2	8.0×10^2	3.0×10^1	3.5×10^1	38	40	1.4	2.6
	8	8.0×10^2	1.0×10^3	1.0×10^1	3.3×10^1	126	120	3.2	3.0
	10	-	1.6×10^3	-	3.2×10^1	-	135	-	4.0
B	0	3.0×10^2	3.0×10^2	3.5×10^1	3.7×10^1	30	30	1.0	1.0
Air temperature: 27.6-53°C, RH: 65-85%	5	6.0×10^2	8.0×10^2	3.0×10^1	3.5×10^1	37	40	1.4	2.5
	8	8.0×10^2	1.0×10^3	1.0×10^1	3.4×10^1	126	125	3.22	3.5
	10	-	1.6×10^3	-	3.2×10^1	-	135	-	4.0
C	0	3.0×10^2	3.0×10^2	3.6×10^1	3.7×10^1	30	30	1.0	1.0
Air temperature: 37-46°C, RH: 67-85%	5	6.1×10^2	8.2×10^2	3.0×10^1	3.5×10^1	40	42	2.5	2.5
	9	8.2×10^2	1.0×10^3	1.0×10^1	3.3×10^1	130	132	3.4	4.2
	14	-	1.6×10^3	-	3.2×10^1	-	145	-	5.0

Average of three replications

Table 4: ANOVA for variations in TPC and TFC of prawn dried in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6- 53°C, RH: 65- 85 %; B- temperature: 27.6- 53°C, RH: 65- 85 %; C- Air temperature: 37- 46°C, RH: 67- 85 %)

TPC

	A			B			C		
Periods	F= 51119.88*			F= 29282.553*			F= 29285.553*		
Treatments	F= 19691.638*			F= 8710.853*			F= 8725.853*		
Periods	0	5	11	0	5	11	0	5	14
Retransformed means:	305.4[a]	781.6[a]	1207.1[b]	315.4[a]	792[a]	1210[b]	325.4[a]	892[a]	1320[b]
Treatment	Solar dryer		Sun	Solar dryer		Sun	Solar dryer	Sun	
Retransformed means:	530.88		968.2	635.88		1068.2	730.998	1020.2	

TFC

	A			B			C		
Periods	F= 624.100*			F= 734.120*			F= 908.075*		
Treatments	F= 786.100*			F= 795.110*			F= 804.343 *		
Periods	0	5	11	0	5	11	0	5	14
Retransformed means:	37[a]	31[b]	20[c]	38[a]	32[b]	22[c]	40[a]	39[b]	28[c]
Treatment	Solar dryer		Sun	Solar dryer		Sun	Solar dryer	Sun	
Retransformed means:	25		34	26		35	29	45	

* Significant at 5% level; a,b,c - Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups.

Table 5: ANOVA for variations in TVBN content of prawn dried in solar dryer and by sun drying under three atmospheric conditions (A-Air temperature: 27.6-53°C, RH: 65-85%; B-Air temperature: 27.6-53°C, RH: 65-85%; C- Air temperature: 37-46°C, RH: 67-85 %)

TVBN

	A			B			C		
Periods	F= 411171.38*			F= 663300.8*			F= 20619.39*		
Treatments	F= 144.5*			F= 217.8*			F=150.22*		
Periods	0	5	11	0	5	11	0	5	14
Means:	30.5^a	39.5^b	130.3^c	30.5^a	39.17^b	130.5^c	30.5^a	40.5^b	136.6^c
Treatment	Solar dryer	Sun		Solar dryer	Sun		Solar dryer	Sun	
Means:	64.89	68.67		64.89	68.67		66.3	72.11	

PV

	A			B			C		
Periods	F= 5434.27*			F= 15753.5*			F= 5213.01*		
Treatments	F= 1252.59*			F= 1252.59*			F= 1629.77*		
Periods	0	5	11	0	5	11	0	5	14
Means:	1.008^a	2.0^b	3.55^c	1.008^a	2.01^b	3.55^c	2.489^a	2.899^a	3.057^b
Treatment	Solar dryer	Sun		Solar dryer	Sun		Solar dryer	Sun	
Means:	1.83	2.54		1.83	2.54		1.87	2.87	

* Significant at 5% level; ^{a,b,c} - Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups

Table 6: Sensory evaluation scores for prawn dried in solar dryer and under sun under three atmospheric conditions (A- Air temperature: 27.6-53°C, RH: 65 – 85 %; B- Air temperature: 27.6 - 53°C, RH: 65 – 85 % C-Air temperature: 37- 46°C, RH: 67- 85 %).

Atmospheric conditions	Colour		Odour		Texture		Taste	
	Solar dryer	Sun	Solar dryer	Sun	Solar dryer	Sun	Solar dryer	Sun
A	3.5	2.0	4.0	2.1	4.5	3.0	4.5	3.0
B	3.5	2.0	4.0	2.1	4.5	3.0	4.5	3.0
C	3.0	2.0	4.0	2.0	4.2	3.0	4.5	3.0

Average of 10 scores
Maximum score: 5.0
Borderline of acceptability score: 1.0.

4.3 Drying of fish

4.3.1 Proximate composition:

Proximate composition of Malabar tongue sole (*Cynoglossus macrostomus*) before and after drying is presented in Table 7. Moisture content was found to decrease from an initial value of 72.1 to 19.9 % upon drying as shown in Fig. 12. Crude protein, crude fat, ash and acid insoluble ash contents increased significantly from 26 to 56.5%, 1.5 to 6.4 %, 2.3 % to 21.2 and 0.02 % to 0.7 %, respectively, upon drying.

4.3.2 Air conditions:

Temperature of air inside dryer and outside, during drying of fish at different times are given in the Fig. 9. The temperature varied between 37.5 to 52^{0}C in test and 27.6 to 42.5^{0}C in control.

Relative humidity inside the dryer and outside, during drying at different times are given in Fig. 9. Relative humidity varied between 67 and 85 % above the fish and 85 and 65 % below the fish in the dryer, whereas it ranged between 72 and 84 %, outside.

4.3.3 Water activity:

Water activity was found to decrease from 0.82 to 0.65 in fish during drying at different atmospheric conditions as shown in Fig. 10.

4.3.4 Sorption isotherm:

Desorption isotherms of prawn during drying in dryer and under sun are shown in Fig. 11. Water activity ranged between 0.86 and 0.65 whereas moisture content varied between 69.1 and 19.9 %.

Table 7: Proximate composition of fresh fish and dry salted fish dried in solar dryer and by sun drying under three atmospheric conditions (wet weight basis).

Atmospheric conditions		Moisture (%)	Crude Protein (%)	Crude Fat (%)	Ash (%)	Acid insoluble ash (%)
A -Air temperature: 27.6- 53°C, RH: 65- 85%	Fresh	69.1	26	1.5	2.3	0.02
	Solar dryer	19.9	56.5	6.0	17.2	0.2
	Sun	20.1	54.1	6.4	21.2	0.4
B -Air temperature: 27.6- 53°C, RH: 65- 85%	Fresh	69.1	26	1.5	2.3	0.02
	Solar dryer	19.9	55.5	6.0	17.2	0.2
	Sun	20.1	54.9	6.4	21.2	0.4
C -Air temperature: 37- 46°C, RH: 67- 85%	Fresh	72.2	26	1.5	2.3	0.02
	Solar dryer	19.9	54	6.0	17.0	0.2
	Sun	20.1	54.9	6.4	21.0	0.7

Average of three replications

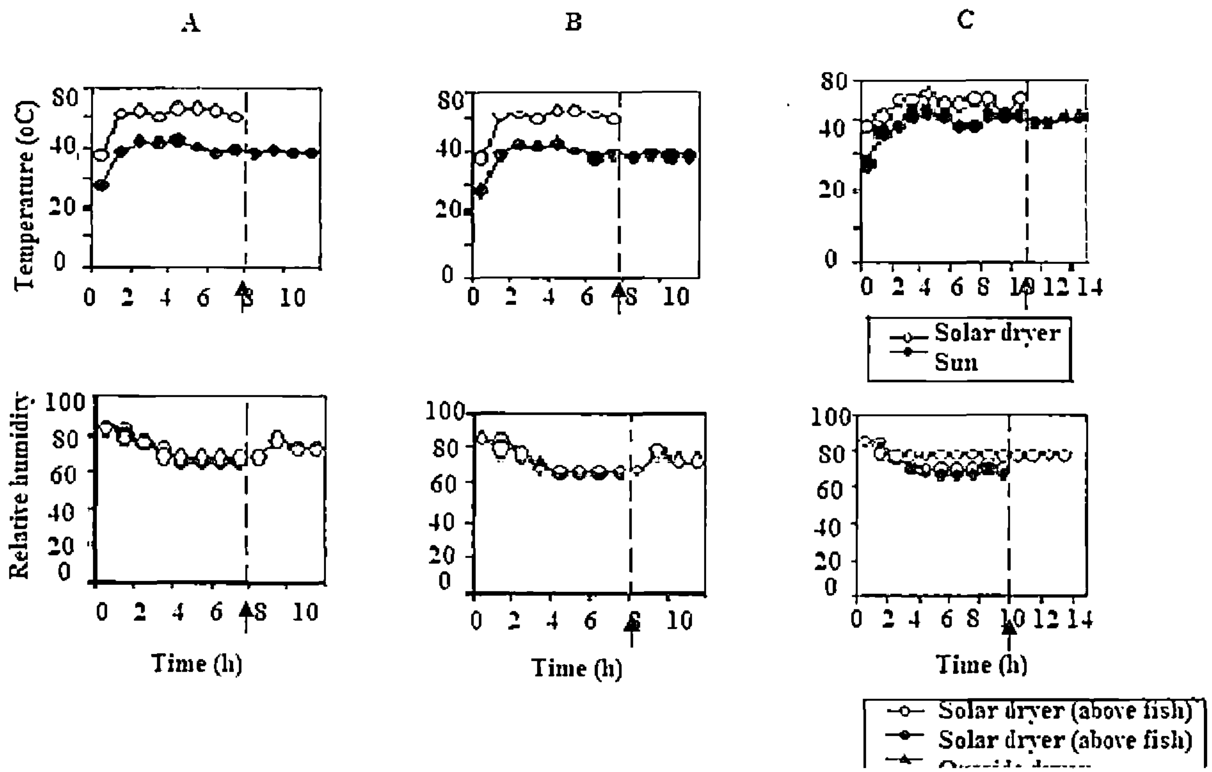


Fig. 9: Variations in temperature and relative humidity of dry salted fish dried in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6-53°C, RH: 65-85%; B-Air temperature: 27.6-53°C, RH: 65-85%; C- Air temperature: 37-46°C, RH: 67-85%).

↑ Continuation of drying next day

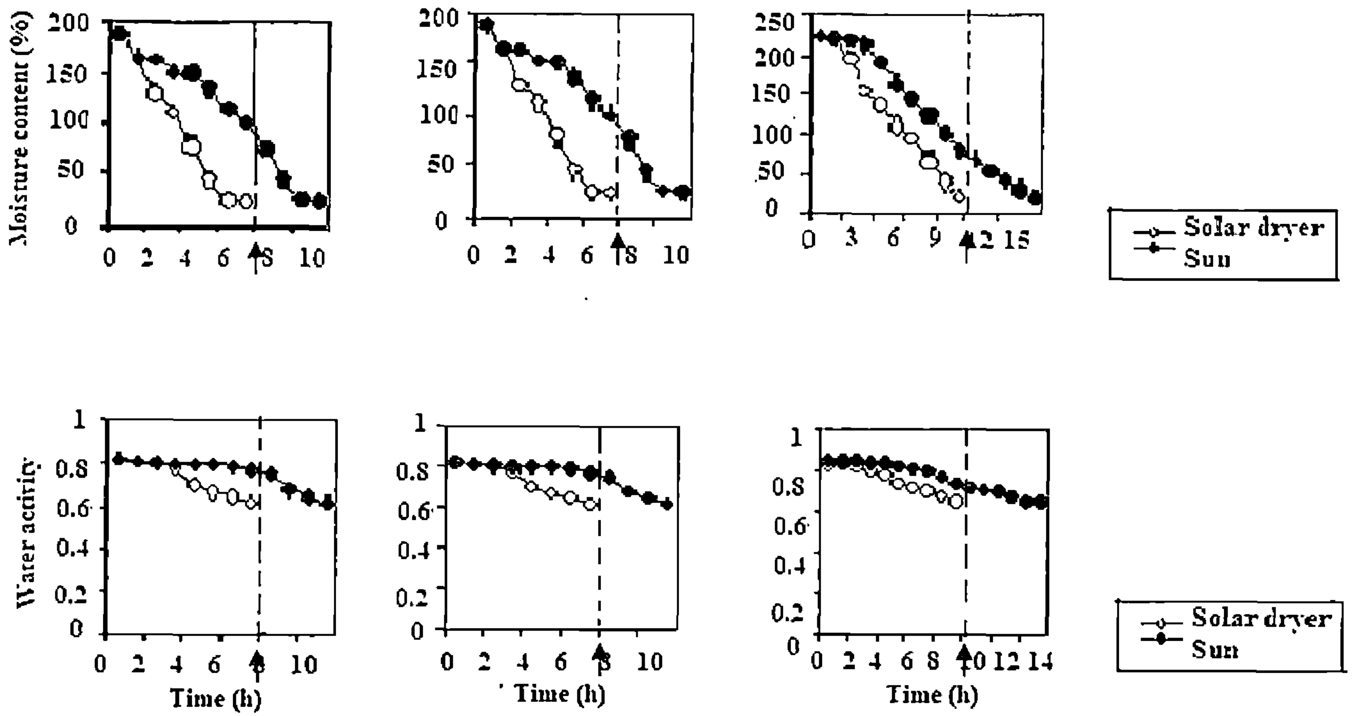


Fig. 10: Variations in temperature and relative humidity of dry salted fish dried in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6-53°C, RH: 65-85%; B-Air temperature: 27.6-53°C, RH: 65-85%; C- Air temperature: 37-46°C, RH: 67-85%).

↑ Continuation of drying next day

Table 8: ANOVA for variations in moisture content and water activity of salted fish dried in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6- 53°C, RH: 65- 85 %;. B-Air temperature: 27.6- 53°C, RH: 65- 85 %; C- Air temperature: 37- 46°C, RH: 67- 85 %)

Moisture content

	A				**B**			**C**			
Periods	F= 23522.2*				F= 16788*			F= 39431.580*			
Treatment	F= 1367.29*				F= 14562.3*			F= 15623.088*			
Periods		0	1	2	3	4	5	6	7	8	9
Retransformed means:	A	69.1^{a}	68.7^{a}	66.94^{a}	62^{b}	58.6^{c}	55.5^{d}	49.65^{e}	34^{f}	-	-
	B	69^{a}	68.7^{a}	66.94^{a}	62.7^{b}	58.6^{c}	55.5^{d}	49.65^{e}	34.0^{f}		-
	C	69^{a}	68.3^{a}	66.4^{b}	62.7^{c}	58.6^{d}	55.5^{e}	50.5^{f}	45.5^{g}	40^{h}	34^{h}
Treatment	Solar dryer		Sun		Solar dryer	Sun		Solar dryer		Sun	
Retransformed means:	47.44		62.94		47.34	62.85		49.83		62.94	

Water activity

	A				**B**			**C**			
Periods	F= 609.679*				F= 678.678*			F= 608.678*			
Treatment	F= 2065.269*				F= 2110.2*			F= 2100.285*			
Periods		0	1	2	3	4	5	6	7	8	9
Retransformed means:	A	0.84^{a}	0.84^{a}	0.83^{a}	0.82^{b}	0.79^{c}	0.78^{c}	0.77^{d}	0.71^{e}	-	-
	B	0.83^{a}	0.84^{a}	0.83^{a}	0.82^{b}	0.79^{c}	0.78^{c}	0.77^{d}	0.71^{e}		-
	C	0.83^{a}	0.84^{a}	0.83^{a}	0.82^{a}	0.79^{b}	0.78^{b}	0.77^{b}	0.75^{c}	0.73^{d}	0.71^{e}
Treatment	Solar dryer		Sun		Solar dryer	Sun		Solar dryer		Sun	
Retransformed means:	0.76		0.82		0.75	0.82		0.75		0.82	

* Significant at 5% level; ^{a,b,c,d,e,f,g,} - Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups.

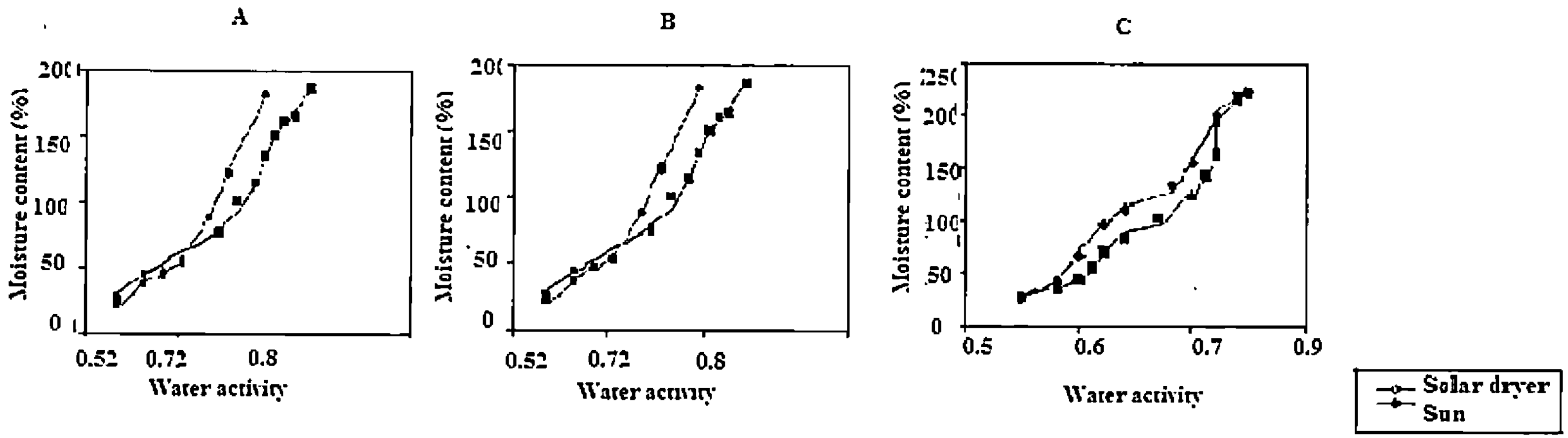


Fig. 11: Sorption isotherms of dry salted fish in solar dryer and by sun drying under three atmospheric conditions (A- Air temperature: 27.6-53°C, RH: 65-85%; B-Air temperature: 27.6-53°C, RH: 65-85%; C- Air temperature: 37-46°C, RH: 67- 85%).

4.3.5 Microbial and chemical composition:

TPC remained fairly constant (1- 4 × 10 ^{4}/ g) in the test whereas it increased from 4.0 × 10^4/ g to 1.6 × 10^5/ g in the control. TFC remained at around 1.0 × 10^2/g or even less throughout the study in the control. Changes in TVBN content of fish during drying in three atmospheric conditions are given in the Table 9. TVBN values of fish increased from 30 to 130 mg % in test and 32 to 167 mg % in control. PV of fish increased from 3.0 to 7.1 milli equivalents O_2/ kg of fat in test and from 3.0 to 9.0 milli equivalents O_2/ kg of fat in control.

ANOVA for TPC, TFC, TVBN and PV for dried fish during drying are given in Tables 10 to 11. For TPC and TFC after applying logarithmic transformation two way analyses with 3 observations was carried out. The test and control of prawn are significantly different, periods and interactions are also significantly different. TVBN and PV are significantly different, periods and interactions are also different.

4.3.6 Sensory parameters:

Table 12 gives the scores obtained for sensory evaluation of dry salted fish immediately after completion of the drying process. Fish dried in solar dryer received considerably higher scores for all the parameters, viz., colour, odour, texture and taste, compared to the sun dried materials.

Table 9: Total plate count (TPC), total fungal count (TFC), total volatile base nitrogen (TVB-N) and peroxide value (PV) of dry salted fish during various stages of drying in solar dryer and under sun under three sets of atmospheric conditions.

Atmospheric conditions	Drying time (hours)	TPC (count/ g)		TFC (count/ g)		TVB-N (mg %)		PV (milliequivalent O_2/ kg of fat)	
		Solar dryer	Sun	Solar dryer	Sun	Solar dryer	Sun	Solar dryer	Sun
A	0	4.0×10^4	4.0×10^4	1.0×10^2	1.0×10^2	32	32	3.0	3.0
Air temperature: 27.6-53°C, RH: 65-85%	5	2.0×10^4	3.1×10^4	0.5×10^2	1.0×10^2	35	145	3.2	4.0
	8	1.0×10^4	2.7×10^4	-	1.0×10^2	127	150	5.2	5.2
	10	-	2.2×10^4	-	1.0×10^2	-	157	-	6.0
B	0	4.0×10^4	4.0×10^4	1×10^2	1.0×10^2	32	32	3.0	3.0
Air temperature: 27.6-53°C, RH: 65-85%	5	2.0×10^4	3.1×10^4	0.5×10^2	1.0×10^2	36	47	4.0	4.0
	8	1.0×10^4	2.5×10^4	-	1.0×10^2	127	150	7.1	5.5
	10	-	2.2×10^4	-	1.0×10^2	-	160	-	7.1
C	0	4.0×10^4	3.0×10^4	3.6×10^2	1.0×10^2	30	30	3.0	3.0
Air temperature: 37-46°C, RH: 67-85%	5	2.1×10^4	8.2×10^2	3.0×10^2	1.0×10^2	38	50	5.0	6.0
	9	1.0×10^4	1.0×10^5	1.0×10^2	1.0×10^2	130	140	7.0	7.0
	14	-	1.6×10^5	-	1.0×10^2	-	167	-	9.0

Average of three replications

Table 10: ANOVA for variations in TPC and TFC of salted fish dried in solar dryer and by sun drying under three different conditions (A- Air temperature: 27.6- 53°C, RH: 65- 85 %; B-Air temperature: 27.6- 53°C, RH: 65- 85 %; C- Air temperature: 37- 46°C, RH: 67- 85 %).

TPC

	A			B			C		
Periods	F= 23772.822*			F= 5213.01*			F= 5213.01*		
Treatments	F= 11692.375*			1 F= 629.77*			F= 1629.77*		
Periods	0	5	11	0	5	11	0	5	14
Retransformed means:	4005^a	2471^a	1493.1^a	4105^a	2488^a	1563^b	5123^a	3467^b	1845^c
Treatment	Solar dryer		Sun	Solar dryer		Sun	Solar dryer		Sun
Retransformed means:	2009.5		2997.09	2119.5		3014.01	2239.5		3496.13

TFC

	A			B			C		
Periods	F= 98.832*			F= 198.232*			F= 58.732*		
Treatments	F= 258.717*			F= 279.717*			F= 256.121*		
Periods	0	5	11	0	5	11	0	5	14
Retransformed means:	107.62^a	71.5^b	44.71^c	110.43^a	69.98^b	52.89^c	120.6^a	72.9^b	49.67^c
Treatment	Solar dryer		Sun	Solar dryer		Sun	Solar dryer		Sun
Retransformed means:	2009.5		2997.09	2119.5		3014.01	2239.5		3496.13

* Significant at 5% level

^{a,b,c} Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroup

Table 11: ANOVA for variations in TVBN content and PV of salted fish dried in solar dryer and by sun drying under three different conditions (A- Air temperature: 27.6- 53°C, RH: 65- 85 %; B- Air temperature: 27.6- 53°C, RH: 65- 85 %; C- Air temperature: 37- 46°C, RH: 67- 85 %).

TVBN

	A			B			C		
Periods	F= 69086*			F= 50628.5*			F= 53478.88*		
Treatments	F= 2204.16*			F= 1922*			F= 2080.125*		
Periods	0	5	11	0	5	11	0	5	14
Means:	31.5^{a}	40.83^{b}	143.16^{c}	30.33^{a}	41^{b}	141.33^{c}	30.33^{a}	43.5^{b}	145.33^{c}
Treatment	Solar dryer	Sun		Solar dryer	Sun		Solar dryer	Sun	
Means:	2009.5	2997.09		2119.5	3014.01		2239.5	3496.13	

PV

	A			B			C		
Periods	F= 8887.97*			F= 13568.97			F= 11013.24*		
Treatments	F= 3090.15*			F= 3171.20			F= 2553.161*		
Periods	0	5	11	0	5	11	0	5	14
Means:	3.008^{a}	6.08^{c}	3.86^{b}	3.008^{a}	3.58^{a}	6.07^{b}	3.008^{a}	3.66^{a}	6.33^{b}
Treatment	Solar dryer	Sun		Solar dryer	Sun		Solar dryer	Sun	
Means:	2009.5	2997.09		2119.5	3014.01		2239.5	3496.13	

* Significant at 5% level;

^{a,b,c} Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups

Table 12: Variations in sensory evaluation scores for salted fish dried in solar dryer and under sun drying under three atmospheric conditions (A- Air temperature: 27.6- 53°C, RH: 65 – 85 %; B- Air temperature: 27.6 - 53°C, RH: 65 – 85 % C- Air temperature: 37- 46°C, RH: 67- 85 %).

Atmospheric conditions	Colour		Odour		Texture		Taste	
	Solar dryer	Sun	Solar dryer	Sun	Solar dryer	Sun	Solar dryer	Sun
A	4.5	2.0	4.1	3.0	3.5	2.0	4.5	3.1
B	4.5	2.0	4.0	3.0	3.5	2.1	4.5	3.1
C	4.5	2.0	4.2	2.6	3.5	2.1	4.5	2.5

Average of 10 scores

Maximum score: 5.0

Borderline of acceptability score: 1.0

4.4 Storage studies of prawn:

4.4.1 Atmospheric conditions:

The maximum temperature of air during storage of dried prawn was 37^{0}C and minimum temperature was 28°C. The relative humidity ranged from 78 % to 84 % during this period.

4.4.2 Moisture content:

The variations in the moisture content of prawn dried in solar dryer and under sun during storage are shown in Fig. 12a. The moisture content remained more or less same ranging from 14.0 to 14.6 % in the test but there was slight increase in the control from 14.6 to 15.6 %. The treatments a well as and periods showed significant difference (Table 13).

4.4.3 Water activity:

Variation in water activity of dried prawn during storage was insignificant in both test and control (Table 13). The variation was only between 0.65 and 0.68 in both are shown in Fig. 12b.

4.4.4 Total plate count:

Fig. 13a shows the variations in TPC for prawn dried in solar dryer and under sun during storage. TPC appears to remain unchanged in both test and control. However, it remained slightly higher in control at around 1.7×10^3/ g compared to 8.0×10^2/ g in test. Results of statistical analysis are given in Table 14. Significant difference was observed between test and control of dried prawn during the storage period.

4.4.5 Total fungal count:

Fig. 13b shows the variations in TFC for test and control of dried prawn during storage. TFC appeared to remain fairly stable during this period at around 1 log TFC in test and 1.5 log TFC in control. The statistical analysis for TFC during storage are given in Table 20. No significant difference was seen between test and control during the period of storage.

4.4.6 Total volatile base nitrogen content:

TVBN contentof test and control increased between 126 and 130 mg % and 135 and 145 mg %, respectively, during storage are shown in Fig 13c. Results of statistical analysis for TVBN content variation during storage of prawn are given in Tables 14. Significant difference in TVBN content was obtained between test and control.

4.4.7 Peroxide value (PV):

The increase in PV of solar dryer- dried as well as sun dried prawn are insignificant during storage, PV values of test and control increased between 3.2 and 3.4 milli equivalents O_2/ kg of fat and 4.0 and 4.4 milli equivalents O_2/ kg of fat, respectively as shown in the Fig 13d. Statistical analysis, however, showed a significant difference in PV of test and control (Tables 14).

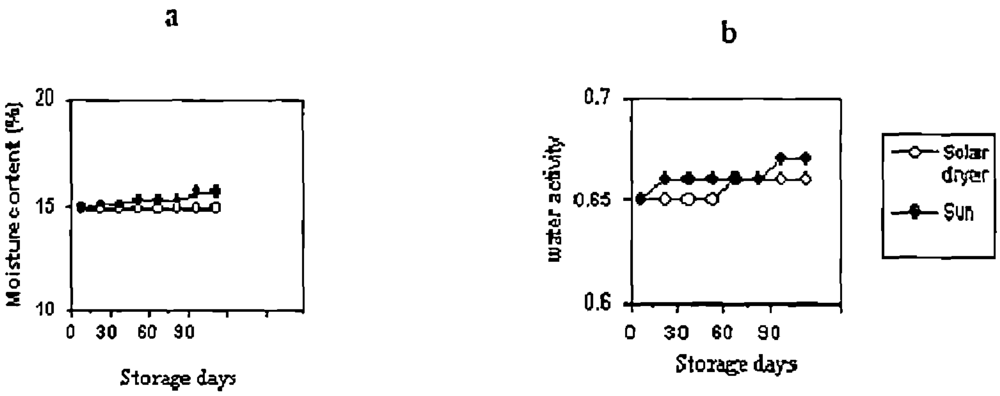


Fig. 12: Variations in moisture content and water activity of prawn dried in solar dryer and under sun drying, during storage.

Table 13: ANOVA for variations in moisture content and water activity of prawn dried in solar dryer and by sun drying, during storage.

	Moisture content				**Water activity**				
Periods	F= 383.774*				F= 1.1918				
Treatment	F= 476.857*				F= 681.085*				
Periods		0	15	30	45	60	75	90	105
Retransformed means:	Moisture	14.1^{a}	14.2^{a}	15.2^{a}	15.4^{b}	15.2^{b}	15.5^{b}	15.5^{b}	15.6^{b}
	a_w	0.62	0.64	0.64	0.64	0.65	0.65	0.65	0.65
Treatment		Solar dryer				Sun			
Retransformed means:	Moisture	20.05				23.15			
	a_w	0.62				0.65			

* Significant at 5% level;

a,b,c Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups

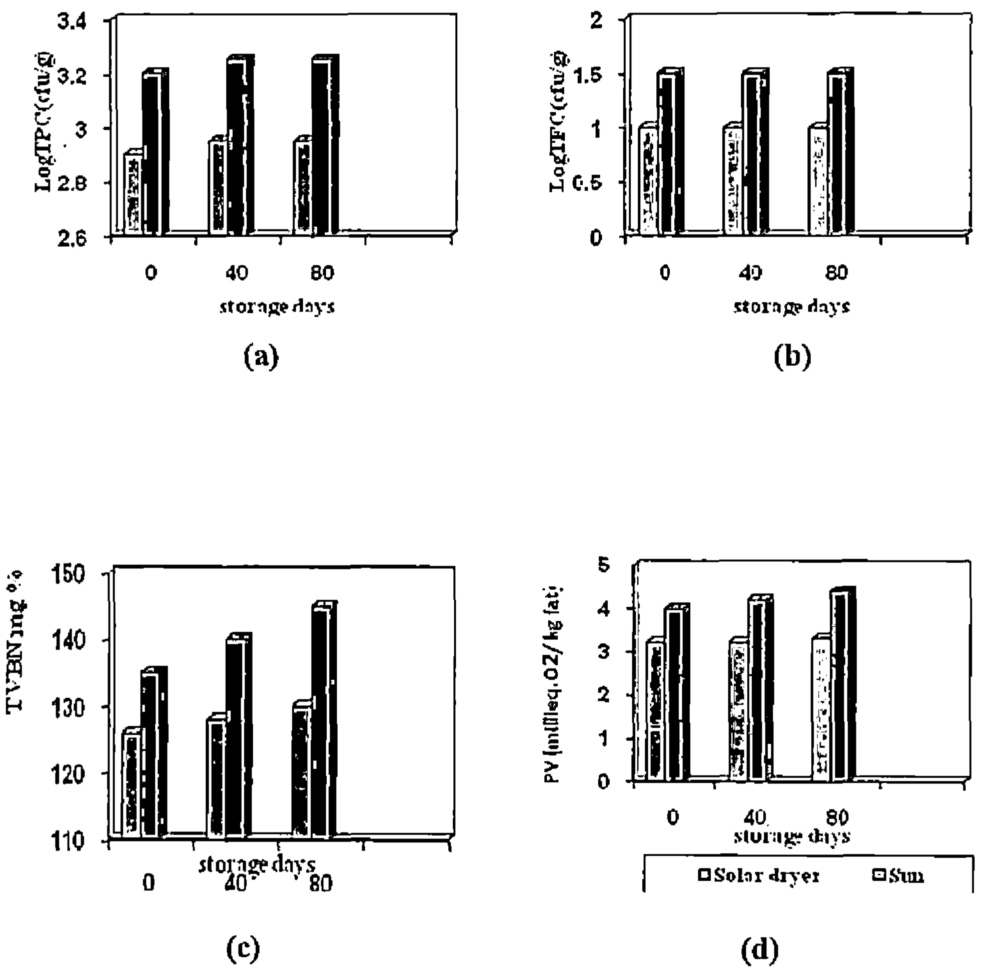


Fig. 13: Variations in TPC, TFC, TVBN content and PV of prawn dried in solar dryer and by sun drying, during storage.

Table 14: ANOVA for variations in TPC, TFC, TVBN content and PV of prawn dried in solar dryer and by sun drying, during storage.

	TPC			TFC			TVBN			PV		
Periods	F= 1671.110*			F= 0.572			F= 45.292*			F= 15.167*		
Treatments	F= 127530.8*			F= 41.582*			F= 468.167*			F= 1504.167*		
Periods	0	40	80	0	40	80	0	40	80	0	40	80
Retransformed means:	1279^{a}	1279^{a}	1357^{b}	14.7^{a}	17.45^{b}	17.57^{b}	-	-	-	-	-	-
Means:	-	-	-	-	-	-	130.166^{a}	133.0^{b}	136^{c}	3.600^{a}	3.67^{a}	3.7^{b}
Treatment	Solar dryer		Sun	Solar		Sun	Solar dryer		Sun	Solar dryer		Sun
Retransformed means:	1125.3		1932.6	123.1		515.2	127.333		139.111	3.1333		4.1889

* Significant at 5% level

^{a,b,c,d,e,f,g,} Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroup

4.4.8 Sensory evaluation:

Sensory evaluation was done for dryer- dried and sun dried prawn based on a 5 point hedonic scale.

4.4.8.1 Colour:

Only a marginal decrease in the mean scores for colour of prawn dried in the dryer, from 3.5 to 3.4 was noticed (Fig 14a). In the case of sun dried prawn the score of 0 day sample was only 2.0, which further decreased to 1.5 in 80 days. Mann- Whitney test (Table 15) indicates that there was a significant difference between test and control on 0^{th}, 40^{th} and 80^{th} day, respectively. The scores for test samples were applicably higher. However, no significant difference was noticed between storage days for both test and control.

4.3.8.2 Odour:

No change was noticed in the mean odour scores in the case of test, whereas it reduced from 2.0 to 1.5 in control (Fig 14b). Significant difference between test and control was evident, on 0^{th}, 40^{th} and 80^{th} day from the Mann- Whitney test (Table 15).

4.3.8.3 Texture:

Significant difference was observed between test and control on 0^{th},40^{th} and 80^{th} day from the Mann- Whitney test (Table 15). The High scores of 4- 4.5 (Fig. 14c) were obtained for test whereas in the case of control the values were rather low.

4.3.8.4 Taste:

Variations in mean scores for taste during storage are shown in Fig. 14d. Scores remained high in the case of prawn in dryer at around at around 4.5. The sun dried sample was definitely judged inferior and in addition, scores decreased further during storage. Significant difference was noticed between test and control on 0^{th}, 40^{th} and 80^{th} day according to Mann- Whitney test (Table 15).

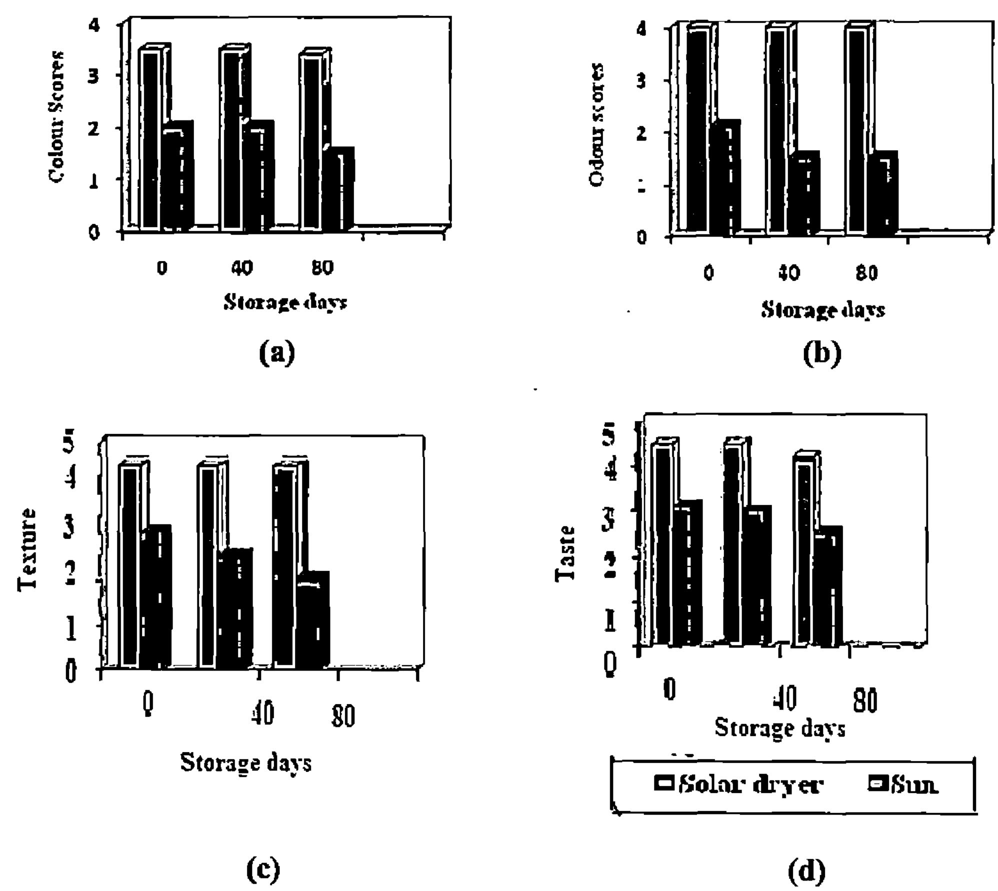


Fig. 14: Variations in sensory evaluation scores for prawn dried in solar dryer and under sun drying, during storage

Table 15: Variations in U- values for the sensory scores of prawn dried in solar dryer and by sun drying, during storage.

	Colour	Odour	Texture	Taste	Critical value U 0.05 (2) 10, 10
0	111.7	116	122	113.9	77.00
40	116	117.3	120.6	111.1	
80	113.9	116.7	120.6	113.9	

4.5 Storage studies of fish:

4.5.1 Atmospheric conditions:

The maximum air temperature during storage was 37^0C and minimum temperature was 28°C. The relative humidity ranged from 78 % to 84 % during storage.

4.5.2 Moisture content:

The variations in the moisture content of dry salted fish during storage are shown in Fig.15. The moisture content remained more or less the same ranged between 20.2 to 20.3 % in the test but there was slight increase in control from 20.2 to 20.7 samples. There was significant difference for moisture content of dry salted fish during the storage days (Table 16).

4.5.3 Water activity:

Variation in water activity of dry salted fish during storage was insignificant in both test and control. The variation was only between 0.65 and 0.68 in both are shown as Fig. 15.

4.5.4 Total plate count:

Fig.16a shows the variations in TPC for dry salted fish in solar dryer and under sun during storage. TPC appeared to increase in test and control from 6.2×10^4/ g to 6.5×10^4/g and 1.2×10^5/ g to 1.8×10^5/g, respectively. The statistical analysis for TPC values during storage are given in Table 17. Significant difference was observed between test and control of dry salted fish during the storage period.

4.5.5 Total fungal count:

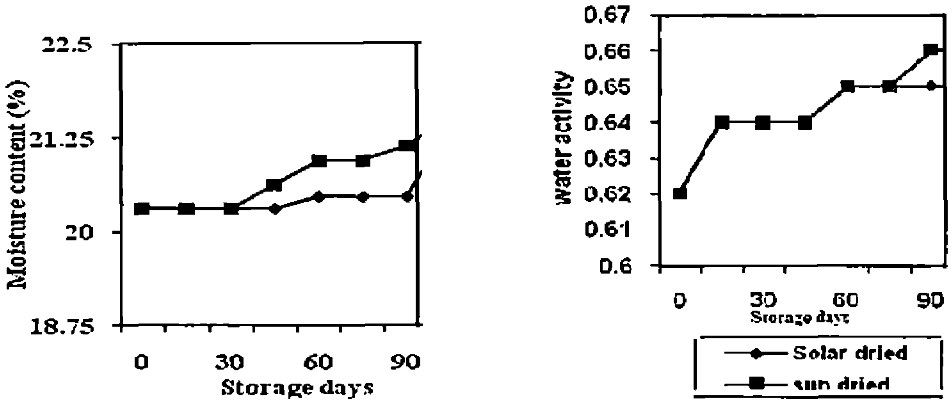
Fig.16b shows the variations in TFC for test and control of dry salted fish during storage. TFC appeared to be not detected in test and at around 3.2×10^1 in control during storage.

4.4.6 Total volatile base nitrogen content:

TVBN content of test and control increased from 127 and 130 mg % to 157 to 170 mg %, respectively, as shown in Fig 16c. Statistical analyses for TVB-N content variation during storage of fish are given in Table 17. Significant difference in TVBN content was noticed between test and control of dry salted fish during storage.

4.4.7 Peroxide value:

PV of test and control increased between 5.2 and 5.5 milli equivalents O_2/ kg of fat in test and between 7.0 and 10.0 milli equivalents O_2/ kg of fat in control as shown in the Fig.16d. Statistical analyses for variation in PV during storage of dry salted fish are given in Table 17. Significant difference was noticed between the test and control of dry salted fish during storage.



(a) (b)

Fig. 15: Variations in moisture content and water activity of salted fish dried in solar dryer and under sun, during storage.

Table 16: ANOVA for variations in moisture content and water activity of fish dried in solar dryer and by sun drying, during storage.

		Moisture content			Water activity				
Periods	F= 383.774*				F= 98.118*				
Treatment	F= 476.857*				F= 681.085*				
Periods		0	15	30	45	60	75	90	105
Retransformed means:	Moisture	20[a]	20.2[a]	20.2[a]	20.2[a]	20.3[b]	20.3[b]	20.3[b]	20.32[c]
	a_w	0.6[a]	0.64[a]	0.64[a]	0.64[b]	0.65[b]	0.65[b]	0.65[b]	0.65[b]
Treatment		Solar dryer				Sun			
Retransformed Means:	Moisture	20.05				23.15			
	a_w	0.62				0.65			

* Significant at 5% level

[a,b,c] Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups

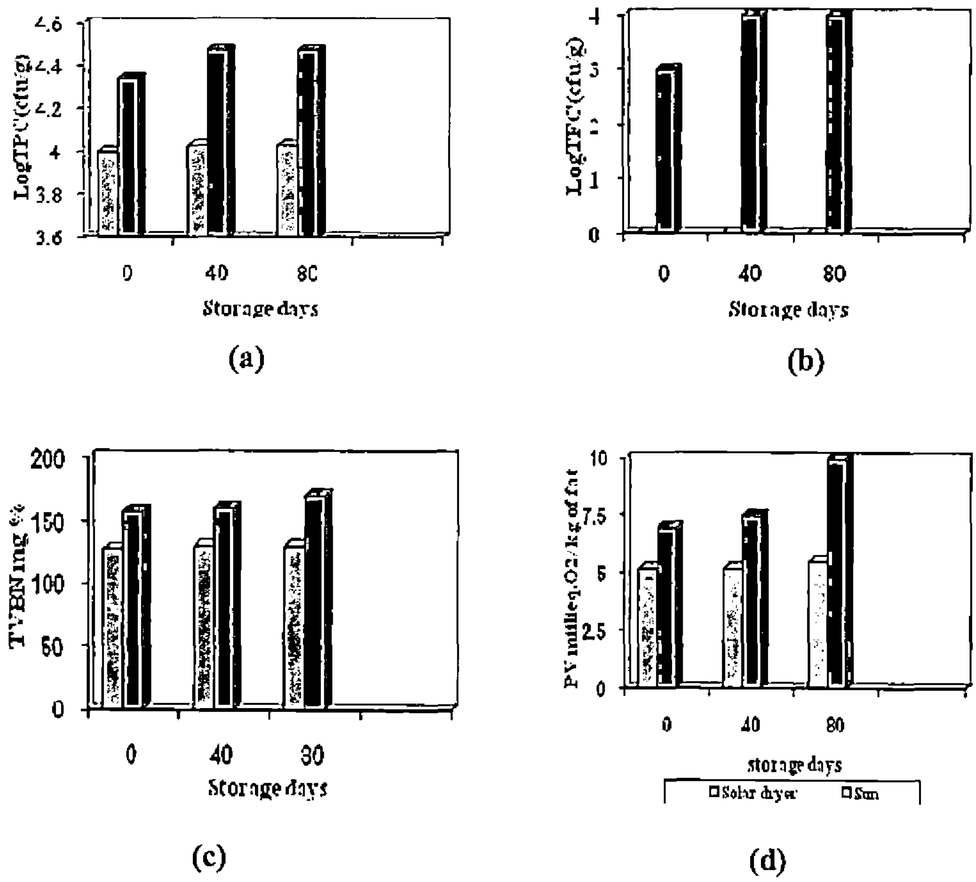


Fig. 16: Variations in TPC, TFC, TVBN content and PV of dry salted fish dried in solar dryer and under sun, during storage.

Table 17: ANOVA for variations in TPC, TVBN content and PV of dry salted fish dried in solar dryer and by sun, during storage

	TPC			TVBN			PV		
Periods	F= 5213.01*			F= 2.694			F= 198.795*		
Treatments	F= 1629.77*			F= 74.829*			F= 1615.410*		
Periods	0	40	80	0	40	80	0	40	80
Retransformed means:	1493.1[a]	2369.1[b]	2688.7[c]	141.333	143.833	146.500	-	-	-
Means	-	-	-	-	-		3.600[a]	5.6167[b]	7.7667[c]
Treatment	Solar dryer		Sun	Solar		Sun	Solar dryer		Sun
Retransformed means:	1566.45		2987.6	128.00		161.7778	5.211		8.00

* Significant at 5% level.

[a,b,c,] Period means with same superscripts belong to same subgroup and with different superscripts belong to different subgroups

4.5.8 Sensory evaluation:

Sensory evaluation was done for the two samples based on a 5-point hedonic scale.

4.5.8.1 Colour:

The mean scores for colour decreased from 4.5 to 4.0 in the case of fish dried in the dryer and from 2.0 to 1.0 in the case of sun drying as given in Fig. 17a .Mean scores obtained at each sampling for test and control were subjected to Mann-Whitney test, the results of which are given in Table 18. There was significant difference between test and control on 0^{th}, 40^{th} and 80^{th} day.

4.5.8.2 Odour:

Scores for odour appeared to remain fairly stable during period of storage at around 4.0 in the case of test and but decreased from 3.0 to 2.5 in the case of control (Fig. 17b). Mann- Whitney test confirms a significant difference between test and control on 0^{th}, 40^{th} and 80^{th} day (Table 18).

4.5.8.3 Texture:

Variations in texture of dried fish during storage are shown in the Fig.17c. Scores remained stable during this period in the range 3.5 in test and 2.0 or less in the case of control. Significant difference between test and control is seen on 0^{th}, 40^{th} and 80^{th} day from the Mann- Whitney test (Table 18).

4.5.8.4. Taste:

The mean scores for taste during storage of fish are shown in Fig. 17d. Changes noticed in the score of dry salted fish were from 4.5 to 4.2 in test and 3.1 to 2.5 in the case of control. However, taste scores for test remained significantly higher compared to those of control according to Mann- Whitney test (Table 18).

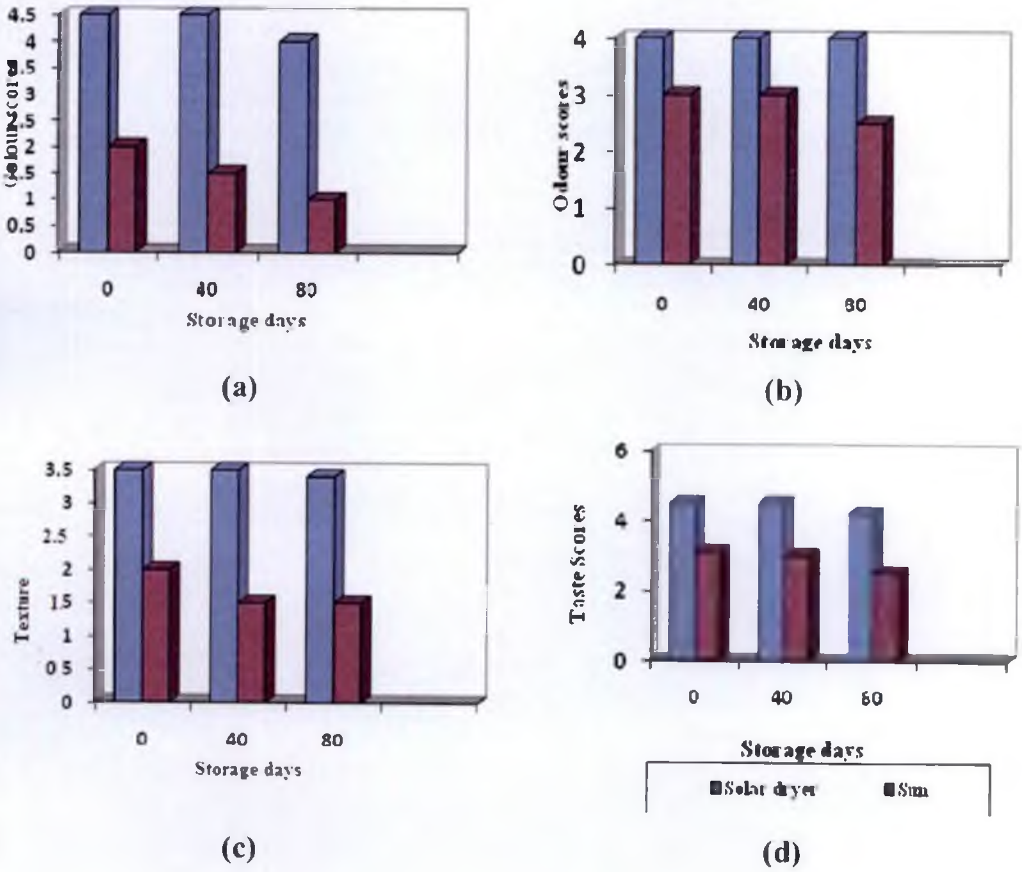


Fig. 17: Variations in sensory scores of fish dried in solar dryer and under sun, during storage.

Table 18: Variations in U- values for the sensory scores of fish dried in solar dryer and by sun drying, during storage.

	Colour	Odour	Texture	Taste	Critical value u 0.05 (2) 10, 10
0	111.6	115.7	124.9	114.3	77.00
40	112.5	113	120.4	110.9	
80	112.9	116.8	120.7	113.7	

DISCUSSION

5. DISCUSSION

5.1 Dryer operation:

The original BARC model solar dryer was initially used for drying fish. The equipment is reported to be very effective for drying of spices, pulses, etc. (Chandak *et al.,* 2010). However, when tried on fish, the temperature was found to increase to as high as 60- 65°C on sunny days. This was well above the minimum cooking temperature of 55°C for fish as reported by Loma (2006). Further, rate of drying of fish was found to be even lower than that in the open air. This is probably due to the inefficiency of the dryer in reducing the relative humidity of air inside. Thus it was decided to modify the design in order to suite fish drying. Modifications included provision of an exhaust fan at the top of the hood that was tapering to the top from all the four sides. Holes were drilled on all four sides of the base unlike only two sides in the BARC model.

The fan provided a greater air flow rate of about 0.08 m/ s. By controlling the fan speed the temperature inside could be maintained at an optimum range of 45-50°C. The effect of forced air flow on drying temperature has been reported by Williams (1977) also. The recommended air flow rate for fish is approximately 1 m/ s (Wheaton *et al.,* 1985). However, this is not required for the dryer as a flow rate above 0.08 m/ s was found to decrease the temperature below 45°C even at maximum sun's radiation in summer.

The base of the equipment was painted black with matt finish at the outside as in the case of the BARC model. This is for the maximum absorption of the radiational heat. The inner surface of the aluminum sheet was left as such because the glossy surface of the metal could reflect some of the sun's radiation on to the fish (Nair *et al.,* 2009). The upper portion of the hood was made up of transparent PVC sheet that facilitated direct heating of the air inside by sun's radiation. The rise in temperature of the air reduces relative humidity of the air; this in turn increases the equilibrium relative humidity (ERH) -relative humidity (RH) gradient thereby increasing the drying rate (Hiraka *et al.,* 1998).

The heated air attains a lower density and tends to move upwards. The fan aids in the flow of air. The fish is spread in trays and are placed at about 25cm from the bottom. The heated, low humidity air picks up moisture as it passes over the fish and the humid air is directed to the outside at the top with the help of the fan. Simultaneously, fresh air enters from all sides at the bottom.

5.2 Studies on drying of prawn and fish:

The drying studies were carried out using three lots of prawn and three lots of fish each under a set of atmospheric conditions (temperature and humidity) to understand the influence of environmental factors. For drying studies prawn were dried directly after beheading, but fish were dressed and salted overnight before drying. In control the samples were placed at the same level as in the dryer and a wind shield was provided to avoid the influence of wind on drying. Thermocouples were placed at different levels in the dryer as well as outside to measure the air temperature (Fig. 5).

Fish/ prawn were loaded after the dryer had reached a fairly stable temperature in the forenoon. However, around noon, the air temperature continued to increase further for a few hours and then remained fairly constant (Figs 6 and 9). Towards the end of the day air temperature got reduced. Relative humidity (RH) of hot air at a level just before reaching the fish, and the air above fish after picking up the moisture, were measured by means of hygrometers hung at the appropriate levels inside the dryer. The variations in the RH during drying of prawn are shown in Fig. 6 and those of salted fish are shown in Fig. 9. As can be observed, the temperature and RH were maintained within a fairly narrow range by adjusting the fan speed. Relative humidity of the outside air was higher in the morning; later it decreased as the temperature increased. This would further decrease after entering the dryer resulting in a greater ERH- RH gradient, which in turn enhances the rate of drying.

Three lots of prawn or fish used for the study were of small size and thickness. They were obtained in the same summer season, a few weeks apart only. Thus, the proximate composition did not show any significant variation between lots (Table 1 and 7). The moisture content of salted fish at the beginning of drying was only around 70 % whereas it was over 78% in the case of prawn. This was because of the partial dehydration effect of salt on fish. The prawn was found to be very low in fat content. Similar results have been obtained by others also (Wood and Flick, 1990). Although higher in fat content than prawn, the fish used can also be considered lean. As expected, all components other than moisture, viz., crude protein, crude fat and ash, increased in content upon drying. Moisture content decreased to about 13 % in prawn and to about 20 % in dry salted fish. At these moisture levels the products were found stable at room temperature. Similar results have been obtained by Opstvedt (1988). As per ISI specifications (ISI, 1986) the moisture content of salted fish must be below 35 %. Presence of salt maintains the water activity sufficiently low at comparatively higher moisture content. In the case of prawn, since preservation is effected by drying alone, moisture content must be further reduced to attain low water activity. Acid insoluble ash content generally refers to the sand content. This was found to be low in all the products indicating that the materials were handled hygienically. As per ISI specifications (ISI, 1986), the maximum limit of acid insoluble ash content in dried or dry salted fish is 1.5 %. However, the sand content of prawn or fish dried in solar dryer was substantially lower compared to their respective controls placed outside. This clearly suggests the ability of the dryer to prevent contamination with sand, dust, etc.

The drying rate and the water activity of prawn and fish seemed to be in a lag phase for a few hours in the initial stages of drying as may be observed in Figs 7 and 10, respectively. This may be on account of lower atmospheric temperature in the forenoon. Later, the curves reached maximum steepness followed by reduction in steepness due to, probably, constant and falling drying rate phases, respectively.

In the initial stages of drying fish, on account of high moisture content, the rate of movement of water molecules to the surface from the inner layers is more or less the same as the rate of evaporation of water from the surface (Kandoran *et al.*, 1971). However, as drying progresses, the amount of water available reduces resulting in a progressive reduction in the rate of water movement to the surface of fish. This, in turn, affects the drying rate resulting in a slow down as can be seen in the graphs. Water activity is a true indicator of the extent of free water available for microbial action. Moisture content, on the other hand, gives the total water content constituted by both free and bound water. The products were dried to a level when its water activity reached slightly below 0.65 (Figs 7 and 10). The corresponding moisture contents were 13 % in prawn and 20% in fish. According to Balachandarn *et al.* (1989), high moisture content, and bacterial and enzymatic degradation limit the shelf life, and the products become organolepticaly of poor quality. Hiraka *et al.* (1998) reported that the final moisture content of the mackerel was reduced to 25% after 7 days of drying by sun drying at 40^0C. The materials used in the study were of small size (prawn of average thickness 1 cm and fish of average thickness 1 cm). Hence, the total drying time can be expected to be lower.

It is evident from Fig. 7 that prawn could be dried faster in the solar dryer compared to that under the sun. The time required to lower the water activity to 0.65 was substantially lower in the dryer. Drying under sun required a period of 9-10 h in the first two lots and 10- 12 h in the third lot. This could be reduced by 4-7h by the dryer. The drying period required was higher in the case of the third lot because the atmospheric temperature remained lower and humidity higher than those atmospheric conditions with respect to the first two lots. There was not much variation in the atmospheric conditions between the first and second lot of prawn or fish during drying. This must be the reason for more or less the same drying time required for the first and second lots.

A very similar pattern of drying was observed in the case of fish (Fig. 10). The atmospheric air temperature and humidity during drying the first and second lot of fish were more or less the same. The shapes of the drying curves are very similar, so also the shapes of their water activity curves (Figs 7a, b and 10a, b). The third lot of fish was dried when the atmospheric temperature was lower and humidity higher. Thus, the drying curves and water activity curves (Fig 7 c and 10 c) are comparatively less steep.

The time taken to reach the stable level of water activity 0.65 was substantially lower in the case of fish dried in the solar dryer compared to that by sun drying. The drying time required for fish was even less compared to that for prawn, whether inside the dryer or outside. This is because fish was salted overnight prior to drying. This has resulted in a significant reduction in the moisture content before it was subjected to drying. The moisture content of prawn at the start of drying was 78- 80% (Fig. 7) whereas it was only 69- 73% (dry weight basis) in the case of salted fish (Fig. 10). The water activity of prawn at the start of drying was 0.9- 0.95 whereas it was only 0.8- 0.85 in the case of salted fish.

No significant variation in the isotherms for test and control were noticed in the first two lots of prawn and fish (Figs 8 and 11). This indicates that the quality variation with respect to the extent of protein denaturation and hence, bound water content, may be more or less the same in products dried by the dryer or under the sun. Bandarra *et al.* (1997) has indicated that sorption isotherm is a good indicator of the quality of the dried fish. However, it may be noted in Fig 8 c and 11 c that there are some variations between test and control, with the latter showing a higher water activity for the same moisture content for most part of the drying process. It is possible that direct sun drying for longer periods can adversely affect the components of prawn or fish. The sorption isotherm for test and control, of both prawn and fish, are more or less of the same pattern.

Total plate count during drying of prawn varied only slightly, well below one log cycle difference, irrespective of the type of drying and atmospheric conditions (Table 3). The extent of increase in counts was slightly more in the case of prawn dried under sun compared to drying in solar dryer. This may be because bacteria may have a greater chance of multiplication in the former on account of lower temperature and lower rate of drying. However, the counts were too low to cause any harm. TFC counts were still lower, and did not increase at all in all the treatments. TPC and TFC did not vary much in all the treatments of fish during drying. However, the counts were comparatively higher than those of prawn, being around 10^4/ g for TPC and 10^2/ g for TFC. This can be account of greater extent of contamination of the raw material only. A slight increase in microbial count was observed in the case of the third lot of fish dried under sun. This must be on account of the slower drying process. The values of TVBN content can increase substantially during drying on account of loss of weight rather than on account of bacterial activity. Huss (1955) and Rhee (1978) has reported TVBN values of 30-

40 mg% for fresh fish and 100- 200 mg% for dry salted fish as the limits of acceptability. In the present study no microbial activity would have caused to form volatile bases since the counts remained low throughout the drying period of prawn (Table 4) as well as in fish (Table 10). However, the values were found to increase to fairly high levels towards the end of the drying period, but definitely below the acceptable limits as proposed by Melton (1983). In both prawn and fish, TVBN values were generally higher in the case of sun dried samples compared to those dried using the solar dryer.

Peroxide value also showed similar trends in both prawn and fish. There was a significant increase in PV of both test and control runs of prawn and fish with the drying period. This can be because of slight oxidation of fat that would have occurred during drying. According to Aitken and Connell (1980) the PV of freshly dried fish/ prawn was 1- 10 milli equivalent O_2/ kg of fat. In the study the values did not exceed 5 milli equivalent O_2/ kg of fat for prawn (Table 5) and 9 milli equivalent O_2/ kg of fat for fish (Table 11), indicating that the materials did not turn rancid upon drying. However, fish consistently showed a higher PV from the beginning than prawn probably on account of greater extent of unsaturation of fat in fish. PV of test and control samples of either prawn or fish were more or less the same throughout the drying period. However, slightly higher values were occasionally seen in, the case of samples dried under sun, probably because of a greater effect of sun's radiation in accelerating oxidation (Olcott, 1962).

Whatever be the processing method adopted, the ultimate deciding factor of marketability of a product is its organoleptic quality (Gill, 1992). As may be observed in the Tables 6 and 12, both prawn and salted fish dried in the solar dryer were given significantly high scores by the judges for all the sensory parameters, than those dried directly under sun. For evaluation a 5- point hedonic scale was used (Appendix I) with score 1 as the borderline of acceptability.

According to Kazimerz *et al.* (1999) direct exposure of fish or prawn to sunlight can induce several undesirable changes. Sun's radiations are capable of accelerating various oxidative changes that can affect sensory quality characteristics such as colour, odour, texture and taste. Sun's radiations, in addition, can adversely affect various components of prawn or fish such as proteins and vitamins, which in turn, may affect the textural and nutritional qualities of the products. Drying period for prawn or fish was substantially lower when dried in solar dryer compared to when dried under sun. Thus, it is likely that the components of prawn or fish were exposed to the harmful effects of the sun for less time resulting in greater retention of quality in the former.

Although subjective, sensory evaluation is the most dependable quality assessment method for fish products (Farber, 1956; Gould and Peters, 1971). The panelists were asked to judge each parameter according to their liking as would be done by the general consumers. Colour is one important parameter that is affected by drying. Excessive drying, high temperature, exposure to sun for a long period, etc., can adversely affect the natural colour and induce reactions like Maillard browning as reported by Cutting (1962) and Pigot and Tusker (1990). This is the likely reason for a lower colour score for fish or prawn dried under sun compared to that in the dryer (Fig.14a). Flavour is a very sensitive parameter which includes various characteristics such as odour, texture and taste as according to Amerine *et al.* (1965). In the present study products dried in the solar dryer consistently received higher scores over their respective controls for all the three parameters (Fig. 14b, c d). Greater loss of odour and flavor- giving substances and development of undesirable flavour on account of Maillard reaction, fat oxidation, etc., might have occurred during sun drying because of longer drying period required. Reactions such as protein denaturation may be responsible for the lower score for texture.

5.3 Studies on storage of dried prawn and dry salted fish:

The first lot of prawn and the first lot of salted fish were dried either in dryer at temperatures ranging between 40 and 50°C and RH between 67 and 75% or under sun with outside atmospheric temperature ranging between 30 and 35°C and RH between 75 and 80%, and were then subjected to storage studies. For this the products were packed in bags of low WVTR (0.01g/ m^2/ 24h at 90% RH and 37°C) in order to minimize the possibility of moisture absorption from outside. Moisture content and water activity appeared to increase slightly with storage period in both prawn (Fig. 12) and fish (Fig. 15). This must have resulted because of absorption of moisture from the air inside the bag or by the entry of moisture through the bag. The permeability of the bag is extremely low which probably is responsible for only a slight increase in both the parameters. However, after a period of 60 days, both moisture content and water activity have risen slightly above their respective maximum limits suggested. Packaging material of greater barrier property may prevent this increase.

Results indicate that the products- dried prawn and dry salted fish, both test and control- could be stored well for the entire study period of 80 days. The variations in different parameters, viz., TPC, TFC, TVBN content, PV and sensory quality (Figs 13 and 14) during storage were not significant with the storage period irrespective of whether dried in solar dryer or under sun. Although not significant, a slight increase seems to be evident with respect to most of these parameters with storage period. This can probably be on account of slight absorption of moisture content (Fig. 12a and 15a), increased microbial activity and fat oxidation.

However, the quality of prawn or fish dried in the solar dryer remained consistently higher compared to their respective controls dried under sun. It may noted from Figs 13 and 16 that the quality parameters viz., TPC, TFC, TVBN content and PV were significantly lower in solar dryer-dried prawn compared to sun dried material. The scores for colour, odour, texture and taste were much higher for solar drier-dried material (Fig. 11). Similar trend was seen in the case of fish also (Fig. 17). The possible reasons for significant variations in quality between the test and the control runs have already been explained earlier.

Further, the differences in the microbial or chemical parameter values and sensory scores between solar dryer-dried prawn or fish and sun dried material appear to be increasing with storage period. Thus, it appears that significant difference between the test and control will occur on further storage, with greater retention of quality in the products dried by solar dryer.

TPC showed a slight increasing trend, although not significant, particularly in the controls (sun dried) of prawn (Fig.13a) and fish (Fig. 15a). The counts were maintained low throughout the storage. This can be on account of the low water activity of the products on the organisms, except a few tolerant ones that attained a chance to grow as the extent of the moisture absorption increased. TPC, however, remained significantly low in the solar dryer-dried prawn or fish compared to their respective controls. This may be because of a slightly higher rate of growth of microorganisms in the control runs of prawn or fish during the drying process. This probably continued during storage also.

TFC was rather low in the solar dried samples of prawn and fish (Fig. 13b and 16b). This is possible as the water activity levels did not rise significantly anytime during storage period and remained at around 0.65 (Fig. 12b and 15b). According to Frazier and Westhoff (1978) fungi are well inhibited below a water activity of 0.65. Fungal count was generally very low, to the extent of about 1×10^2/ g only, in prawn (Fig. 13c). In fish it was almost nil in the solar dryer-dried material (Fig. 15b). Fungi, in general, are more tolerant to lower water activity than bacteria and therefore, they may be involved in the spoilage of dried products (Katz and Labuza, 1981). However, the extent of increase in fungal growth may not be sufficient to cause any decrease in the quality of the products. Thus it may be assumed that fungi may not have any involvement in lowering of quality of either solar dryer-dried or sun dried prawn or fish during the 80 days period of study.

TVBN content showed a similar trend as that of TPC in dried prawn (Fig. 13c) and dry salted fish (Fig. 16c). This is possible because TVBN compounds are produced by bacterial spoilage (Connell, 1975). But the values did not increase beyond about 180 mg% in any of the treatments. Huss (1988) reported that TVBN content reached 30- 40 mg % in fresh fish and 100- 200 mg% in dry salted fish at the beginning of spoilage. TVBN content of prawn or fish dried by the solar dryer remained significantly lower as compared to their respective controls.

One good indicator of the intermediate stages of fat oxidation is peroxide value (Tarr, 1944; Bernheim *et al.*, 1948; Gray and Melton, 1983). The species of prawn used was very lean (Table 1) and even after drying the fat remained below 0.5 %. The fish used, although lean, had higher fat content than prawn (Table 7). However, a slight increase in PV was seen in prawn probably on account of the small amount of oxygen present inside the bags (Fig. 13d). But the increase was not significant and may not have affected the taste at all. PV was significantly higher in the control run either in the case of dried prawn (Fig. 13d) or in the case of dry salted fish (Fig. 16d), right from the beginning of storage. This is possible as the drying period required for control was substantially greater resulting in a greater extent of fat oxidation. This probably continued during storage, thus showing a higher level compared to the test samples.

As noticeable in Figs 14 and 17, the scores for all the sensory parameters, viz., colour, odour, texture and taste, remained significantly higher in prawn and fish dried by the solar dryer compared to their respective controls dried under sun. It may also be noticed that the quality of the sun dried materials reduced at a higher rate than the solar dryer- dried products. It is, therefore, a clear indication that the type of drying would influence the storage stability of the products. It may also be noted that the score values for most paramerters of dryer-dried prawn and fish remained at around 4 or even more when the maximum score in the scale was only 5. In the case of control runs of prawn or fish, the scores were nearing the limit of acceptability towards the end of the study. As mentioned earlier, this reduction in quality is on account various microbial and chemical changes that had already taken place during drying, and which continued to take place during storage. The solar dryer, however, is able to substantially reduce these changes on account of reduced drying time and greater protection given to products from the harmful effects of sun's radiation.

5.4 Production cost:

The increase in cost of production for drying seafood in the designed solar dryer over that by conventional sun drying was worked out as given in Appendix-II. Small sized prawn may be dried at an additional cost of Rs 2.40/ kg product and small sized flat fish at an additional cost of Rs. 2.00/ kg. The price of sun dried prawn in the local market is around Rs. 700/ kg and that of sun dried and salted flat fish is around Rs. 300/ kg. The increase in cost of production on account of using the dryer is thus negligible. The solar dryer-dried products are definitely superior to conventionally sun dried products with respect to all the sensory parameters tested.

It may be expected that the nutritional quality of the products are also less affected on account of the shorter duration of drying and the proper conditions inside the dryer. These, in addition to the greater hygienic conditions of drying, would make the products dried in solar dryer more acceptable in the market. It may also be noted that the capital investment is very low. The equipment used for the study costs only around Rs. 5500. The model could be scaled up for a greater capacity making it more viable for a small scale industry.

SUMMARY

6. SUMMARY

1. The main objectives of the project were to study the drying efficiency of a new design of a solar dryer in comparison with conventional sun drying and to evaluate quality variations in dried prawn (*Metapenaeus dobsoni*) and dry salted fish (*Cynoglossus macrostomus*) during storage at room temperature.

2. The BARC model dryer was modified to suite drying of fish. The dimensions of the dryer were 120 × 80 × 80 cm with an aluminum base that was painted black and a tapering hood of transparent polyvinyl chloride sheet with an exhaust fan at the top.

3. Beheaded prawn and salted fish samples were placed inside the dryer (test) as well as outside (control) and subjected to drying. Fish was dressed and salted overnight prior to drying.

4. Moisture content, water activity, total plate count (TPC), total fungal count (TFC), total volatile base nitrogen (TVBN) content and peroxide value (PV) of the samples and temperature and relative humidity of air both inside and outside the dryer were monitored during drying.

5. The drying period was substantially reduced by the dryer. Prawn that took 11 h when dried directly under the sun, required only 8 h, when dried in the dryer. In the case of fish, direct sun drying required 10 h whereas it took only about 7 h in the dryer. The period was lower in the case of fish probably due to the dehydration effect of salt.

6. The quality variations in prawn or fish were significantly lower when dried using the solar dryer compared to direct sun drying. The quality parameters, viz., TPC, TFC, TVBN and PV of prawn as well as of salted fish remained at lower levels when dried in the dryer.

7. Higher sensory evaluation scores for colour, odour, texture and taste obtained for solar dryer- dried products compared to the sun dried products also indicate that former were of superior quality upon drying as well as storage.

8. The sorption isotherms obtained for test and control were not very different in shape either in the case of prawn or in the case of fish indicating that effect of the bound water on the products were not very significant.

9. Dried prawn and fish, both of test and control, were packed in low permeable polypropylene- polyamide bags and stored at room temperature for a period of 80 days.

10. Quality changes during the storage period were monitored based on various tests, viz., moisture content, and water activity and TPC, TFC, TVBN content, PV and sensory evaluation based on colour, odour, taste and texture.

11. The results indicate that both test and control samples of dried prawn and dry salted fish remained acceptable throughout the storage period of 80 days. However, quality of prawn or fish dried in the solar dryer was found to be of superior quality throughout. This can be on account of shorter drying period and reduced harmful effects of sun's radiation on the products in the dryer.

12. The increase in cost of production using the dryer compared to that of conventional sun drying is only Rs. 2.40/ kg dried prawn and Rs. 2.00/ kg dry salted fish. This is only nominal considering the price of the same products in the market.

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7. REFERENCES

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ABSTRACT

STUDIES ON DRYING OF FISH USING A BARC- TYPE SOLAR DRYER

by

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ABSTRACT OF THESIS

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ABSTRACT

A study was conducted with the aim of evaluating the drying efficiency of a newly designed solar dryer (modified BARC type) in comparison with conventional sun drying. The materials used for drying were beheaded prawn *(Metapenaeus dobsoni)* and salted fish *(Cynoglossus macrostomus)*. Rate of drying was found to be influenced by the atmospheric temperature and humidity, either using dryer (test or by sun drying (control). In the case of prawn, the drying period was 7h by dryer compared to control which took about 10h whereas in the case of fish it was only 7h compared to control which took about 9h. Various parameters such as moisture content, water activity, TPC, TFC, TVBN content and PV, during drying were monitored. The quality variations in prawn or fish were significantly lower when dried using the solar dryer compared to direct sun drying. Sensory evaluation based on colour, odour, texture and taste, also proved that the solar dried samples were of superior quality compared to control. Sorption isotherm for test and control did not vary much in shape for both prawn and fish. This indicates that the effect of the type of drying on the bound water of the products. For conducting storage studies the dried prawn and dry salted fish, both test and control, were packed in low permeable polypropylene- polyamide bags and stored at room temperature for about 80 days. Quality parameters, viz., moisture content and water activity, TPC, TFC, TVBN content, PV and sensory evaluation based on colour, odour, taste and texture were evaluated during storage. Both test and control samples remained acceptable throughout the storage period. However, the quality of prawn or fish dried in solar dryer was found to be superior compared to their respective sun dried control samples. The additional cost was only Rs 2.40/ kg for dried prawn and Rs 2.00/ kg for dry salted fish. The equipment is recommended for small scale production of dried products.

APPENDIX- I

SCORE SHEET FOR SENSORY EVALUVATION

Date:

You are given samples of dried prawn. Kindly evaluate the following:

i) Colour and odour of dried prawn/ fish
ii) Texture and taste of dried cooked prawn/ fish

Use the quality rating scale for evaluation of quality; put the appropriate score against each quality parameter under the corresponding sample code.

Quality rating scale:

Description of quality	**Score**
Excellent	5
Very good	4
Good	3
Fair	2
Borderline of acceptability	1
Unacceptable	0

TYPE OF PRODUCT	QUALITY CHARACTERISTICS	SAMPLE CODE	
		A	B
DRIED PRAWN/ FISH	COLOUR		
	ODOUR		
DRIED COOKED PRAWN/ FISH	TEXTURE		
	TASTE		

Name of judge:

APPENDIX- II

Cost of fabrication of solar dryer and additional cost for drying seafood

Materials required	Cost (Rs)
a) Aluminum frame and strips	2075.00
b) Aluminum sheet (0.4 mm thickness)	810.00
c) Fan and accessories	1000.00
d) Miscellaneous items	300.00
e) Fabrication charges	1200.00
Cost of solar dryer	**5500.00**

Additional cost for drying prawn/ fish:

Quantity that can be loaded per day = 7- 8 kg

Production yield per day

a) Dried prawn @ 25 % = 1.9 kg

b) Dry salted fish @ 30 % = 2.3 kg

Production per year @ 200 sunny days:

Dried prawn =1.9 × 200 = 380 kg.

Dry salted fish = 2.3 × 200 = 460 kg.

Recurring expenditure:

a) Depreciation on equipment value @ 10 % = Rs. 550.00

b) Fuel charge:

Power consumption per year = 65 kwh (units)

Total charge @ Rs. 4/ unit = Rs. 260.

c) Cost of PVC sheet (to be replaced once a year) = Rs. 110

Total production cost per year = Rs. 920

Additional cost per kg dried product is

Prawn = 2.40/ kg

Fish = 2.00/ kg