Chapter 3
CHAPTER 3
REVIEW OF LITERATURE - II

3.0 REVIEW OF RESEARCH WORK DONE ON SOLAR DRYING OF FRUITS AND VEGETABLES

A lot of research work has been done by solar scientists on design, development and testing of solar driers for different agricultural/non-agricultural products in different regions of the world. Successful applications of solar driers have been reported for the following food/industrial products:

A. Solar drying of cereal Grains:
   A1 – Wheat
   A2 – Rice
   A3 – Maize

B. Solar drying of Timber, Fodder

C. Solar drying of Coffee, Tobacco

D. Solar drying of fruits and vegetables

As the present study is concerned with the application of solar energy technology for food processing, particularly applications of solar driers for fruits and vegetables drying, taking chillies (Jwala and Pusa Sada Bahar Varieties) and grapes (Thompson Seedless), under consideration. A detailed review of research work done on solar drying of various fruits and vegetables have been attempted along the following lines:

3.1. REVIEW OF RESEARCH WORK DONE ON SOLAR DRYING OF FRUITS AND VEGETABLES

3.2. REVIEW OF RESEARCH WORK DONE ON SOLAR DRYING OF CHILLIES

3.3. REVIEW OF RESEARCH WORK DONE ON SOLAR DRYING OF GRAPES

Lawland (1966) gave the basic design of cabinet solar driers (Figure 3.1.). It consists of a rectangular box some 1.8 to 2.4 m by 20 cm to 1.2 m. the drying product is supported on mesh trays. The interior should be painted...
black, taking care that the paint used is not toxic. To get better efficiencies, the wall and floor were recommended for insulation and double glazing of solar roofs. In some designs, air enters through perforations in the drier base and exits through holes at the top of the walls. In other designs, as shown in Figure 3.2, the air enters through the front wall ports and rear front wall ports and rear from exists form the rear wall.

![Typical Brace Drier](image)

**Figure 3.1: Typical Brace Drier**

This type of solar drier was later on investigated by Kapoor and Agarwal (1973) and for fruits and vegetables, Nahwali (1966), by Trim and Curran (1982) for fish. Bhatia and Gupta (1976) for apricots, by Clark (1981) for coconut and for chillies (Anony, 1980). A lot of design variations of this solar dryer have been studied, few modifications in design were:

- Better air circulation is said to result from interval pipes;
- Placing a layer of dark coloured stories in the cabinet base to act as a heat store, to improve drying rate during cloudy or rainy periods;
- During drying of fruits and vegetables, loss of colour and vitamins can be reduced if a sheet of black painted metal or black plastic is placed above the crops to shade it;
- Airflow rates have been reported to increase, if a black painted chimney is attached to the drier exit;
- Covering air entry and exit holes with fine reduces problems of insects entering drier;
- The use of small loading and unloading doors on rear wall avoids continually moving glazed root and thus increases its life.

Figure 3.2: Walk-through drier

Doe et al (1977, 1979) in Bangladesh, Anedelina (1978) in Papa New Guinea. Pablo (1978) in Philippines and Trim and Curran (1982) in Galapagos Island studied the applications of solar tent driers (Figure 3.3.) for the drying of fruits and vegetables. It was made from locally available materials such as woods and poles bamboos, plastic film etc. Polythene is also locally available. Only UV stable films were to be imported. Besides the other applications fish drying in tent driers in Bangladesh was of particular interest. Shorter drying time obtained than with sun drying, typically 25% less time taken in fish drying Bangladesh. With variations in the designs of tent driers –

Shaw and Both (1979) utilized these driers in Peru for pre-cooked potato drying. This was a tent dryer with several layers of trays in the shape of a rectangular box approximately 4 m X 1.5 m X 1 m. advantages of these dryers were that these are easy to build with locally available material and very easy to operate and can be easily dismantled for safe storage between
drying seasons. As far as design variations are concerned, other tent shapes such as semi-circular have been reported to be less liable to win damage. Solar tent driers, with other modifications such as horticultural greenhouse designs have been successfully used for fish drying in Bangladesh.

Figure 3.3: Tent Drier

New Mexico Solar Energy Association, New Mexico (1978) designed a solar air heated based dryer (Figure 3.4.). In this design of solar dryer, the separate solar air heater (collector) is glazed with fibreglass and contains a stack of trays. Air heated by air heater passes upwards through the trays filled with the product and exists from the cabinet. The feet stand in small tins containing kerosene to prevent insects climbing into drier. This type of drier can be constructed by locally available material. Fibreglass air heater can be replaced by double skin of polythene. Its operation and maintenance can be done by user itself, only some pre-training is required.

This type of solar air heaters assisted driers have been utilized successfully for the solar drying of food products which are sensitive to sunlight. A greater degree of temperature control is possible and a several types of products can be dried simultaneously. Cheema and Ribiero (1970)
utilized this solar air heater assisted dryer for the drying of Cashew, Banana and Pineapple in Thailand.

Gutierrez et al. (1979) for grapes in Chile, Pablo (1980), for fish in Philippines, Mastosudigo et al. (1979) for onion drying in Indonesia, and Moy et al. (1980) for taro roots in U.S.A.

Figure 3.4: New Mexico indirect drier

Macdowell (1973) proposed, a design of a fuel assisted solar biomass dryer (Figure 3.5.) to overcome drying problems in humid tropical countries. Its major applications were in fruits, vegetable and spices drying. In this type of dryer a tray supporting the product is placed under a double glazed conventional solar roof and air enters the drying chamber through hoes in the walls situated under the tray. In addition this drier has firebox connected to a flue that passes under the tray to an external chimney. During times of cloudy weather or at night, a fire can be lit and heat radiating from the pipe allows the product to continue to dry. The flue pipe passing through the drier must be smoke proof and the flue fitted with a damper which has to be kept closed down. When sun drying is being carried out to avoid cooling by the flue. The firebox should be facing the prevailing wind to improve draught and make
sure sparks from the chimney are carried away from the polythene cover. This type of dryers can be constructed by a trained user with locally available materials and can be maintained and operated by use itself after a little training. Although this type of solar drier is more costly than other types of same size solar dryers available, it has a great advantage of allowing the product to be completely dried in one stage and can be utilized, even under bad weather condition, particularly in humid climates.

![McDowell fuel-assisted solar biomass drier](image)

**Figure 3.5: McDowell fuel-assisted solar drier**

Excell et al. (1978, 1979, 1980) and Boothumijund et al. (1983) designed a solar chimney drier (Figure 3.6.) for the drying of fruits and vegetables. This type of drier consisted of a solar collector with a heat absorbing blackened interior and a drying chamber fitted with chimney. Several design variations of this drier have been successfully applied in Thailand for drying of fruits and vegetables. A major disadvantage was that it is a semi-permanent structure, so occupies a lot of land and can be easily destroyed by wind and storm surges.
Sandhu et al. (1979) designed, developed and tested the performance of multi-rack natural convection solar dryer for the drying of cauliflower, onion, spinach and potato. They concluded that the efficiency of multi-rack dryer is a function of the dryer and optimised the optimal loading rate to get good quality dried vegetables.

Bodewes et al. (1979) designed, developed and tested a simple type of solar dryer for onion drying. Quality of dried onions was found very satisfactory and could be stored for periods of more than a year. When placed in airtight containers.

Kalra and Bhardwaj (1981) designed, developed and tested two models of simple solar dryers, one with trays in a separate drying chamber and one with trays inside the collectors. Green peas, okra, and potato products were satisfactory dried and qualities of dried product were better than open air sun dried products.
Chundwat and Jain (1981) studied solar cabinet drying of ginger and turmeric and compared the results with sun drying of the same. They found that not only the drying rate of ginger and turmeric was faster but also their quality of the dried products was better than those dried in open air sun.

Menon and Cheema (1981) designed, developed and tested a solar dryer for the drying of date fruits.

Trim and Ko (1982) designed, developed and tested a solar dryer of a double skin tent design (inner skin of a black plastic sheet, the outer of a clear sheet) with a forced air draught provided by an electrical fan. The performance of the solar drier for the drying of capsicum peppers were compared with traditional open air sun drying, drying times with solar dryer was reduced by 65%. The quality of solar drier dried pepper was fully acceptable. The solar dryer was thus of an efficient and effective design. The collection efficiencies obtained, ranging from 32 to 52 %, were high, compared.

Patranon (1984) developed a fruits and vegetables dryer (Figures 3.7. and 3.8.). The maximum efficiency in this dryer was obtained when outlet area to absorbing area was 0.8%. This design, along with other modification was successfully utilized in different countries for the solar drying of different fruits and vegetables.

Figure: 3.7: Box dryer, Patranon (1984)
Sodha et al (1985) reported an extensive study of two methods of solar drying of mango on typical summer days at New Delhi and these two methods are: (i) open floor drying and (ii) cabinet type solar drier. The cabinet drier was constructed using locally available materials. Figure 3.9 shows experimental variation of moisture content with sunshine hours for open sun drying and cabinet type drier. It was observed that the drying in the first 4-5 hours is very high due to constant rate of drying. After this the drying rate is considerably lower. The drying in this region (falling rate) is higher in the cabinet type drier.
Figure 3.9: Simulated moisture content as a function of sun-shine hours for different products.

The high weather dependent risk and drying limitations due to extremely low buoyancy induced air flow of natural convection solar drier stimulated Muhlbauer et al (1998) at the Institute for Agricultural Engineering, University of Hohenheim to develop solar tunnel drier in which a fan is providing the air flow required to remove the evaporated moisture. The electric power requirement of the fan is very low and can be operated by one photovoltaic module independent of electric grid. Figure 3.10. shows the schematic diagram of a solar tunnel drier. Numerous tests in regions of different climatic conditions have shown that fruits, vegetables, cereals, grain, legumes, oilseeds, spices, and even fish and meat can be properly dried in the tunnel drier.
Hauser et al (1989) and Schirmer et al (1996) reported experimental investigations of the performance of solar tunnel drier for drying of apricots and bananas in Morocco and Thailand respectively. A comparison of the drying behaviour of bananas in solar tunnel drier with that of natural sun drying was studied. Drying of either apricot or banana in solar tunnel drier takes less time than that required by natural sun drying. The results show that the temperature profiles depend not only on solar radiation but also on the moisture content of the products. In addition, the products being dried in the tunnel drier are completely protected from rain, insects, and dust, and dried products were of high quality in terms of flavour, colour and texture. The pay

Figure 3.10: Solar Tunnel Drier
back period of the drier was estimated to be 3 years when the drier was constructed locally.

Field tests of solar tunnel drier have demonstrated its potentiality for drying of agricultural products in the tropics and subtropics and it is worth adoption if the product has a market value and the quality of the product is reflected in its price. Again, photovoltaic driven solar tunnel drier has the advantage that the temperature of the drying air automatically controlled by the solar radiation. The air flow is driven by a fan operated by a solar module and the air passes through the single cover collector between the cover and the absorber.

Patil and Annamalai (1986) designed, developed and tested two different crop dryers at Kasaragod, Kerla. First was a solar cabinet dryer, which was chamber type with direct heating and natural air convection arrangements. This type of dryer was suited for conditions with abundant solar energy. Second, was an electrical dryer, which was a large tray type dryer with mixed flow and forced air circulation devised for drying 1000 Kg coconuts. Performances of the both type of dryer were very satisfactory and cost-economics was a viable one for the local community.

Garango (1987) in Burkui Faso, carried out the energy balance analysis of a solar tunnel dryer. This analysis was based on a systematic study of the dryer working either empty or loaded with agricultural produce. The influence of different parameters on the drying was analysed and satisfactory results were obtained during drying days.

Onilude and Oloso (1988) designed and development and tested the performance of a solar dryer for the drying yam (Dioscorea rotundata) and flakes and Cassava (Manchot Utillessima) chips. This dryer was made from locally available materials. On experimentation, it yielded very good results. The highest average temperature recorded in the dryer was above 25K.

Sharma et al (1989) has studied the experimental performances of an indirect type solar fruit and vegetable dryer. The dryer comprise of plastic covered flat plate collectors and a drying chamber linked by thermally and acoustically insulated pipes. A series of experiments were conducted on typical summer days in the Italian policoro climate on drying of vacumi fruits and vegetables. The limited experiences gained with solar drying system
indicates that the unit is structurally and functionally sound. It has withstood wind, rain, snow and sunshine over a period of 3 years. The experimental results suggested that even under unfavourable weather conditions, the unit is able to produce good quality products. Due to low investment, the solar dryer is useful for application on small farms.

Spagna et al. (1989) carried out experimental investigation of different solar dryers suitable for fruits and vegetable drying. An experimental investigation of 3 types of solar dryers (2 Natural and 1 forced convection) for fruits and vegetables was carried out drying the summer in Southern Italy. Mushrooms, green chillies and tomatoes were used in the experiment and weighed at 2 hour intervals during drying.

Chauhan and Patel (1989) studied the sun drying characteristics of groundnut as per the practices adopted by the farmers of the region. They choose three heaps of uprooted plants for the experiments. All three heaps were divided into three layers i.e., top, middle and bottom layer. In the sun drying of whole plants, it was after 96 hours of drying the moisture content of the top, middle, and bottom layers were 17.13%, 15.10% and 13.36% (rdb) respectively.

Mathur and Verma (1989) developed a solar dryer for the drying of vegetables. They combined a direct exposure type, indirect type and shaded type into one unit to form a combined solar dryer and evaluated its performance. Results indicated that the direct exposure type dryer required minimum time to reduce the moisture content of Okra from 733.33 (db) to 5.5% (db) in 47 hours as compared to the indirect and shaded type. It was also found that the drying rate of vegetables varies with the height of the tray. Quality evaluation of dried Okra for colour, flavour and taste were found acceptable.

Bhatnagar and Ali (1989) suggested an optimum design of a solar dryer for various classified group of agricultural and other food products (Table 3.1.), based on drying requirements of various products i.e. temperature, initial moisture content and final moisture content of the products. They made a review of sun drying procedure and drying equipments available, and also discussed the suitability of different types of solar dryer for different food products in different regions.
Table 3.1: Drying requirements of agricultural and food products.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Product</th>
<th>Type of solar drying</th>
<th>Temp. required °C</th>
<th>Initial moisture content (%)</th>
<th>Final moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Apple</td>
<td>Direct</td>
<td>66</td>
<td>60 - 70</td>
<td>15 - 20</td>
</tr>
<tr>
<td>2</td>
<td>Banana</td>
<td>Direct</td>
<td>74</td>
<td>70 - 80</td>
<td>2 - 5</td>
</tr>
<tr>
<td>3</td>
<td>Beans (baked)</td>
<td>Direct</td>
<td>60</td>
<td>10 - 20</td>
<td>3 - 4</td>
</tr>
<tr>
<td>4</td>
<td>Beans (green)</td>
<td>Direct</td>
<td>65</td>
<td>10 - 20</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Beets</td>
<td>Direct</td>
<td>60 - 70</td>
<td>10 - 15</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Unsultisfied cabbage</td>
<td>Indirect</td>
<td>60</td>
<td>80 - 85</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>7</td>
<td>Sultified cabbage</td>
<td>Indirect</td>
<td>74</td>
<td>80</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>8</td>
<td>Sultified carrots</td>
<td>Direct</td>
<td>70</td>
<td>70 - 80</td>
<td>4 - 5</td>
</tr>
<tr>
<td>9</td>
<td>Cauliflower</td>
<td>Indirect</td>
<td>60</td>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>Chillies</td>
<td>Direct</td>
<td>60</td>
<td>70 - 80</td>
<td>10</td>
</tr>
<tr>
<td>11</td>
<td>Corn (sweet)</td>
<td>Direct</td>
<td>65</td>
<td>80 - 85</td>
<td>10 - 15</td>
</tr>
<tr>
<td>12</td>
<td>Corn (shelled, yellow)</td>
<td>Direct</td>
<td>45</td>
<td>20 - 25</td>
<td>10</td>
</tr>
<tr>
<td>13</td>
<td>Corn (shelled, white)</td>
<td>Direct</td>
<td>45</td>
<td>20 - 25</td>
<td>10</td>
</tr>
<tr>
<td>14</td>
<td>Copra</td>
<td>Direct</td>
<td>40</td>
<td>45 - 50</td>
<td>6</td>
</tr>
<tr>
<td>15</td>
<td>Date</td>
<td>Indirect</td>
<td>35 - 50</td>
<td>65</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>Fish</td>
<td>Direct</td>
<td>50</td>
<td>65 - 75</td>
<td>16</td>
</tr>
<tr>
<td>17</td>
<td>Garlic</td>
<td>Direct</td>
<td>43 - 48</td>
<td>70 - 80</td>
<td>6 - 7</td>
</tr>
<tr>
<td>18</td>
<td>Ginger</td>
<td>Direct</td>
<td>60</td>
<td>80 - 85</td>
<td>13 - 15</td>
</tr>
<tr>
<td>19</td>
<td>Grapes</td>
<td>Direct</td>
<td>60</td>
<td>83 - 85</td>
<td>10 - 16</td>
</tr>
<tr>
<td>20</td>
<td>Groundnut (shelled)</td>
<td>Direct</td>
<td>45</td>
<td>40 - 60</td>
<td>9</td>
</tr>
<tr>
<td>21</td>
<td>Jawar</td>
<td>Direct</td>
<td>45</td>
<td>20 - 25</td>
<td>10</td>
</tr>
<tr>
<td>22</td>
<td>Mushroom</td>
<td>Indirect</td>
<td>68</td>
<td>60 - 70</td>
<td>5</td>
</tr>
<tr>
<td>23</td>
<td>Mustard</td>
<td>Direct</td>
<td>45</td>
<td>20 - 30</td>
<td>9</td>
</tr>
<tr>
<td>24</td>
<td>Onion</td>
<td>Indirect</td>
<td>71</td>
<td>80 - 86</td>
<td>3 - 5</td>
</tr>
<tr>
<td>25</td>
<td>Orange</td>
<td>Direct</td>
<td>55</td>
<td>90 - 95</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>26</td>
<td>Paddy</td>
<td>Direct</td>
<td>60</td>
<td>20 - 25</td>
<td>10</td>
</tr>
<tr>
<td>27</td>
<td>Peas</td>
<td>Direct</td>
<td>60</td>
<td>25</td>
<td>5</td>
</tr>
<tr>
<td>28</td>
<td>Potato chips</td>
<td>Direct</td>
<td>60</td>
<td>75 - 80</td>
<td>4</td>
</tr>
<tr>
<td>29</td>
<td>Potato (sultified)</td>
<td>Indirect</td>
<td>74</td>
<td>60 - 70</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>30</td>
<td>Potato (unsultified)</td>
<td>Indirect</td>
<td>63</td>
<td>70 - 75</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>31</td>
<td>Radish</td>
<td>Direct</td>
<td>60 - 65</td>
<td>70 - 75</td>
<td>5</td>
</tr>
<tr>
<td>32</td>
<td>Rice (silled)</td>
<td>Direct</td>
<td>60</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>33</td>
<td>Soybean</td>
<td>Direct</td>
<td>45</td>
<td>20 - 30</td>
<td>7 - 8</td>
</tr>
<tr>
<td>34</td>
<td>Sweet Potato</td>
<td>Direct</td>
<td>65</td>
<td>70 - 80</td>
<td>5</td>
</tr>
<tr>
<td>35</td>
<td>Tomatoes</td>
<td>Direct</td>
<td>65</td>
<td>85 - 90</td>
<td>&lt; 3</td>
</tr>
<tr>
<td>36</td>
<td>Turmeric</td>
<td>Direct</td>
<td>60 - 70</td>
<td>80 - 85</td>
<td>13 - 15</td>
</tr>
<tr>
<td>37</td>
<td>Wheat</td>
<td>Direct</td>
<td>45</td>
<td>45</td>
<td>10</td>
</tr>
</tbody>
</table>
Anwar et al. (1989) studied the theoretical design consideration for the design of solar based forced convections fruits and vegetables drier. They discussed, in detail, the drying requirements such as, initial and final moisture content of the product to be dried, the optimum temperature and air flow rate required for drying, climatic factors and materials for construction and also suggested a step by step design for solar flat plate collector of matching capacity.

Thanvi and Pandey (1989) made a comprehensive comparative study of different types of solar driers developed at Central Arid Zone Research Institute, Jodhpur. They estimated annual energy saving fro 1 m² base area of each device by taking into account the capacity of the dryer, its performance for drying of materials, moisture content of materials (Table 3.2.).

Table 3.2: Comparison of various types of solar dryers developed at C.A.Z.R.I., Jodhpur (Rajasthan).

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Specification of solar dryer</th>
<th>Capacity (Kg)</th>
<th>Drying time (days)</th>
<th>Efficiency</th>
<th>Cost (Rs.)</th>
<th>Yearly energy saving (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Simple solar cabinet dryer (base area 1.37 m²)</td>
<td>13 – 14</td>
<td>7 – 8</td>
<td>14</td>
<td>1000</td>
<td>201</td>
</tr>
<tr>
<td>2.</td>
<td>Improved solar dryer with temp. regulation (base area 1.68 m²)</td>
<td>16 – 17</td>
<td>5 – 7</td>
<td>20</td>
<td>1200</td>
<td>229</td>
</tr>
<tr>
<td>3.</td>
<td>Low cost solar dryer (LCSD)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.</td>
<td>LCSO-1 (Single sloped) (base area 1.67 m²)</td>
<td>16 – 17</td>
<td>7 – 8</td>
<td>19</td>
<td>800</td>
<td>205</td>
</tr>
<tr>
<td>b.</td>
<td>LCSO-2 (Single sloped) (base area 1.45 m²)</td>
<td>13 – 14</td>
<td>8 – 9</td>
<td>12</td>
<td>650</td>
<td>169</td>
</tr>
<tr>
<td>4.</td>
<td>Inclined solar dryer (base area 1.12 m²)</td>
<td>10 – 12</td>
<td>4 – 5</td>
<td>20</td>
<td>850</td>
<td>306</td>
</tr>
<tr>
<td>5.</td>
<td>Low cost inclined dryer (LCID)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a.</td>
<td>LCID-1 (Tarfelt casing and PVC glazing)</td>
<td>10 – 12</td>
<td>5 – 6</td>
<td>15</td>
<td>450</td>
<td>245</td>
</tr>
<tr>
<td>b.</td>
<td>LCID-2 (Aluminium casing, base area 1 m²)</td>
<td>10 – 11</td>
<td>5 – 6</td>
<td>15</td>
<td>700</td>
<td>286</td>
</tr>
<tr>
<td>6.</td>
<td>Multirack tilted type dryer (base area 6.6 m²)</td>
<td>60 – 65</td>
<td>6 – 7</td>
<td>18</td>
<td>3900</td>
<td>219</td>
</tr>
</tbody>
</table>
They made an assumptions that the dryer is used for 300 days in a year for dehydrating the material from 85% moisture content to 5%, the dryer is loaded with its lower limits of capacity and the material within the higher limit of dehydration periods indicated in the Table 3.2. It can be seen from the table 3.2. that more energy can be saved by the use of the inclined solar driers in comparison to that saved by the simple cabinet dryer.

Mannan and Singh (1988-89) studied the comparative performance of a multirack solar dryer and solar cabinet dryer for the drying of Methi (Fenu Greek Leaves) in both dryers simultaneously. Results indicated that the performance of mini-multirack was substantially superior than cabinet dryer. It was 60% better.

Eddy etal (1991) developed a multipurpose solar dryer for application in tropics. In face, it was a modification of a multi purpose solar tunnel dryer; originally developed for application in a rid zones. This type of dryer consisted of a small centrifugal blower, a collector and a tunnel drying chamber. Results show that compared to natural sun drying, the drying time of cocoa, coffee and coconut could be reduced uptime 40%, solar drying by this dryer improved the quality of the product in terms of colour, flavour and appearance; reduce the risk of micro organisms growth prevents insect infestation and contamination by foreign matter and mycotoxins.

Assayo (1991), Saponronnarit etal (1991), Saponronnarit etal (1993) investigated a forced convection dryer for the drying of banana. The dryer comprised of a drying cabinet covered by 12 m$^2$ of clear glass and 32 m$^2$ of flat plate solar air heater (Figure 3.11.). Results indicated that first law efficiency of the solar dryer was linearly proportional to moisture content and dry mass of banana per unit solar receiving area. The maximum efficiency was about 30% and occurred at an average moisture content of about 220% dry basis and a dry mass of bama of 3.7 Kg/m$^2$ of solar receiving area. Simple financial analysis showed that the pay back period varied from 1.5-5.4 years. An empirical equation setting up a relationship among efficiency, moisture content and dry mass was found. Drying time for each batch was 7 days (6 hrs/day).
Soponronnarit et al. (1992) investigated the drying strategy for banana by employing. It was found that appropriate specific airflow rate of 10 Kg/h dry banana and fraction of air cycled of 90%. Drying air temperature should be around 60°C, if product quality was to be maintained.

Dogger and Raja (1992) tested a small scale-forced convective photovoltaic solar crop dryer under laboratory conditions using a solar simulator. The dryer consisted of a solar photovoltaic fan, a drying chamber and an air heater of plate type. Nearly constant performance of the dryer was achieved during day light hours. The air temperature and air flow rate were controllable. The dryer is supposed to be the best alternative to the forced convective solar crop dryer using fossil fuels.

Reynand (1992) designed developed and tested two types of indirect type passive solar dryers, with a low capacity, 20 kg to 50 kg of produce. Both dryers used forced convective systems each dryer had a blower unit that runs on solar cells that drawn air through dryer unit. The operating speeds for 2 types of DC ventilators (one cross flow one centrifugal) the airflow rate profit
inside the drying units and the surface area of the solar cells were determined. Apples drying tests were conducted and results were quite encouraging.

Diamante and Murno (1993) studied an indirect type of solar dryer for the drying of sweet potato slices. The solar drying rates of sweet potato slices were affected by the fluctuating chamber temperature over the drying period and one linear falling rate period. Fick's diffusion equation was used to derive the mathematical model for the drying of sweet potato slices and this model described solar drying of sweet potato slices to a moisture content below 20% dry basis. The mean effective drying chamber temperature and sample thickness were the main factors that affected the solar drying process of sweet potato slices.

Bassey et al. (1994) used heated Chimney's and reduced collector air gap height to improve the performance of an indirect passive solar dryer. The tests were done under outdoor conditions in Sengal on two dryers, using four chimney configurations heated with waste sawdust and using two collectors with air gap heights of 4 and 5 cm. Results indicated that performance of the dryer can be improved if temperature in the chimneys are maintained over 50°C above the ambient temperature for more than 4 hrs and if the chimney is at least 2 meters high.

Tiris et al. (1994) developed and tested a solar drier, which consisted a solar air heater and drying chamber for the drying of agricultural products. This solar drier was successfully tested using sultana grapes, green beams, sweet peppers and chilli peppers. Traditional sun drying experiments were employed. The drying curves of the solar dried products are compared with traditional sun drying results: Application of solar dryer reduced the drying time by factors of 1.7, 2.2, 1.8 and 2.2, respectively for sultana grapes, green beams, sweet and chilli peppers presented mass losses and provided better product quality.

Nazarov et al. (1994) studied the influence of preliminary infrared treatment of process of drying fruits. Results indicated that this treatment decreases the time of drying and improved the quality of product.
Sharma et al (1995) tested natural and forced convection solar driers to identify the most appropriate and economic design to meet the requirements of the rural users. They tested three types of solar driers and these are: (i) a cabinet type natural convection solar drier. (ii) a multistacked natural convection solar drier. The criteria used for the fabrication of the designs are: (i) the mode of operation, (ii) quantity of the product to be dried and (iii) availability of technical know-how, resources and grid power.

Solar drying tests of vegetables were carried out, using these three different types of driers and the total weight loss for drying test with mushrooms. From the experimental results it was obvious that drying is much faster in the case of indirect forced convection cabinet drier and the multistack solar drier. There was no difference in the quality of the dried end products solar cabinet driers undoubtedly demonstrated a faster drying rate than the multistack design, but it can not be used to dry a particular product on large scale. The system can not be used to dry more than 7-10 kg of product. This indirect multiself forced convection solar drier was very efficient and can be used to dry a large quantity of material over a given drying period. The system can be used on a semi-industrial scale.

Olufayo and Ougnkunle (1996) conducted a study in Ibadam (Nigeria) to assess the rate of drying of cassava chips under different natural conditions. Samples were collected at regular intervals and moisture contents determined in the laboratory. The sunshine hours, daytime temperature and relative humidity were recorded during collections of samples, in order to study their influence on drying. There were no significant variations in the drying patterns of chips dried at about equal weight per unit area. The average ambient equilibrium moisture content was about 16% (wb) after about 70 h of sunshine. However, the thickness of the layer of chips had significant effect on nature and pattern of drying.

Schoenau et al. (1996) evaluated energy conservation potential by exhaust air recirculation for a commercial type heated air batch hay dryer. The design of the exhaust air recirculation is that only about 30% of the total exhaust air is recirculated through the heater inlet. Experimental tests were conducted on the dryer with and without exhaust air recirculation. Maximum
energy savings of 27% and 17% were achieved with exhaust air recirculation during fall and summer dry operation, respectively.

Chauhan et al. (1996) studied the drying characteristics of coriander in a stationary 0.5 tonne/batch capacity deep-bed dryer coupled to a solar air heater and rockbed storage unit to receive hot air during sunshine hours and off sunshine hours, respectively. The drying bed was assumed to consisted of a number of their layers of grains stacked upon one another. The theoretical investigation was made by writing the energy and mass balance equations for different components of the dryer cum-air heater cum storage and by adopting a fruits difference approach for simulation. The results indicated that for reducing the moisture content from 28.2% (db) to 11.4% (db), the solar air heater took 27 cumulative sunshine hours, i.e., about 3 sunshine days, whereas the solar air heaters and the rockbed storage combined took 31 cumulative hours, i.e., about 2 days and 2 nights at an airflow velocity of 250 Kg/nm.

Hallal et al. (1996) designed, developed and tested the staircase solar dryer for the drying of fruits and vegetables.

Tiris et al. (1996) developed and tested the efficiency of a solar collector. Results indicate that the collector used in the solar drying system was an efficient and effective unit for practical drying applications.

Ekechukwu and Norton (1997) designed, developed and tested the performance of a solar chimney for natural convection solar dryer. The experimental chimney consisted of a 5.3 mt. high and 1.64 diameter cylindrical polyethylene-clad vertical chamber; supported by a steel framework and draped internally with a selectively absorbing surface performance of the chimney was tested monitored extensively with or without the selective surface in place.

Fuller (1997) reported the application of a large natural convection based solar drying system for the drying of copra, a very important export crop in Pacific Islands, in the island of Routma, near Fiji. The solar dryer being utilized here is a glazed wedge shape structure, rising from 0.9 meters in height at the low end to 6.4 meters at the high end, and has a floor area of
200 m². This dryer has been constructed from concrete, steel and a quality glazing material, so that the dryer should have a long life with minimum maintenance. The solar dryer has a capacity of five tonnes of fresh copra. Air circulation is by natural convection and there is no supplementary heating systems. As far as, quality of dried copra is concerned, it is necessary to load the material approximately within six hours of cutting, only then first grade copra can virtually be guaranteed with this solar dryer. When the outside is temperature is between 28°C and 32°C and has a relative humidity level of 40-80%, then the temperature of the air inside the temperature of the air inside the dryer will range from 67°C during the day to 45°C at night. With these conditions copra will take three days and with proper management two loads of copra can be drier each week.

Ratti and Mazumdar (1997) developed a simulation code to predict the batch drying performance of a packed bed of potatoes, e.g. cylinder or slices of carrot, apples etc, subjected to time-varying air conditions. This model allowed for shrinkage of the particles. The time-dependant inlet air drying conditions permit the simulation of the case of a solar dryer in which the inlet air temperature is necessarily a function of the hour of the day. All the parameters involved in the model were obtained independently from experimental solar dryer data. The results compared well with published experimental data for solar drying of sliced carrot.

Helwa and Abdulrahim (1997) designed, developed and tested the performance of solar dryers with pebble beds for the drying of agricultural products in arid regions. This solar drying system consisted of an air heater and a dryer chamber connected to a greenhouse. Composite pebbles, which are constructed from cement and sand, are used to store energy for night operation. The pebbles are placed at the bottom of the drying chamber and are charged during the drying process itself. Results indicated that the amount of energy stored in the pebbles depends on the air mass flow rate, the inlet air temperature and the properties of the storage materials. The composite pebbles can be used efficiently as storing media.

Forson et.al. (1997) designed, developed and tested a mixed mode natural convection solar dryer (a dryer in which the crop is dried by a
combination of the direct absorption of radiation and by natural convection where air heated by solar energy, is passed over the crop). Two dryers of the aforesaid designs were fabricated, each having 1000 and 1,500 Kg of various agricultural products (such as cassava, pepper, maize, okra etc). These driers were tested Agona-Asafo in the central region of Ghana. The results of these preliminary tests indicate that it takes 3-5 days to dry 1,000 Kg of pepper from moisture content level of 78% to a safe storage level of 8%.

Abdullah et al. (1997) designed, developed and tested a greenhouse effect solar dryer to dry vanilla pods. Results indicate that the average drying time for vanilla pods was between 49 to 53.5 hrs: for the case of heating augmentation using coal briquettes stoves. The total amount of coal briquettes used to produce drying air temperature between 33°C to 65°C and RH of about 34% during daytime was 61 Kg equivalent to 6.1 KW heating rate and the average electrical energy usage of 36.5 KWh, respectively. Quality tests result indicated that the dried products were of grade 1A of the export quality standard with xanilive content of 2.36%.

A lot research work of designing, developments and testing of both type, direct, viz. simple cabinet drier; improved drier with chimney, multirack-ticked type and on forced convection dryers, has been, done at Central Arid Zone Research Institute (CAZRI), Jodhpur, for the drying of fruits and vegetables, Garg (1974), Pande (1980), Thanvi et al. (1987), Thanvi et al. (1988), Thanvi et al. (1989), Thanvi et al. (1996) and regions, the high isolation and regions, and low humidity suggests the application of natural convection dryers instead of forced convection type solar driers, which are more costly and dependent on electric power. The design and performance of direct type solar cabinet drier revealed that the size of this unit was quite large compared to its capacity of holding the material and less radiation are incident on its glass plane during winter season due to low altitude of the rain. In view of these facts, it is therefore necessary that the air gap between the hardware and simultaneously a ticting arrangement should be to keep the unit at uniform tilt in accordance, with latitude and reason of operation so that the solar drier can utilize the maximum. Solar radiation through out year keeping this idea in mind, Thanvi et al. (1998), designed, developed and tested a
ticked type commercial solar drier at CAZRI, Jodhpur. A series of drying trials for dehydrating vegetables, viz. spinach, okra, tomato, mint, ginger, red and green chilies, carrot, coriander leaves, fenugreek, peas, cabbage, onion, sweet potato bitter ground, sugar beet, bathua and fruits viz. bev, sapodilla grapes etc were conducted successfully. The leafy vegetables viz. spinach, coriander, mint etc were washed three times water and excess of water was removed before loading material in the drier. The other vegetables viz. okra, green chilies and sweet potato were washed, cut into circular pieces and load in the dryer. The tomatoes were cut their slices and were properly arranged for in a single layer on drying trays so that products can be dried a little faster.

Table: 3.3. Solar Drying of different fruit and vegetable at CAZRI, Jodhpur.

<table>
<thead>
<tr>
<th>Item</th>
<th>Loading rate (kg/m²)</th>
<th>Moisture content (%)</th>
<th>Drying times (days)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>Inside dryer</td>
</tr>
<tr>
<td>Spinach</td>
<td>4.5</td>
<td>92</td>
<td>5</td>
<td>2.0</td>
</tr>
<tr>
<td>Coriander</td>
<td>4.0</td>
<td>90</td>
<td>8</td>
<td>2.0</td>
</tr>
<tr>
<td>Mint</td>
<td>3.0</td>
<td>86</td>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>Okra</td>
<td>10.0</td>
<td>88</td>
<td>6</td>
<td>3.0</td>
</tr>
<tr>
<td>Green Chilly</td>
<td>10.0</td>
<td>85</td>
<td>6</td>
<td>3.5</td>
</tr>
<tr>
<td>Tomato</td>
<td>5.0</td>
<td>95</td>
<td>4</td>
<td>2.0</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>11.0</td>
<td>79</td>
<td>7</td>
<td>3.5</td>
</tr>
<tr>
<td>Ber</td>
<td>15.0</td>
<td>82</td>
<td>14</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Goyal et al (1999) conducted solar tray drying of potato chips and compared the drying of the same with mechanical tray drying and open sun drying. They found that the effect of pretreatment's and drying conditions on starch, total sugar and reducing sugars and effect was non-significant for non-reducing sugar contents. The mechanical tray dryer required 35-42 minutes of solar tray dryer look 4.15-5.00hours and sun drying look 6.30-7.15hours.

Phillip (1999) designed, developed and tested a forced convection solar drier for the drying of onions flakes, potato chips and also for the drying of onions flakes, potato chips and also for other agricultural products. The
layout of the drier is shown in the Figure 3.12. The system consists of solar air heaters, blower drying chamber and electrical backup. Results indicated that onion flakes could be dried in solar dryer in the 6.5-7 hours during the months of April-June. The cost of drying was Rs. 5.00 per kilogram of dried onion flakes. The quality of dried products acceptable potato chips were also dried before drying, they were peeled sliced and blanched. In each experiment 20 Kg fresh potato chips were dried in 2 hours and 30 minutes from an initial moisture content of 85% (wb) to 3% (wb) final. This can be also operated through biomass gasifier based thermal backup during non-sunshine hours. With increased pollution problems and shortage of fossil fuels, such a system-based on solar air heating system will have a greater acceptability.

Figure 3.12: Layout of solar dryer for onion dehydration

Solar scientist at University of West Indies have designed, developed and tested many solar drier since 1973 under solar energy project for a
variety of agricultural crops and timber species, such as sorrel (Hibisens Sobdariffa), bamass (Musa Sapientu) and Mahogany (Swietenia macrophylla). These driers varied in size from the 2.2 m² wire basket drier to the 149 m² roof collector. Most of these solar dryer used solar air heaters. The smaller solar driers use natural convection or chimneys for air circulation, and the bigger ones (forced convection dryers) used solar air heaters of more than 10 m². Recently, Headly and Hinds (1999), of the same university, designed, developed two medium scale solar dryers for drying onions (Allium cipa), hay and similar crops which require a relatively low drying temperature less than 45°C.

A brief description of these dryer are given in the foregoing pages:

(1) Solar Dryer I

This dryer uses a corrugated galvanized steel roof of of 149 m² and a fan which supplies air at 5.6 m²/s with a pressure drop of 747 Pa. Air is sucked into the ceiling space from one end of the roof and is ducted to the fan which than it into the plenum chamber at floor level. Bags of onions or bales of hay are placed on the top of the plenum whose roof is perforated to allow the air to flow through it and then through crop. The crop is stacked so that heated air does not bypass it and escape to the ambient without removing moisture. This dryer does not employ an auxiliary heating system since farmers for whom it was built not think it was necessary calculations show that drying will take place even when temperature rise is low. The maximum capacity of the this dryer is ten tonnes a day.

(2) Solar dryer II

This dryer uses a glazed 40 m² solar air heater which is connected to fan. The drying chamber in this case consists of two standard to enhance heat retention. By means of the ducting system, the fan sucks air through solar air heaters and forces it into the containers, where onions are placed on the racks. One of the containers is insulated.

Sopian et.al. (1999) constructed and tested the solar assisted drying system using the double pass collector. The six collectors with a length of 2.4 meters and width of 1.2 meters are connected using internal minified. Porous
media is added in the second channel of the collector. The porous media acts as a storage medium for the system. Therefore, higher and steady outlet temperature can be obtained even under intermittent solar radiation conditions. The outlet temperature can be reached 20°C for average solar radiation of about 200 w/m² and airflow rate of about 20 Kg/sec. Besides the fruits and vegetables drying, the system can also be useful for other food products.

Rajaraman et.al. (1999) studied the integration of solar dryers with an efficient thermal storage system to match the time-dependant supply and endues requirements based on the studies carried out on Latent Heat Thermal Storage (LHTS) systems (Velraj et al (1997), Velraj and Seeniraj (1999)), Rajraman, et.al., observed that when air is used as the heat transfer fluid in LHTS System, nearly uniform heat flux can be achieved. Thus, they concluded for air based solar drying application LHTS systems are most suitable. The performance of the such integrated systems can be improved by thermal conductivity of PCM with the addition of high conductivity material into the PCM.

Mkrttchian et al (1999) carried out research on drying buildings intended for drying of different types of food products, including fruits and vegetables, based on passive use of solar energy. Many factors determine the thermal response of a drying building. Apart from the orientation and form of a drying building, the construction materials are very significant. The choice of materials for surfaces exposed to direct sunlight and shaded surfaces, and the "openness" of a driving building to solar radiation are important criteria. Two quite distinct cases must be treated separately: "low-mass" types of construction with high insulation values but low heat capacity, and "high-mass" constructions with a high heat capacity and thus a slow thermal response. Very well insulated driving building which make extensive use of solar protection devices are therefore integral components of the whole design in well planned drying buildings. A drying building is in direct contact with its surroundings by its roof, the external walls and the basement of dark, through which heat exchange occurs. In the Armenian drying building construction, heat losses through the roof and the basement of dark will be
minimized by good thermal insulation. Measures to make passive use of solar energy will concentrate mainly on the external walls. In particular, the wireless of solar energy play a decisive role. Their size, position and construction have considerable influence on the heat balance of a drying building. The optimisation of their transmission properties have been and continue to be important technological developments. Coating on the glazing reduce the transmission of thermal radiation, while a further improvement can be achieved with multiple glazing and suitable frame constructions. They having typed sufficient temperature the air fowl in drying building directs in basement of dark, where in accumulated with the help utilization. At night or in gloomy days the powerful jet of hot without a fan is directed upwards in drying building. As the radiation and temperature conditions charge markedly on a daily and yearly basis, the value of wireless of solar energy is clearly raised by including temporary protection from the sun or further insulation (awnings, blinds). The heat gain from radiation through wireless of solar energy can be considerable, but the benefit is significant only if this heat is stored at least for some length of time in the basement of dark. Solid drying building components(walls, ceilings) are well suited to this purpose. This effect can be consciously reinforced, for example by positioning a black wall immediately behind a glazed southern fasted, so that it can absorb the incident radiation and store the heat. It should be possible to direct air from the drying building into the basement of dark so that the heat can also be used there. The air between an adsorbed and a glass cover is heated by the solar radiation. If the heated air is directed through ducts into the drying building and used for heating, the whole system is described as an “air collector”. In an appropriately designed collector, heat is transported by natural convection. In many cases ventilator fans must be used to circulate the air. The air circulation within a drying building plays a decisive role in all passive solar measures, it can be natural convection, supported by a favourable layout of the drying rooms, as well as forced circulation associated with an air collector. The energy gained during periods of intensive radiation should be stored for periods with little or no radiation input. The diurnal temperature compensation can be achieved by ceilings and walls alone if these are constructed of massive materials. When warm air collectors are used, the “loading” of this
heat storage can be reinforced by blowing the heated air from collector through a network the ducts e.g. in the ceiling of drying building.


3.1.1. CONCLUSIONS FROM THE REVIEW OF SOLAR DRYING OF FRUITS AND VEGETABLES

Of all the various designs of solar dryers available, three types of solar dryers have the best potential for the drying of food products with higher quality. These are the natural convection cabinet-type solar dryer, the forced convection indirect solar dryer and the greenhouse type solar dryer. The cabinet-type solar dryer is relatively cheap to construct and to operate. However, its performance is limited. The forced convection indirect type solar dryer has varying designs. The basic system incorporate a flat plate solar air heater and a drying chamber auxiliary power is required. Its performance is higher than the cabinet type of solar dryer. The greenhouse type solar dryer is simple direct dryer and may incorporate a solar air heaters. This dryer has a great potential for high performance drying of large bulky products which need not be moved around frequently during the drying process.

- Idea of drying buildings given by (Mkrttchian, 1999) needs more exploration, as it can be a cost-effective option for large scale industrial solar drying of fruits and vegetables.

- Solar dryers with auxiliary heating systems have mainly been used in case of forced convection dryers in indirect mode. The heat requirement of auxiliary heating systems is provided by products of combustion of gaseous fuels coming in direct contact with drying air and thus polluting the drying product along with a negative impact of its quality. Since for many rural area, electrical fans cannot be used an
available fuels are mainly solid fuels. These systems need modifications to suit the requirements of rural areas.

- As pollution problems associated with fossil fuels, becoming more serious of fossil fuels, irregular electrical power supply or complete non-availability of it in remote rural areas, solar driers get more acceptability in coming years, particularly those based on solar air heating systems, due to their highly efficient drying operations.

There is very little doubt that solar drying systems could make a considerable impacts on economics of developing countries, but so far, available systems have not been use to their fullest potential. There are lot of reasons behind this, major ones are as follow:

- Farmers of developing countries have a tendency to produce more food than to dry it. Therefore, applications of technologies, which enhance the production, are more encouraged at the expense of solar drying systems. Another problem is that food production in developing countries is very low, as a result there is great reluctance among the farmers to realize the benefits of solar dryer. However, among cash crops, driers are being utilized widely.

- Need for Year Round Solar Dryers – Most farmers in developing world face the problems of restricted resources. There is a very low level of awareness regarding the existence and significance of solar drying driers, which have been developed, so far, are season/crop specific. Therefore, there is a need to develop solar driers which are useful for farmers, the year around.

- There is not enough field experiences about solar driers among researchers as well as farmers, which is a great barrier for the widespread dissemination of solar drying research, development and demonstration programmes, now underway are still made under laboratory of the scale needed for widespread adoption of technology.

- Due to lack of insufficient field experiences, solar driers still have a relatively immature status and only a limited range of economically attractive systems exists. Therefore, to overcome all these barriers
large-scale field demonstrations are needed to get sufficient operating experience and them to build confidence among the ultimate users system i.e., farmers.

- The major constraint for the limited acceptance of solar dryers is due to a long payback period and high initial investment. Innovations should be made in this regard.

- Large-scale dryers capable of handling tonnes of drying materials are more promising than small-scale ones.

- There is a need to design dryers which can yield maximum utilization factor of capital investments, i.e., dryers should be multi-product and multipurpose.

- In general, an auxiliary heat source should be provided to ensure reliability, to handle peak loads and also to provide continuous drying during periods of no sunshine. Rock bed heat storage is not a viable option as compared to latent thermal heat storage one.

- Forced convection indirect type of solar dryers are preferred because they offered better control more uniform drying and because of their high collection efficiency. However, the application of other power sources should be kept to a minimum.

- Other methods of solar drying, such as low cast solar desiccant driers should be developed on commercial scales.

- Retrofit systems should be examined in detail.

- Solar air heaters, still lack a standard test procedure which needs to be developed at the same time, innovations should be made to reduce the high cost of solar air heaters for their wider acceptance among end users, i.e. farmers.
3.2. REVIEW OF RESEARCH WORK DONE ON SOLAR DRYING OF CHILLIES

Primary processing of red chillies mainly consists of drying and milling to powder form. For better retention of colour, higher yield of finished products and reduced quantitative and qualitative loss, it is necessary to adopt improved methods of drying and milling of chillies.

Dried chillies, usually, contain about 60% stalk, 40% pericarp and 54% seeds. Important constituents of colour and capsaicin are concentrated in the pericarp. About 20% of the capsaicin in the chillies has been noticed in the placenta, connecting seeds and pericarp (Sumathy Kutty and Mathew, 1984). Table 3.4. shows the capsaicin percentage and colour value in the two varieties of chillies, i.e. Jwala and Pusa Sada Bahar, undertaken for the present study.

Table 3.4: CAPSAICIN CONTENT AND COLOUR VALUE IN SELECTED VARIETIES OF CHILLIES

<table>
<thead>
<tr>
<th>Chilli Variety</th>
<th>Pericarp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capsaicin (%)</td>
</tr>
<tr>
<td>Jwala</td>
<td>0.68</td>
</tr>
<tr>
<td>Pusa Sada Bahar</td>
<td>0.50</td>
</tr>
</tbody>
</table>

The review of literature on different aspects of drying of chillies was carried out by taking into account the research work done by several researchers and is being discussed in the following pages:

Garg and Krishnan (1974) designed, developed and tested a solar cabinet dryer suitable for small agricultural products. This dryer was based on the principle of a hot box. Experiments on drier were conducted for the drying of chillies. The drying time for chillies was reduced by about 50% of the time required for open air sun drying method and quality of chillies was also better. The average efficiency of utilization of solar energy, i.e., the ratio of the heat used in the evaporation from chillies to the total incident radiation was 14% in case of the solar dryer cabinet versus 7% in case of the open air sun drying method.
Laul et al (1970) described that chilli pods were pricked longitudinally on one side only be sharp steel nails fitted on a wooden block.

Breag et al (1972) reported sun drying of all spice beanies in and out of the sheds during rainy days broke many berries and therefore mechanical drying was found to be more suitable.

Vijayan (1974) reported sun drying of cardamom. With 2% sodium carbonate in a special type of glass chamber which could exclude rain and moisture and at the same time provide necessary ventilation.

Pruthi (1976) reported that sun drying of chillies in Japan was followed drying, dressing and again sun drying before packaging. The entire stem or plant with the fruits is out and hunt from bars and then exposed to sun for partial sun drying. He also reported that photosensitive spices have cardamom, and to some extent bleach in the sun due to oxidation of chlorophyll and carotenes present in them.

Laul (1977) developed and improved technology for the sun drying of chillies which had several advantage over the traditional method. He developed a chemical emulsion known as DIPSOL (a water based emulsion containing potassium carbonate, refined groundnut oil, gum accara and butylated hydroxy anisole) which reduced the drying time to a week. Fresh ripe chillies were dipped in the emulsion for 5 minutes and then sun dried.

Luhadiya and kulkarni (1978) took green chillies after pricking and blanching (4 minutes in boiling water) and then treated with different solutions and dried in a cabinet dryer. They confirmed that pricking and blanching increased the drying rate.

Drying characteristics of chillies have been studied at G.B.P.U.A and T, Pantnagar, for both sun drying as well as hot air drying. Also, the performance of cement concrete floor with black tar coating, wire mesh elevated to 0.5 meter and 1 meter high stand with thickness of chilli bed varying between 1.11 to 1.19 centimetre were studied. Heated air drying studies were conducted with and without stalks at two hot air temperature (323 and 328K) and at three different air velocities (1,1.25 and 1.5 meter/second) at 10 centimetre bed thickness. Concrete floor with tar coating was reported to be
the best surface for sun drying as it gave higher drying rate. In heated air drying, chillies without stalks with air temperature at 328K and 1.5 m/s air velocity gave minimum drying ratio with 12 hours required to reduce the moisture from 355.4 to 16.5% (db). Chillies with stalks dried at a slower rates (Anonymous, 1981).

Alam and Singh (1981) developed a solar cabinet dryer for drying of perishable, semi-perishable and wet processed food materials. The capacity of the chillies that can be dried was about 30-50 Kg batch and took about 4-7 days per batch.

Alam and Singh (1982) studied drying of chillies on seven different surface, namely mudfloor, concrete floor, jute cloth, white canvas, tarpaulin, black and white polythene sheets. Out of which olive green tarpaulin and black polythene gave a saving of 21% time as compared to mud floor.

Akola Centre of Post Harvest Technology has developed a modified waste fired drier for different agricultural commodities, including chillies (Anonymous, 1981). It is suitable for the drying of 200 Kg fresh red chillies per batch within a total period of 16 hours by reducing moisture contents of chillies to 16.5% (wb) from initial 73.40% (wb).

Trim and Ko (1982) designed, developed and tested a forced convection solar for red peppers (Fig 3.13.). Results of their studies indicated that the forced convection solar dryer was of an efficient and effective design; the collection efficiencies obtained, ranging from 32 to 52% were high compared with those reported for other designs. Temperatures attained within drying chamber were ideal for the drying of red peppers. The performance of the forced convection solar drier was compared with traditional sun drying; drying times with the solar dryer was reduced by 65% than that of traditional sun drying. The quality of the forced convection solar dried red peppers was fully acceptable.
Srivastava et al. (1984) developed a solar cabinet dryer for drying of perishable, semi perishable and wet processed food material. The dryer is simple in design and does not require any mechanical prime cover or electricity. It is free from fire hazards and can be fabricated from materials such as word glass plywood, wire mesh MS Sheet etc. experiments with chillies were done and it was seen that it took 4-7 days/batch to dry the product from 70-80% (wb) to an equilibrium moisture content. The capacity of the dryer is 30-50 Kg/batch.

Illyas et al. (1987) developed a chilli punching machine which is capable of punching chillies at the rate of 10 Kg/hr. The holes punched by the machine are uniformly spread over the entire surface area of the chillies. The
machine is easy to use and operate and it is possible to adjust the gap between the needles and tray which facilitates punching of chillies of different size.

Malviya and Gupta (1987) designed, developed and tested natural convection solar dryer for the drying of horticultural and vegetable crops. It consisted of:

(i) A flat plate collector of 85 x 250 cm
(ii) A duct of 7 x 85 x 250
(iii) A drying chamber with a projected area of 42 x 90 cm and 40 cm deep with 6 trays.

Drying of chillies pepper was studied. Because of no direct exposure of chillies to sun and efficient removal of hot moist air by natural convection process, no discolouration and charring of chillies was observed drying time was much less than that of open air sun drying. The organoleptic quality of chillies pepper dried in natural convection dryer was much better than those dried in open air sun drying.

Mary et al. (1989) studied the sun drying characteristics of pepper. Pepper were either dried directly or dipped in hot water for one minute before sun drying (CFTRI Method) on three different surface and their quality was compared. Little differences were observed in drying behaviour when fruits were dried on the bamboo mats concrete floors, tarpaulin sheets, although samples dried on the bamboo mats were more contaminated with extraneous matter. (3.1 compared with 1.4 and 1.2% respectively) and were of reduced quality. All the samples of peppers dried using the CFTRI Method attained a deep black colour.

Spagna et al. (1989) studied the experimental investigation of different solar dryers suitable for fruits and vegetable drying. An experimental investigation of 3 types of solar dryers (2 Natural and 1 forced convection) for fruits and vegetables was carried out during summer in Southern Italy. Mushrooms, green chillies and tomatoes were used in expedients and were weighed at 2 hours intervals during drying. The air temperature inside and outside the dryer was measured using PT – 100 sensors. Initial and final moisture contents of samples were determined using the oven drying method.
Drying was much faster using the indirect forced convection dryer than with cabinet or multi-stalked natural convection dryer; particularly on cloudy days. There was so significant difference in the quality of the dried product between the three dryers. It was concluded that the cabinet type natural convection dryer is suitable for drying a small quantity of food product on a household scale, the integrated solar collector-cum-drying system is suitable for limited crop volume on farms and the indirect multi-shelf forced convection dryer is suitable for large scale industrial use.

Kachru and Srivastava (1990) pre-treated the chillies in hot lye solution consisting of 0.5% of KON in water at 80 ± 2°C. Chillies were then washed in water and dried in solar cabinet drier. Results indicated a lower period of drying time as compared to other methods of sun drying. Quality of dried chillies was also better in solar cabinet drying than in sun drying.

Chandy et.al. (1992) studied the effect of some physical treatments on drying characteristics of red chillies. The study was conducted to evaluate the effect of pricking, destalking and chopping on the drying characteristics of fresh red chillies. They took two methods of drying, i.e., sun drying and mechanical drying (fluidized bed dryer). In both methods, the moisture content was reduced to a level of 8-9% (db). Results indicated that chopping treatment excelled overall followed by pricking, destalking and control. The time required for mechanically dried product was less than the sun-dried product, irrespective of different pre-treatments, which is due to the uniform exposure of chillies to the drying air in case of fluidized bed dryer. The time and energy required for mechanical drying of chopped chillies was only 33% and 3.32% respectively of the time and energy required for the control. These values for the drying of pricked chillies were 50% and 7% and for destalked chillies 92.5% and 86%. The chopping treatments excelled overall in terms of drying and energy required.

Phillip et.al. (1993) studied the installation and performance monitoring of a commercial solar drier for chillies. A forced convection solar dryer with a drying capacity of 200 Kg of red chillies was installed at a rural industry in Cambay, Gujarat. The system consisted of 12 m² flat plate air heaters installed on the roof, a drying cabinet per batch, installed inside a room and 1
hp electric blower. The system was commissioned on February 1993 and commercial production of chilli powder began in summer. The system was successfully used to dry 60 Kg of red chillies every day in three-batches. The time required to dry an individual batch varied from 20 to 12 minutes.

Sukmaran (1995) fabricated an agricultural waste fired tray dryer for the drying of red chillies at Post-Harvest Technology Centre, Baptala. This chilli dryer was essentially consisted of blower, furnace with heat exchanger and tray dryer bin of two quintal holding capacity. The heat was provided by the burning of agricultural waste material in the furnace under controlled rate (12-16 Kg/hr) to generate a temperature of 45-50°C. Results indicated that fresh red chillies from 70.00 (wb) moisture content could be dried within a total period of 20 hours compared to 12-15 days required in open yard sun drying. The quality of chilli dried in agricultural waste type dryer was much better than those dried in sun drying and no wrinkles was found on the surfaces of dried chillies with compared to sun drying saving of about 15/quintal was possible with the use of agricultural waste dryer.

Hossain et.al. (1999) studied solar drying of green chillies using the solar tunnel drier (Figure 3.14.), with a capacity of 100 Kg of chillies. The drier consists of a flate plate air heating collector (10 m X 2m), a tunnel-drying unit (10 X 2 m) and two small d fans (5 cm, 12 V) to provide the required airflow over the product to be dried. These are connected in a series as shown in Figure 3.14. Both collector and the drying unit were covered with 0.2 mm thickness plastic sheet Black paint was used as an absorber material in the collector. The product to be dried was placed in a thin layer and plastic net of 2 mm X 2 mm sieve size in the tunnel drier. Glass wool was used as insulation material to reduce heat loss from the drier. The whole system was placed horizontally on a raised platform of 0.8 m height. The air at required flow rate is provided by two dc fans operated by one photovoltaic modules (40 W). To prevent the entry of water inside drier unit during rain, the cover was fixed like a sloping (15°) solar radiation passed through the transparent cover of the absorber. Ambient air forced through the collector. Heat was transferred from absorber to air in the collector and heated air from collector while passing over the products absorbed moisture products. Solar radiation also
passed through the transparent cover of the drier and heated the product in the drier. This enhanced the drying rate of green chillies. During drying period the average temperature rise in the drier was 17.67°C above the ambient temperature. The balanced green chillies were dried to moisture content of 12.43% from 88.5% in three days of drying in solar tunnel dryer as compared to four days of drying in the solar tunnel drier of non-blanched samples to a final moisture contents of 12.45, 1.83 and 40.39% (wb) respectively. The blanched samples, in addition chillies dried in solar tunnel drier were saved from rain, insects and dust and were a high quality product.

Figure 3.14: Solar tunnel drier utilized by Hossain et al (1999) for chilli drying
Mastekbayeva et al. (1999) investigated a solar biomass hybrid dryer based on the Hohenheim solar tunnel dryer. They designed and fabricated a prototype dryer for small holding capacities, having a width of 1.8 meter and a total length of 8.25 meter (collector length has 4 meter and dryer length is 4.25 meters). Five fans, each of 14 watt capacity were used to blow air over the absorber surface. Glass wool insulation with a thickness of 4 cm was used to reduce the heat loss. An ordinary 0.2 mm thick UV stabilized polythene sheet was used as a glazing. Experiments were conducted on the drying of chillies. 19.5 Kg of fresh red chillies were dried from a initial moisture content of 76% (wb) to a final moisture content of 6.6% (wb) with in 12 hours. The drying was carried out in biomass solar-biomass sequence within a duration of 3-8 – 1 hours respectively. They also conducted full load experiments for ear to be black mushrooms. 21 Kg of fresh harvested was loaded in the dryer initially. The moisture content was reduced from 91.4% to 9.8% during drying periods of 11 hours and 30 minutes for a biomass solar biomass drying sequence of 2-8 – 1 hours respectively. The final dried products were of similar quality as that of the same dryer during solar only operations. Results indicated that for both products, chilli and mushrooms drying was faster and is within one day in normal sunny weather, against 2-3 days in solar only operation of a tunnel dryer for the nominal capacity of dryer. The solar-biomass hybrid tunnel dryers seems to offer an attractive and reliable drying method as they overcome the limitations of solar drying during cloudy days and also enable drying night time. The facilitating of continuous year round operation of the dryer thus improves the financial viability of the dryer respectively.

Hossain and Bala (1999) studied the geometric dimension, weight of 1000 chillies, bulk density of chillies (variety balijuri) at Bangladesh Agricultural University, Mymensingh. They conducted the experiments at moisture content of 5.14, 13.94, 26.47, 40.69, 58.94 and 73.03% (Wet basis). Length of the chillies was found to be linearly dependent on moisture content. Chilies posed flat shape from the moisture content 5.14 to 40.69% (Wet basis) and in this moisture range the width and thickness were linearly dependant on moisture content. Above the moisture content of 40.69% chillies
of remained round in shape and diameter also increased with the increase of moisture content. The weight of 1000 fruits, bulk density and specific heat was found to be linearly dependent on moisture contents and these properties increased with the increase of moisture contents from 5.14 to 73.03% (Wet basis).

Palaniappan et.al. (1999) carried out fabrication and performance testing of full energy delivery systems (fad) units having 290 m² and 210 m² solar collector for chillies and coriander respectively. They concluded that the solar heating fad units for spices drying are technically and economically viable option, offering a quality dried product and a pay back period of less than 2 years. Solar air heating (GAH) system saves fuel wood 406 t/year worth of monetary cost around Rs 5.48 lacs (at the fuel wood cost of Rs 350/t).

Roy et.al. (2000) developed and tested four cabinet type solar driers. A forced convection dryer for the drying of chillies, mango leather and groundnut at Farm Machine Power Engineering Division, Bangladesh Agricultural Research Institute, Gazipur. All the four cabinet type solar driers were fabricated using wood, hardboard, thermacole, glass and wire mesh. Results indicated that good quality mango-leather was produced in solar driers and apparently there was not much difference between the two methods in respect of drying rate, though the temperature of the solar was 10 to 12°C higher than the ambient temperature. Shelf life study revealed that mango-leather can be safely stored in high density PVC container. Application of KMS in mango-pulp had a negative impact on the quality and shelf life of mango-leather. As far as, a chilli drying is concerned, the drying rate of red chillies was slightly faster of in solar dryers than in sun drying. The solar dryer (Forced convection produced better coloured chillies than the natural sun drying. Dried red chillies were safely stored in tin container.

Hossain etal (1998, 2000) investigated the adsorption and desorption equilibrium moisture contents for red and green chillies (variety Balujuri). They determined the aforesaid moisture contents experimentally by dynamic method using saturated salt 20, 30, 40, and 50°C. All isotherm curve were sigmoid in shape. The adsorption and desorption isotherm of green chillies
was higher than that of red chillies. Hysteresis was studied for a whole range of humidity. Hysteresis decrease with the increase of temperature and was higher in green chillies than red chillies.

### 3.2.1. CONCLUSIONS DRAWN FROM THE REVIEW OF SOLAR DRYING CHILLIES:

All the studies reviewed on solar drying of chillies lead us towards the following conclusions –

- Sun drying should be least preferable due to reasons mentioned in review.
- Forced convection indirect type solar dryers have a very good potential for chilli drying due to greater control on different variables, i.e., temperature and relative humidity etc.
- Other solar dryer, such as the solar cabinet dryer, the greenhouse type of solar driers, tent and tunnel type solar driers can also be successfully utilized for chillies drying as there are no strict conditions of temperature and air flow in chillies drying.
- As far as pre-treatments, before drying are concerned, one can opt for one or many pre-treatments depending upon the objective of the drying.
- Recently innovated “fed” units (Palianippan 1999) for spices drying is very technically and financially viable option offering a good quality products and a payback period of less than 2 years, along with appreciable fuel saving and low initial investments.
- Solar biomass based dryers can also be a very good technical and financially viable option due to its year round functioning, high drying rate and shorter payback period.
- As the fast food products market is expanding very rapidly globally, demand of Indian spices has grown up considerably international market. All these spices products, are made through dried chilli products such as chilly powder etc. The existing and very popular method of open air sun drying should be preferred least due to its
disadvantages. Solar dryers of various designs should be encouraged to get be utilized on larger scale, so that we can get properly dried chillies. Properly dried chillies will further enhance the quality of spices products to be made from them and consequently, a good demand in a rapidly growing and very competitive domestic as well as international markets of fast food products.
3.3. REVIEW OF RESEARCH WORK DONE ON SOLAR DRYING OF
GRAPES

A lot of research have already been done on different aspects of solar
drying of grapes by several researchers. A review of same being has done
here, in the foregoing pages.

Marousis et al (1984) designed, developed and tested a cabinet solar
tray dryer for 500 Kg capacity of fresh grapes. An array of air-cooled flat plate
collector was installed to heat the drying air stream. Current were dried in
the first drying experiments. Currants were dried in the first experiments
parallel experiments were performed with a rate of drying agent on the drying
time of currants. The thermal performance of dryers and collectors was found
satisfactory.

Bansal (1989) discussed in detail about the various techniques of raisin
production through solar driers. The results of various solar drying techniques
are shown in Table 3.5. Along with the better quality, the losses in these
techniques are also low. Shorter drying periods is obviously the main
advantage Gains of raisins in various methods are shown in Figure 3.15.

Table 3.5: Evaluation of various solar drying methods in comparison to
traditional methods

<table>
<thead>
<tr>
<th>Methods</th>
<th>Traditional</th>
<th>Solar Drying Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Protection from dust</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Drying Time</td>
<td>8-10 15-20</td>
<td>7-8 7-8 12-16 5-6</td>
</tr>
<tr>
<td>Layer thickness grapes per m² of floor area</td>
<td>18-20 100-25</td>
<td>20 20 70-80 25 22 35</td>
</tr>
<tr>
<td>Production surety</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>

(1) Floor drying with flat foil cover
(2) Floor drying plastic foil tunnel
(3) Wire mesh drying with foil cover
(4) Tunnel with a blower
(5) Solar dryer with free convection
(6) Wire mesh layer dryer with air collector and blower.
Figure 3.15: Approachable gains in the amount of product achieved by use solar drying methods.

Yadav and Ahlawat (1994) worked on the performance testing of solar dryer for the drying of grapes. The different types of solar dryers taken for comparative performance evaluation were 1) Indirect mode solar cabinet dryer 2) Natural convection solar dryer. Different parameters viz; ambient temperature, on let air temperatures relative humidity and air velocity were noted at regular intervals throughout the day with the help of necessary instruments test the performance of the different models. Treated grapes samples were allowed to dry in all the three different dryers to study the drying time and organoleptic qualities of the dried grapes (raisins) were studied. The results of the study show that the day-long average temperature recorded in different type of solar dryers (Solar dryers I-III) were 59°C, 58°C and 57°C respectively with average insulation of 450 and 581W/m² on the horizontal and inclined plane and an average ambient temperature of 40.2°C, a maximum temperature of 72°C was a chief in solar dryer I, followed by 68°C in solar dryer II and solar dryer III, with a maximum. Solar insulation of 880 and 660 W/m² on the inclined and horizontal plane respectively. Further, it was observed that treated grapes samples look lero time to dry compared to untreated samples. The comparative performance testing results of three different types of solar dryers indicate that the drying rate is highest in solar
cabinet dryers but organoleptic qualities are of the grapes dried in the natural convection dryer are the best.

Mahmutoglu et al. (1996) investigated the open floor seen and solar drying of different treated grapes and their storage stability (rar snetanas). Pretreatment solutions containing 5% $K_2Cv_2O_3$ plus 1% + 5% olive oil and 4% $K_2Cv_2O_3$ + 2% ethyl oleate the drying rates nearly to same extent as compared to untreated grapes. Drying rates were classified for the tested drying methods: solar drying > such drying on: concrete ground > seen drying on wooden racks or on polypropylene canvas sheet: Increasing $K_2Cv_2O_3$ concentration from 4% to 7% in ethyl oleate (2%) solution increased drying rates on concrete ground. Treatments with $SO_2$ gas (645 mg/Kg), in addition to ethyl oleate, further increased the drying rates but the colour of the product was rated to be too light and unacceptable to the market. The moisture content of the product was found to be non-uniform. Storage stability of treated, dried was investigated in (1) modified atmosphere (1% $O_2$ + 13% $CO_2$) (2) vacuum packed and (3) ordinary plastic packed storage at 60°C. Untreated grapes had the lowest hunter limit (lightness), a (redness) b (yellowness) values compared to treated grapes. Storage caused colour parameters to decline to decline, but this reduction was less pronounced for $SO_2$ gas treated dried grapes.

Raju et al. (1989) developed a natural convection solar drier with a loading capacity of 200 Kg per batch for the dehydration of grapes (Figure 3.16.) Before drying the grapes were treated in a solution containing ethyl oleate solution, $K_2O_3$ and oleic acid. Then they were fumigated in sulphur dioxide fumes for 6 hours 200 Kg of grapes were load in the dryer. Results indicated that 78% initial anersture content of grapes was reduced to 15% with in 4 days. The average drying efficiency was 31.7%.
Kazarian and Amiryan (1999) developed and tested autonomous small dimensioned installation in armenia because of small size agricultural farms over there. It consisted of the air heater, water heating collector and drying chamber. The air heater is carried out as a united design together with the water heating collector. The upper part of the water heating collectors as an absorber for the air heater and on etc whole length situated metallic net in the manner Z-figmative profile and the whole design was covered a double glass cover. This combined solar radiation installation was intended for all – the year round use; as a hothouse for antlivation of sprouts (in the winter – spring period) and as a dryer in summer autumn period. Results of experimentssolar radiation installation shown that with the use of – accumulated heat, the duration of drying of apricot look 4-5 days, for grapes 7 days and for apples 2,5,3 days at the specific loads accordingly 12-15 Kg/m² 15.20 Kg/m², 8-10 Kg/m². the production of finished products is 0.85-0.98 Kg/m². The traditional drying of apricots, grapes and apples were look, 9, 16-17 and 5-15 days. The developed, combined solar radiation installation allowed to accelerate a process of drying approximately 15-50%. A sketch of installation is shown in the Figure 3.17.
Sehery et al. (1999) studied in the drying of grapes, figs, tomatoes and onions using direct mode, indirect mode, mixed mode solar dryers and also using natural sun drying. Results of their studies indicated that in all experiments solar drying was a more efficient method for drying all samples of fruits and vegetables, especially for grapes, figs and onion. Grapes dried using mixed mode from 83% to 30% moisture in 4 days at an average temperature of 55°C while natural drying reduced the moisture to 57% for the same period of time at 27°C. In comparison of Indirect solar drying, they noted the similar effect, since this method reduced moisture to 16.5% for 8 days. While in natural drying, the samples dried to 43% moisture for same period of time. Results of their studies are shown in the table 3.6., along with ambient, collector, chamber temperatures and energy delivered, and efficiency of collector in table 3.7.
Table 3.6: Time required for drying of fruits and vegetables samples using different drying methods

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<th>Sample</th>
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Table 3.7: Ambient, collector, Chamber, temperatures and energy delivered and efficiency of collector at Tripoli in summer from 8-8-1995 – 16-8-95.

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<td>Chamber</td>
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<td>59.5</td>
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<tr>
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<td>23</td>
<td>43.0</td>
<td>43.0</td>
</tr>
<tr>
<td>13.10.95</td>
<td>23</td>
<td>59.5</td>
<td>60.0</td>
</tr>
<tr>
<td>14.10.95</td>
<td>23</td>
<td>56.0</td>
<td>56.0</td>
</tr>
<tr>
<td>15.10.95</td>
<td>23</td>
<td>57.5</td>
<td>56.0</td>
</tr>
<tr>
<td>16.10.95</td>
<td>21</td>
<td>40.0</td>
<td>40.0</td>
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</table>
Pangavhane et al. (1998) developed a multipurpose natural convection (indirect mode) solar dryer and vegetable crops. It consisted of a flat collector and a drying chamber with five drying trays (Figure 3.18.) experiments on the drying of grapes were conducted in this dryer and also in the open sun for quantatere evolution. Before drying the grapes were given pre-treatments with dipping solution (2% commercial dipping oil + 2.5% K$_2$CO$_3$) for increasing the permeable of the grapes skin. The variation of moisture ratio with time is shown in Figure 3.19. it is observed that moisture content was reduced from 78% to 15.4% with in 10 days in the open air Sun drying while in natural convection solar dryer it look only 6 days to reach the same level of moisture content. The average efficiency of the natural convection was 2.3% and 12.6% in open sun drying. The dryer efficiency was highest during the first day. They also made organoleptic evaluation of the raisins produced through sensory evaluation. The organoleptic qualities of solar dryer raisin were to and better than that of open sun drying. However, more browning was found in open sun drying as compared to indirect type solar drying, which may be direct exposure to solar radiation and longer drying time. The climatic data viz. total solar radiations on the area covered by the collector, only maximum, minimum and average temperature of the ambient and air inside the dryer during the successive days of drying experiment are summarized. The curve is also presented. The efficiency of solar dryer has also have given in the same table which it compares to that of open sun drying. It is observed that the maximum air temperature reached in the drying chamber using solar air heater varies from 64.1 to 69°C and the average temperature varied from 49.6 to 54.1°C on different drying days. While the maximum ambient temperature varied from 36.8 to 40°C and the minimum average temperature varied from 26.6 to 31.1°C with an average ambient temperature from 32.7 to 36.7°C on different drying days. Table 3.8. gives values of different parameters measured during trial.
Figure 3.18: Sectional Details of Natural Convection Solar Dryer
TABLE 3.8:
Details of the measured values of different parameters during drying trial (16/4/98 to 25/4/98) and comparative performance of solar and open sun drying

<table>
<thead>
<tr>
<th>Days of imposer</th>
<th>Radiation (W/m²)</th>
<th>Ambient air temperature, °C</th>
<th>Dryer inside air temperature, °C</th>
<th>Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max</td>
<td>Min</td>
<td>Aver</td>
</tr>
<tr>
<td>1</td>
<td>527</td>
<td>37.5</td>
<td>31.1</td>
<td>35.2</td>
</tr>
<tr>
<td>2</td>
<td>544</td>
<td>38.7</td>
<td>28.0</td>
<td>34.5</td>
</tr>
<tr>
<td>3</td>
<td>567</td>
<td>38.9</td>
<td>28.0</td>
<td>34.5</td>
</tr>
<tr>
<td>4</td>
<td>561</td>
<td>40.0</td>
<td>27.2</td>
<td>34.9</td>
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<td>5</td>
<td>572</td>
<td>37.0</td>
<td>26.6</td>
<td>33.5</td>
</tr>
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</tr>
<tr>
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<td>38.8</td>
<td>28.4</td>
<td>35.3</td>
</tr>
<tr>
<td>9</td>
<td>563</td>
<td>39.9</td>
<td>28.0</td>
<td>35.7</td>
</tr>
<tr>
<td>10</td>
<td>360</td>
<td>39.3</td>
<td>27.7</td>
<td>35.2</td>
</tr>
</tbody>
</table>

![Diagram](image)

Figure 3.19: Diurnal curve for a solar cabinet dryer with indirect heating mode for Data
Sukhmeet Singh et al (1998) conducted experimental studies on solar dehydration of grapes (per lette variety, which grown in Punjab). As perlettle variety is very low in sugar, osmotic treatment was given to overcome low sugar problem, in addition with sulphur bleach pre drying treatment. They utilize two types of solar dryers for experimentation (figure 3.22. and 3.23.) their key results of raisin production through solar dryer is given in figures 3.22. and 3.23. Finally, they concluded that multirack solar dryer with variable inclination proved to be more efficient than force convection solar dryer as it can dry more grapes per unit aperture area in the same time. Moreover it does not require electric power supply and they recommended the multi rack solar dryer for raisin production of farm level. In their opinion, Forced convection dryer with auxiliary electric heater can be more suitable for industrial application whose continuous time bound production is required. They further suggested that semi-continues loading should be adopted instead of batch type loading. As former will result in faster drying of grapes.

Two types of solar dryers were used for dehydration purpose:

(i) Multi-shelf Dryer with Solar Air Heater (Dryer I)

(ii) Multi-rack Solar Dryer with Variable Inclination (Dryer II)

Multi-shelf Dryer with Solar Air Heater (Dryer I) consists of a flat plate polar air heater, an electric air blower run by electric motor and a multi-shelf dehydration chamber (Figure 3.20.). Solar air heater has an aperture area of 2 sq.m. and it is inclined at an angle of 45° to the horizon. Multi-shelf chamber grapes were dehydrated simultaneously in both the dryers. Grapes in all the trays were weighed thrice a day. ambient air temperature, temperature in dryers and solar radiation intensity on aperture were recorded every one and half hours. Experiment was repeated (June 25th to July 3rd) to confirm the results. The difference this time was that TSS of grapes used was 17.23 and treatments 1, 2 and 3 were tried. Forced convection dryer was loaded with 7.835 kg of grapes while 4.2 kg of the grapes were loaded in natural convection dryer.
Figure 3.20: Multirack solar dryer with variable inclination.

Figure 3.21: Multi dryer with solar air heater.
Figure 3.22: Percentage of the total moisture removal vs. drying time

Figure 3.23: Percentage of the Total Moisture Removal vs. Drying Time
(Repeat Experiment)
3.3.1. CONCLUSIONS DRAWN FROM THE REVIEW OF SOLAR DRYING OF GRAPES:

From the review done in afore going pages the following conclusion can be drawn:

- Among all the available varieties of grapes, Thompson Seedless is still the most suitable one for raisin making however other varieties with low brix content such as Pusa seedless etc can also be used for raisins, production after certain pre-treatments such as dipping in sugar solution etc.

- Natural green or golden bleached raisins prepared from more 24% Brix grapes (Thompson Seedless) are preferred most in the marked.

- A standardised raisin making process involves the following steps:
  a) Sorting and Checking
  b) Lye treatment with 0.2 to 0.3% hot solution of NaOH at 90-95°C for 2-3 seconds.
  c) Sulphuring the berries using 2g per Kg of burnt sulphur fumes for 4 hours.
  d) Drying at 60-65°C temperature in a truck/ tunnel or a rack dryer.
  e) Curing and moisture equalisation
  f) Packaging and storage

- The moisture content in the raisins should be less than 18% (between 14.5-18%).

- Drying ration i.e. amount of fresh fruit to dried fruit is usually 4:1.

- As far as application of solar dryer in raisins making is concerned, traditional method of sun drying which is still very common in India take very long time and quality, also suffers consequently the market price of raisins. They also do not give farmers a high level of production secret.
As far as solar dryers are concerned, Greenhouse Type Solar Dryer, Solar Tunnel, Solar Cabinet Dryer are the best available options, under natural convection type of solar dryers. So far, various studies have been done on drying of grapes in these solar dryers, as described in section 3.3. The only problem usually encountered in with Cabinet type solar dryer, which drives the grapes faster, but quality suffers due to occasional excessive heat energy inside the dryer. Qualities of dried grapes are usually better in Greenhouse Type Solar Dryer and Solar tunnel driers.

- The newly developed idea of combined solar radiation installations needs a through exploration as if can be applied for other fruits and vegetables simultaneously.

- Of all varieties of grapes caused so far in various places and in various experimental studies. Thus making raisins, Thompson Seedless have so far been proved the best one.

- Pre-treatments always enhances the drying time of grapes of all various pre-treatments applied. So far, ethyl oleate a long with other solvents has so far proven the best pre-treatment.

- As the production of grapes in India increasing (Table 1.5.), along with energy crisis and environmental problems, solar driers can be a very viable alternative, provided proper innovation should be done in reducing their payback periods better designs for effective temperature and relative humidity, etc., control should be done through proper research and development in this field.

- Review of various studies on solar drying of grapes, done in the section 3.3., shows that solar energy technology has extremely bright potential in India. For a better efficient utilization of solar technology for the drying of grapes at various locations, the conventional air heating systems employing metalled absorber and glass may be too expensive for the solar drying; foil plastic collectors involving UV stabilized materials have to manufactured on a larger scale for a better market penetration of solar drying of grapes.
Solar drying systems with heated air at $60^\circ$ C and 40% Rh can be effectively used for raisin production imparting following advantages:

a) Prevention of contamination from dust, fine sand particles and other foreign matter deposited in direct seen drying.

b) Prevention of change in colour due to slow shade drying.

c) Shorter drying period.

d) Adequate energy and labour saving.

e) Minimum use of sulphur may reduced due to fast rate of solar drying.