Proc. Fla. State Hort. Soc. 92:180-183. 1979.

A LOW-COST, SMALL-SCALE SOLAR DRYER FOR FLORIDA FRUITS AND VEGETABLES

C. J. Wagner, Jr., R. L. Coleman and R. E. Berry
U. S. Citrus and Subtropical Laboratory,[1]
P. O. Box 1909,
Winter Haven, Florida 33880

Abstract. **Two models of a new low-cost, small-scale solar dryer were used to dry Florida fruits and vegetables. These models are easily constructed with simple materials and can be built in a few days. The dryers use the principle of a parabolic reflector to increase radiation on the product, and thus shorten drying time. The lighter weight, lowest cost model has a food drying area of 5.3 ft^2 (.49 m^2). Grapes, mangos, peaches and muchrooms were test dried on these dryers and products compared with those from other dryers. Preliminary results indicate products from these new dryers are comparable with other solar dried products or products dried by a conventional hot-air dryer.**

Because of present and predicted shortages of fossil fuels, other sources of energy are becoming increasingly important. Solar energy is readily available most of the year in Florida and the Southeastern United States. Acceptable dried fruits and vegetables were produced (3, 5, 6) in previous tests with an experimental solar dryer at our laboratory. The elaborate and expensive enclosed dryer used for those tests had two adjustable (polished anodized aluminum) reflectors to concentrate radiation (2). Other small-scale solar food dryers described in a survey by the Brace Institute (1) are similar to flat plate solar collectors and do not have the advantage of additional radiation gained from reflectors. There is a need for low-cost, small-scale solar dryers that have the advantage of radiation gain from reflectors, can use natural air convection, and may be easily constructed.

Recently Coleman (4) described two models of a low-cost small-scale solar dryer that meet these needs. These models use reflectance to increase radiation concentration in a unique and inexpensive way. Such dryers could be used by homeowners and farmers to dry fruits and vegetables. In some preliminary tests, food tray temperatures, air temperatures and solar radiation were monitored in the first model small-scale dryer (plywood dryer). A later model of lower cost and lighter weight (strip-frame dryer) has been used to dry Florida grapes, mangos, peaches and mushrooms. This report describes the two model dryers and compares drying data for peaches with data for peaches dried with a hot-air dryer and an elaborate experimental solar dryer (used for reference).

Experimental

Samples and pretreatments

Florida grown grapes, mangos, mushrooms and peaches, as well as peaches grown in Georgia and South Carolina, were sorted, washed and pretreated as follows:

Grapes. Muscadine grapes ('Fry' and 'Higgins' cultivars) were either left whole, or deseeded by cutting a hole through the center with a cork borer. This removed all the seeds and a small amount of the grape flesh. In practice this could be recovered and used for other grape products.

Mangos. Mangos of the 'Tommy Atkins' variety were sliced as described by Wagner *et al.,* (5).

Peaches. Peaches were halved by hand and pitted, or exposed to steam for 30 sec at 214°F (101°C), then peeled, halved by hand and pitted. All peach halves were dipped for 5 min in 2.0% sodium bisulfite in water.

Mushrooms. After washing, the mushrooms were dipped for 10 min in a sodium hypochlorite solution equivalent to 300 ppm chlorine. After draining, mushrooms were sliced into 3/8-in. (9.5 mm) -thick pieces and dipped for 10 min in a solution of sodium bisulfite (600 ppm SO_2) and methyl paraben (600 ppm).

Drying equipment

Plywood dryer. The first model small-scale solar dryer we developed had an effective drying area of 3.4 ft^2 (.32 m^2). It was a box constructed of 1/4-in. (.63 cm) plywood about 4 ft (1.22 m) on each side with an open front. A parabolic curve with a focal point of 5 in. (12.7 cm) was traced and cut away from two parallel sides of the box. Holes were drilled at 1-in. (2.5-cm) intervals along the perimeter of the parabola on both sides. Parallel strings through these holes formed a paraboloid trough across the 4-ft (1.22-m) width of the box. Using the string as a guide and support, 3, 18-in. (45.7-cm)-wide overlapped sheets of heavy duty aluminum foil were guided around the strings, thus forming an aluminum reflector within the box, with 13.6 ft^2 (1.26 m^2) of reflective surface. Screw hooks attached to the sides and 1/8 in. (.32 cm) dia. wire strung from the top of the box were used as supports for a food tray located along the central focal area. The food tray was made from perforated aluminum sheet (natural union jack perforated available at most hardware stores) framed with aluminum angle [3/4 in. x 3/4 in. x 1/8 in. (1.9 cm x 1.9 cm x .32 cm)]. The sides of the parabolic trough were then covered with 4 mil (0.1 mm) polyethylene sheeting. A removable front cover of polyethylene completed the enclosure of the dryer, except for air inlet and exhaust slots at the bottom and top. The tilt angle for this dryer could be adjusted by tilting the dryer against a vertical surface for support. Material costs for this dryer were: $30.32—dryer, $8.44—food tray.

Wooden strip-frame dryer. This lower cost, slightly larger scale model of the same type dryer was developed after the plywood dryer, using a similar principle of a parabolic reflector formed from string supports and foil. However, this model was more open, lighter in weight and easier to construct than the plywood dryer. Fig. 1 shows a side view of this model which had a 5.3 ft^2 (.49 m^2) drying capacity and was described by Coleman (4). In this side view (at A) the dashed lines represent the border of the 4 mil (0.1 mm) thick polyethylene film that envelops the whole dryer, except for air inlet and exhaust slots. This was essentially the same dryer as the plywood dryer except the solid wooden sides were replaced with an open wooden framework. The framework for the parabolic trough reflector was made from two, three-layered 1/4 in. (6 mm) thick red cedar lathing strips shaped on a template of nails in plywood, and fastened together with carpenter's wood glue. The parabolic laminate is shown (at E). After drying, the two wooden parabolic curves were connected and aligned with 5, 4-ft (122 cm)

[1]Southern Region, U. S. Department of Agriculture, Science and Education Administration.
Mention of a trademark or proprietary product is for identification only and does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture and does not imply its approval to the exclusion of others which may also be suitable.

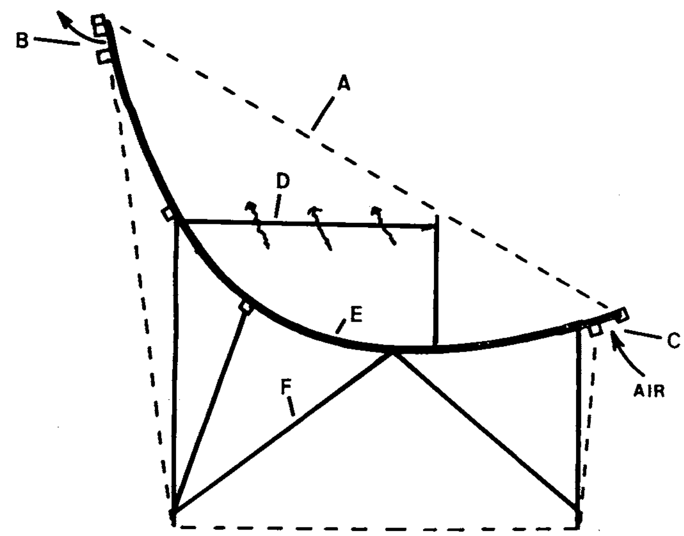

Fig. 1. Side view of strip-frame dryer: A—polyethylene film enclosing dryer; B—slot for exhaust air; C—slot for inlet air; D—food tray; E—parabolic reflector; F—support for the reflector.

long, 1 in. x 1 in. (2.5 cm x 2.5 cm) wood strips to form a box-shaped framework and support structure. Holes drilled at 1 in. (2.5 cm) intervals through the parabolic curves allowed string to be stretched to act as support and guide for foil, as with the plywood dryer. This parabolic reflector could also be positioned at various angles by propping up or elevating one edge. A drying tray (at D) for the food sample was supported on a frame made from 1 in. x 1 in. (2.5 cm x 2.5 cm) wood strips. The tray was made as described above for the plywood dryer. It had an effective drying area of 5.3 ft^2 (.49 m^2). The focal point for this parabolic reflector shown (at E) was 10 in. (25 cm), and the drying tray was centered across this focal point, i.e., 10 in. (25 cm) from the center of the parabola. Exhaust air and inlet air slots are shown (at B and C) on Fig. 1. Support members such as shown (at F) reinforce the structure. Material costs were: Dryer—$10.29, food tray—$11.61.

Florida solar energy center (FSEC) dryer. A much more elaborate and costly solar dryer with 2 manually adjustable planar reflectors and forced air circulation was described by Bryan *et al.* (2) and was built at the FSEC. It has a total effective drying area of 6.6 ft^2 (.61 m^2). This dryer was used to prepare several samples for reference.

Hot-air dryer. An atmospheric pressure, forced draft, pilot-scale, tray-type conventional dryer described by Wagner *et al.* (5) was used also to prepare reference samples.

Tests

Plywood dryer. Tray temperatures and air temperatures inside and outside the dryer were monitored at 30 min intervals. In addition, heat flux on the tray top and bottom was measured during the same 30-min intervals using solar cells described by Wagner *et al.* (7). Drying data for peaches were obtained.

Wooden strip frame dryer. Temperatures and relative humidities of air at the inlet and exhaust of the dryer were monitored. Drying data for peaches, grapes, mangos and mushrooms were obtained.

FSEC dryer. Drying data for peaches were obtained for reference.

Hot-air dryer. Drying data for peaches were obtained for reference.

Analyses

Solids content. A vacuum oven method was used [16 hrs at 158°F (70°C) at a pressure of 10 mm Hg]. Samples were weighed before and after drying in the vacuum oven, and the remaining weight was assumed to represent total solids.

H_2O/solids ratio. This value was obtained by determining initial solids content and weighing as drying progressed. It was confirmed by determining final solids content. The ratio was determined by subtracting the % solids from 100 and dividing by % solids. The H_2O/solids *ratio then* shows H_2O remaining/solids.

Heat flux. Values from a horizontal model 8-48 Eppley pyranometer (Newport, Rhode Island) were integrated on an Esterline-Angus Model PD-2064 data logger. Energy values on the food tray were obtained from calibrated modified silicon solar cells as described by Wagner *et al.* (7). The heat flux ratios, the sums of the solar radiation received on the top and bottom of the food tray divided by the radiation received on a horizontal pyranometer, were calculated.

Results and Discussion

Two models of a small-scale inexpensive solar dryer using a unique, low-cost paraboloid reflector to augment radiation have been designed, built and studied. Both use direct and reflected radiation and are totally enclosed, except for air inlet and exhaust ports. Both were inexpensive and easy to construct, but the strip-frame dryer was about one-third ($10.29) as costly as the plywood dryer ($30.32) and as effective. Most of the data reported here were obtained with the plywood dryer model, but the conclusions should apply to the wood strip-frame dryer as well, since the general construction, design and reflector principles are so similar. Either model could be used for drying grapes, mangos, peaches or mushrooms.

Average tray temperatures followed average air temperatures inside and outside the plywood dryer (see Fig. 2 and 3), whether it was empty or loaded with peaches. In Figure 2, with the solar dryer tilted at 28° for initial studies, the

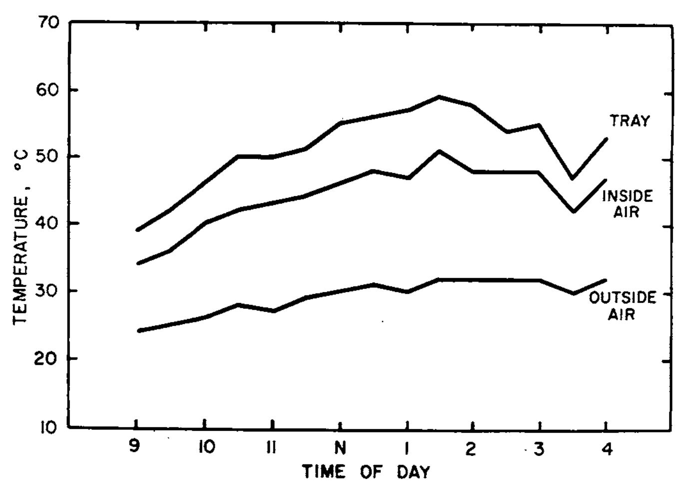

Fig. 2. Temperature profiles in the plywood dryer with no load.

average temperature difference between the air inside and ambient air was only 15°C (59°F) and the maximum tray temperature was 59°C (138°F). After adjusting the dryer tilt to 62° [an average of the annual maximum and minimum sun angle at solar noon at this latitude (28°N)] we obtained the temperature patterns displayed in Figure 3. In this test, although Florida peaches were being dried, the average difference between inside and outside temperature of the plywood dryer was higher (20°C, 68°F) because of the more advantageous angle to the sun. Maximum tray temperature was 66°C (151°F). Radiation received on a horizontal pyra-

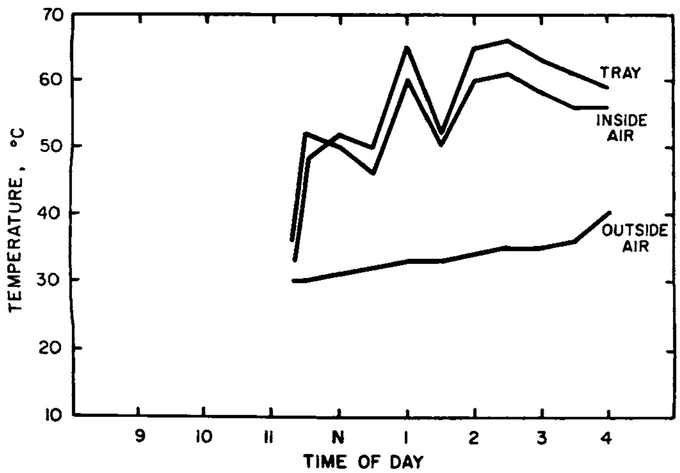

Fig. 3. Temperature profiles in the plywood dryer during peach drying experiment.

nometer during the same time period for these 2 tests shown in Fig. 2 and 3 showed only a 7% difference [339 cal/cm² to 364 cal/cm² (1.25 x 10^3 Btu/ft² to 1.34 x 10^3 Btu/ft²)].

Table 1 shows that heat flux ratios from 1.78 to 2.40 were obtained for the plywood dryer, indicating the advantage gained because of the reflector, as compared with direct sun drying. Preliminary measurements of radiation received on the food tray [3.4 ft² (.32 m²) drying area] are shown. Theoretically, if all the reflector surface radiated onto the drying surface [13.6 ft² (1.26 m²) on 3.4 ft² (.32 m²)] and the reflector surface was perfect, a heat flux ratio of 5 could be obtained. In direct sun drying a maximum heat flux ratio of 1 can be obtained.

Table 1. Ratio of heat flux on 3.4 ft² (.32 m²) (plywood model) solar dryer food tray.[z]

Test period hrs	Heat flux[y] cal/cm²	Food tray cal/cm² Top	Bottom	Ratio
5.5	315	378	257	2.02
8	534	584	364	1.78
7	438	611	440	2.40
7	469	636	468	2.35

[z]Dryer tilted at 28°, while food tray is horizontal.
[y]Measured on a horizontal Eppley pyranometer.

A unique aspect of these dryers is the dispersion of solar radiation due to natural aberrations and the imperfect paraboloid formed from the foil/string construction. Thus, instead of a highly concentrated, heat-intensive line along the focal points, as would be expected with a perfect paraboloid mirror, we observed a plane of intensified radiation dispersed fairly evenly about the focal line. Although tray temperatures for the plywood dryer were fairly uniform, peach samples from different sides were analysed for percent solids after 4.6 hr drying at an angle of 62° to determine drying uniformity. Results shown in Table 2 indicate the drying profile across the tray from front to back. Although samples varied from 24.4% to 29.2% solids, no significant differences in % solids were found in peach halves from the east half of the tray to the west, or from the northern to the southern part of the food tray. The mean % solids for these samples was 26.4 with a standard deviation of 1.8% for 4.6 hr drying.

Raisins were produced from muscadine grapes ('Fry' and 'Higgins' cultivars) over 4 solar days on the strip-frame model (Table 3). Although initial % solids for the 2 cultivars differed by only 0.7%, the loading rate for a single layer varied by 0.4 lbs/ft² (2 kg/m²) because of grape sizes. Although the 'Fry' grapes dried to a higher % solids than the 'Higgins' grapes they had a longer drying time (28.5 hrs to 25.8 hrs) and received more radiation [1666 cal/cm² to 1467 cal/cm² (6.14 x 10^3 Btu/ft² to 5.41 x 10^3 Btu/ft²)]. Commercial raisins usually have 85% solids and have been processed with many additional steps as explained by Van Arsdel *et al.* (8). There was a loss of wet grape solids while deseeding 'Fry' and 'Higgins', respectively, at 7.3% and 14.5% but in commercial operations these solids would be recoverable.

Table 2. Percent solids of Florida peach halves in the 3.4 ft² (.32 m²) plywood model solar dryer after 4.7 hrs of drying.

Sample locations on the food tray: Western half	% Solids	Eastern half	% Solids
1st Row N corner	24.4	1st Row N corner	25.0
2nd Row middle	28.7	2nd Row middle	26.0
3rd Row middle	—	3rd Row middle	26.7
4th Row S corner	25.2	4th Row S corner	29.2

$\bar{x}$ = 26.4 S_d = 1.8.

Table 3. Solar drying data on muscadine grapes in 5.3 ft² (.49 m²) wooden strip-frame dryer, 4 consecutive days on 2 samples.

Sample	Drying time hrs	Heat flux[z] cal/cm²	Final solids %	H_2O/solids
Fry, 17.8% solids @ 3.0 lbs/ft²	6.5	411	24.5	3.08
	7.25	464	39.9	1.51
	7.25	394	62.8	0.59
	7.5	397	87.0	0.15
Higgins, 18.5% solids @ 2.6 lbs/ft²	5	353	24.8	3.03
	7.67	438	31.4	2.18
	5.67	269	47.3	1.11
	7.5	407	80.9	0.24

[z]Measured on a horizontal Eppley pyranometer.

As a test of effectiveness of the two experimental model dryers, peaches dried in the experimental dryers were compared with similar samples prepared in an elaborate, costly (FSEC) solar dryer and a conventional hot-air dryer for reference. Final % solids, drying times, radiation received and loading rates were compared (Table 4). The drying times (Table 4) indicate an accumulation of several daily drying periods of solar exposure of up to 7.5 hr each (depending upon weather conditions) with overnight storage between daily drying periods. Commercially dried peaches usually have a solids content of 72-75% (8). Tests with the

Table 4. Drying data on peaches dried in three solar dryers and a hot-air dryer.

Dryer	Drying time hrs	Heat flux[z] cal/cm²	Loading rate lbs/ft²	Final solids %
Plywood	17.25	1162	1.0	85.7
	28.25	1370	1.6	76.2
	26.25	1460	2.8	66.6
Strip-frame	25.75	1284	2.0	74.4
FSEC	20.25	1121	2.0	77.2
Hot-air	6		1.8	77.3
	6		2.1	78.4

[z]Measured on a horizontal Eppley pyranometer.

Table 5. Solar drying data for sliced mangos (2 consecutive days) and mushrooms (3 consecutive days) in the strip-frame dryer.

Sample	Initial solids %	Loading rate lbs/ft^2	Drying time hrs	Heat flux[z] cal/cm^2	Final solids %	H_2O/solids
Mango						
cv. Tommy Atkins	14.2	1.0	7	428	54.7	0.83
1/4 in. slices			6	400	88.2	0.13
Mushrooms	3.8	2.0	4.5	97	5.4	17.5
3/8 in. slices			7.2	389	16.4	5.1
			6	292	86.8	0.15

[z]Measured on a horizontal Eppley pyranometer.

plywood model showed, as would be expected, that final % solids decreased as loading was increased. Since the plywood and the strip frame models have the same reflective area, these drying data indicate air circulation may be a predominant influence. Results from the FSEC dryer (with an electric fan for forced air circulation) appeared to verify this. Peaches dried in the FSEC dryer required less time and radiant energy than those dried in the strip frame model at the same loading rate. Except for the lowest loading rate [1 lb/ft^2 (4.93 kg/m^2)] the advantage in the FSEC dryer is achieved at the cost of additional energy for the forced-air circulation system. As expected, conventional hot-air drying required less drying time than did either solar dryer. All 3 solar dryers produced dried peaches with commercially satisfactory solids contents.

Preliminary results of drying sliced mangos and mushrooms on the strip frame model are shown in Table 5. At a loading rate of 1.0 lb/ft^2 (4.9 kg/m^2) mango slices dried to 54.7% solids in 7 hr. The H_2O/solids ratio was reduced from 6.04 to 0.83. The second solar period (6 hrs) was longer than necessary, for mangos should be dried to the same final solids contents as peaches (72-75%). Thus, this sample was somewhat overdried. These results indicate mangos could be satisfactorily dried on this model dryer in less than two solar days. Mushrooms loaded at 2.0 lb/ft^2 (9.8 kg/m^2) dried to an acceptable 87% solids in 3 solar periods (17.7 solar hrs). The H_2O/solids ratio during the first period was reduced from 19.8 to 7.5, while in the second period it was reduced to 5.1. Although no formalized sensory evaluations were carried out, informal tests have indicated all the products dried with these low-cost small-scale solar models were acceptable.

In conclusion, a low-cost, easily constructed solar home food dryer has been developed; it uses a unique parabolic reflector formed from strings and aluminum foil to augment solar radiation and shorten drying time. It produced dried fruit and vegetables comparable with those from an elaborate, costly solar dryer or from a conventional hot-air dryer.

Literature Cited

1. Brace Research Institute. 1975. A Survey of Solar Agricultural Dryers, Tech. T99 Report, Quebec, Canada.
2. Bryan, W. L., C. J. Wagner, Jr., and R. E. Berry. 1978. Food drying with direct solar augmented by fossil energy. Trans. ASAE 21(6):1232-1236 + 1241.
3. Coleman, R. L., C. J. Wagner, Jr., W. L. Bryan and R. E. Berry. 1978. Preliminary evaluations of sulfite pretreatments for sun-dried and hot-air dried green peppers. *Proc. Fla. State Hort. Soc.* 91:146-148.
4. ———————. 1979. Available solar dryers for home and farm applications. Proc. Viticultural Conference, July 27, Tallahassee, Florida.
5. Wagner, C. J. Jr., W. L. Bryan and R. E. Berry. 1977. Preliminary solar drying studies of some Florida fruits and vegetables. *Proc. Fla. State Hort. Soc.* 90:158-161.
6. ———————, R. L. Coleman, W. L. Bryan, and R. E. Berry. 1978. SO_2 absorption in mangos, nectarines and peaches prepared for drying. *Proc. Fla. State Hort. Soc.* 91:117-119.
7. ———————, W. L. Bryan and J. M. Miller. 1978. Energy flux values to a solar food dryer from modified solar cells. *Proc. of the 1978 Ann. Mtg. of Amer. Sec. of ISES, Inc.*
8. Van Arsdel, W. B., M. J. Copley, and A. I. Morgan, Jr. 1973. Food Dehydration, Vol. 2, Practices and Applications. Avi Publishing Co., Inc., Westport, Connecticut.

Proc. Fla. State Hort. Soc. 92:183-186. 1979.

STORAGE STABILITY OF SOLAR DRIED AND HOT-AIR DRIED GREEN PEPPERS

R. L. Coleman, C. J. Wagner, Jr., R. E. Berry and W. L. Bryan
*U. S. Citrus and Subtropical Products Laboratory,**
P. O. Box 1909,
Winter Haven, Florida 33880

Abstract. **During storage, changes in flavor and color of dried green peppers were not as great as changes in vitamin C content. Solar dried or hot-air dried samples, pretreated with different concentrations of sodium bisulfite solutions were stored at 35°F (2°C), 70°F (21°C), or 85°F (30°C). Retention of vitamin C, flavor, color and SO_2 were periodically determined over 12 weeks. Rapid reduction in vitamin C content tended to follow the reduction of SO_2 content at 70°F (21°C) and 85°F (30°C).**

In the U. S., green peppers (*Capsieum Amuum* L.—bell peppers) are grown on commercial farms, as well as in smaller home and farm gardens in the South. Large quantities of peppers are available for drying 2 or 3 times each year (1). Commercially, green peppers are commonly preserved by hot-air drying and the dried products may be used

*Southern Region, U. S. Department of Agriculture, Science and Education Administration.
Mention of a trademark or proprietary product is for identification only and does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture and does not imply its approval to the exclusion of others which may also be suitable.