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Solar Drying in Africa

Proceedings of a Workshop held in Dakar, Senegal, 21-24 July 1986

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ABSTRACT / RÉSUMÉ / RESUMEN

Abstract -- This book presents the proceedings of a workshop on solar drying in Africa attended by 24 participants involved with solar drying research relevant to the continent. Of the papers, 17 describe research activities on socioeconomic aspects, design and testing of solar dryers, and future research needs. In addition, a summary of the discussions held during the workshop to assess the state of the art of solar drying research in Africa are outlined, focusing on progress made and on possible research and collaborative activities that are needed to overcome the technical and socioeconomic problems that limit the development and introduction of improved solar dryers.

Résumé -- Voici le compte rendu d'un colloque sur le séchage solaire en Afrique auquel participaient 24 personnes effectuant des travaux de recherche propres à ce continent. Au nombre des communications, 17 décrivent les activités de recherche sur les aspects socio-économiques, la conception et l'essai des séchoirs solaires, ainsi que les besoins futurs de recherche. En outre,le lecteur trouvera un résumé des discussions sur l'état de la recherche sur le séchage solaire en Afrique, notamment les progrès réalisés et les activités de recherche coopératives nécessaires pour surmonter les problèmes techniques et socio-économiques qui entravent la mise au point et la diffusion de séchoirs solaires améliorés.

Resumen -- Este libro contiene los trabajos presentados en un seminario sobre secamiento solar en Africa, al cual asistieron 24 participantes del área de investigación en secamiento solar referida a este continente. Diez y siete de los trabajos versan sobre actividades de investigación en aspectos socioeconómicos, diseño y prueba de secadores solares y necesidades futuras de investigación. Se describe además la discusión sostenida durante el seminario para sopesar el estado de la investigación en secamiento solar en Africa, discusión que se centró en los progresos realizados y en las posibilidades de investigación y acciones colaborativas necesarias para superar los problemas técnicos y socioeconómicos que obstaculizan el desarrollo y la introducción de secadores solares mejorados.

CONTENTS

SOME RESULTS FROM SOLAR DRYING TESTS AT THE CENTRE NATIONAL DE RECHERCHES AGRONOMIQUES

Hyacinthe Modou Mbengue[1]

Abstract *-- In Senegal, most of the cereal harvest is dried in the field, apart from a small portion which is intended for immediate domestic consumption. Various methods are used for drying unthreshed grain in the field. In some cases, entire plants are cut at harvest and sun-dried directly on the ground. In other cases, the ears are cut and piled in bulk or tied in sheaves of about 10 kg, and left to dry in large heaps on the ground. When this is done, during the 5-6 weeks of drying, the exposed grain may be attacked by rodents, insects, and birds, even though the grain is sometimes wrapped with thorny branches. The aim of this research was to test new dryer prototypes that could improve grain drying, especially sorghum. Tests were conducted using a natural convection crib-dryer and four prototype dryers equipped with solar collectors. The crib-dryer is of particular interest because it affords a more efficient way of drying and storage than the traditional methods used by the farmers. To warrant the purchase of such a dryer purely on the basis of economics, it must be able to reduce losses directly by 14.3%. The secondary advantages, such as freeing parcels of land and better distribution of harvest for mechanical threshing operations, appear less tangible in the eyes of the farmers. Four types of metallic frame dryers were fabricated in the workshops of the Centre national de recherches agronomiques (CNRA) in Bambey, and tested in the Centre to determine their relative efficiencies. The four prototypes differed in the type of covering on the upper surface (glass or sheet metal) and by the presence or absence of a chimney. The chimneys, which were of semiparabolic form, were added to the structure to induce an upward hot airflow. Temperatures at various locations inside the dryer were monitored by thermocouples. Wind direction, airspeed at the dryer inlet, and outside air temperature and humidity were also recorded to determine their effects on the air temperature inside the dryer and on the drying of the product. For each dryer, recordings were made covering periods of at least 4 days, with three to six readings taken per day. The results indicated that the temperature difference between the interior and the exterior of the dryer rarely exceeded 10 °C. This occurred because, in reality, there was no solar collector feeding hot air to the dryer, thus the interior temperature of the dryer was not much*

[1] Centre national de recherches agronomiques de Bambey, Sénégal.

higher than the ambient. To determine whether there were any significant differences between the four types of dryer, and to assess the influence of wind speed, exterior temperature, and time of day, a multiple linear regression model was developed in which the dryer interior temperature was the dependent variable. This solar dryer study will have to be reconsidered, because a temperature increase of only 10 °C is certainly too small given the intense periods of sunshine experienced in Senegal. The solar performance of the dryer is minimal, so that its drying efficiency is not much better than that of a crib-dryer. For this reason, adding a chimney has little effect, although a chimney should induce a hot airflow and lead to better drying if the solar dryer is well designed. Covered plate collectors are more efficient than bare plate collectors.

Scope of Research

The main edible and cash crops of Senegal are millet, sorghum, maize, rice, haricot beans, groundnuts (peanuts), and cotton. Market gardening is of some importance in the Niayes region and on the outskirts of major centres. All these agricultural activities include fairly extensive drying operations before storage to ensure that the products will be preserved well.

The edible and cash crops are generally harvested between mid-September and the beginning of November. Drying of these products starts, therefore, in October and ends in January. During this period, the mean temperature varies between 25.4 and 28.3°C according to climatic zone (coastal, subtropical, Sudanese, or Sahelo-Sudanese), relative humidity varies between 72 and 51%, and vapour pressure between 16.7 and 13.6 mm of mercury (Anonymous 1974, 1978).

A portion of the grain crop is lost before consumption. Losses in the postharvest production chain are due to inadequate methods of drying, handling, storage, and processing. These losses start in the drying stage, which is the first operation in postharvest production. In Senegal, most of the grain crop is dried in the field, apart from a small portion that is intended for immediate consumption. In some cases, entire plants are cut at harvest time and sun-dried directly on the ground. In other cases, the ears are cut and piled in bulk or tied in sheaves of about 10 kg which are left to dry in large heaps on the ground. Under these conditions, during the 7-8 weeks of drying, the grain is attacked and contaminated by rodents, insects, mould, and birds. Improvements in the sun-drying techniques would allow maximum utilization of solar radiation and other climatological factors, a reduction in the various forms of contamination and pollution and hence an improvement in the quality of produce, and a reduction in the drying time for agricultural products. Thus, crop losses due to sudden rainfall, insects, birds, and rodents would be reduced (Fournier 1980).

The aim of this research was, therefore, to test new dryer prototypes that could improve local grain drying, especially for sorghum. Tests were conducted on a natural convection crib-dryer and four prototype dryers equipped with solar collectors. The tests were conducted during 1977 and 1978.

Materials and Methods

Crib-Dryer

The crib-dryer (Fig. 1) consisted of a wooden structure in the form of a parallelepiped 5 x 2 x 2 m, i.e., a loading capacity of 20 m^3. It was raised 30 cm above the ground to ensure good air circulation and to prevent access by rodents and other small animals. The base and the sides of the crib were covered with a metallic screen. Palmyra wood was used as the construction material because it was available and is resistant to termites.

The grain used was sorghum. The ears were tied in sheaves of about 30 kg each and symmetrically placed in staggered rows along the longitudinal axis of the dryer.

Ten dryers of this type were installed in the village of Ndiamsil in the district of Lambaye (Department of Bambey) in 1977 and 1978. It was originally intended to conduct a study on actual product drying including the economic aspects, but this study was subsequently restricted to a cost-benefit analysis.

Solar Dryers

Four prototypes of metallic frame dryers were fabricated and tested at the Centre national de recherches agronomiques (CNRA) in Bambey to determine their relative effectiveness (Figs 2-4). These structures were 3 x 1 x 1 m and were covered at each end by a double mesh, one fine and the other coarse, to prevent access by rodents. The floor and sidewalls of each dryer were covered with black-painted metallic sheet. The four prototypes differed in the type of covering on their upper surface (glass or sheet metal) and in the presence or absence of a chimney: without chimney but with a sheet-metal upper surface (NC/SM); without chimney but with a glass upper surface (NC/G); with chimney and a sheet-metal upper surface (C/SM); with chimney and a glass upper surface (C/G).

The chimneys, which were of semiparabolic form, were added to the structure to induce an upward hot airflow. Also, the dryers having chimneys were equipped with a conical inlet section to provide better directed airflow from the outside into the dryer.

Temperatures inside the dryer were monitored to determine its effectiveness. Wind direction, air speed at the dryer inlet, and ambient air temperature were also recorded to determine their effects on the air temperature inside the dryer and the drying of the product.

Temperatures inside the dryer were measured with thermocouples installed at several locations: at 25, 50, and and 75 cm above the floor. This pattern was repeated every 25 or 50 cm along the dryer. Air speed was measured with a Florite anemometer and wind direction was obtained from a weather vane installed 2 m above the ground. Ambient air temperatures (wet and dry bulb) were measured in the shade with standard thermometers.

For each dryer, recordings were made for periods of at least 4 days with three to six readings taken per day. Each dryer was loaded with 200 sheaves of grain, each weighing 7 kg. The experiment

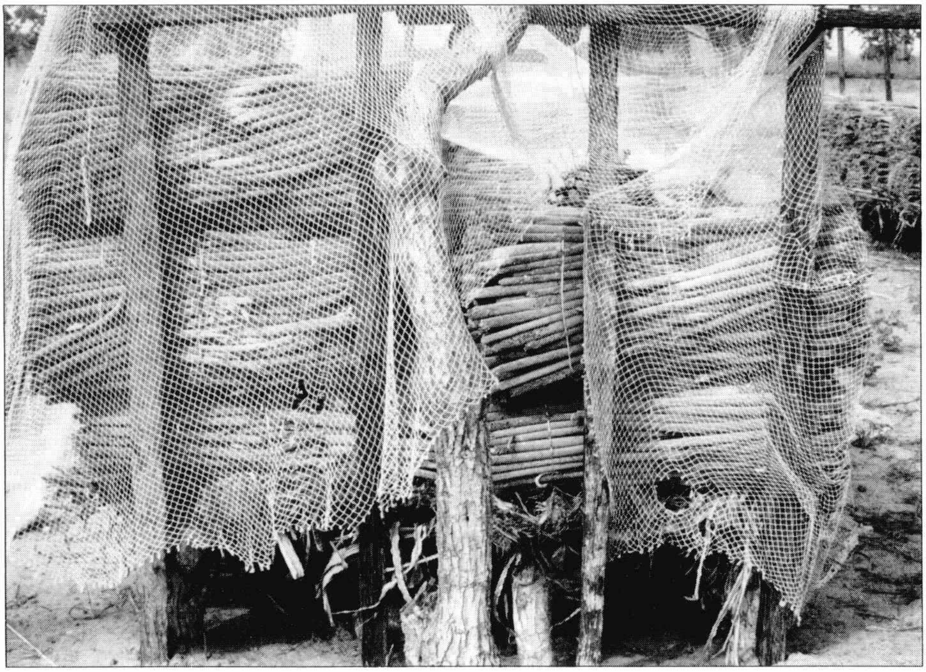

Fig. 1. Improved traditional structure.

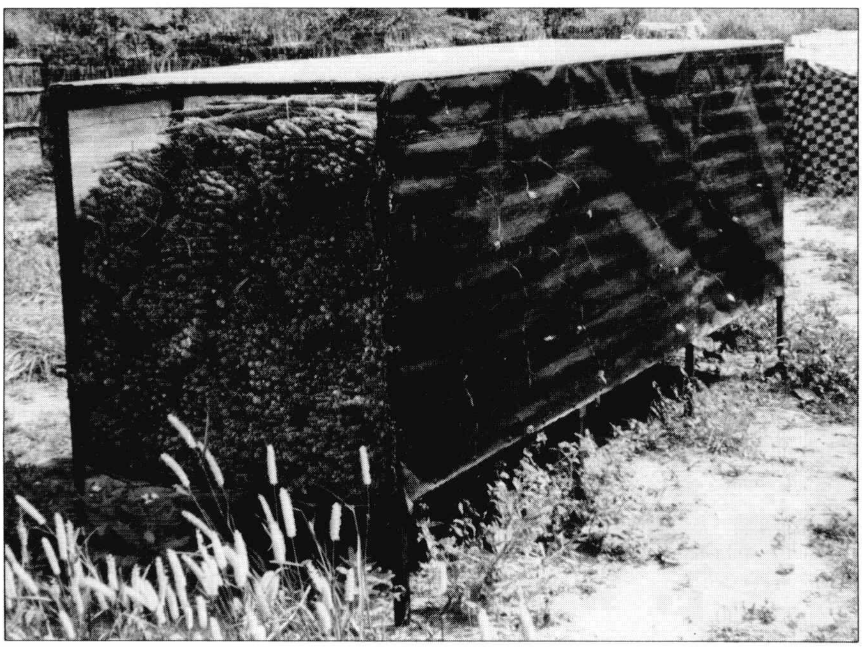

Fig. 2. Dryer with glass upper surface but without chimney.

Fig. 3. Solar dryer with glass upper surface and chimney.

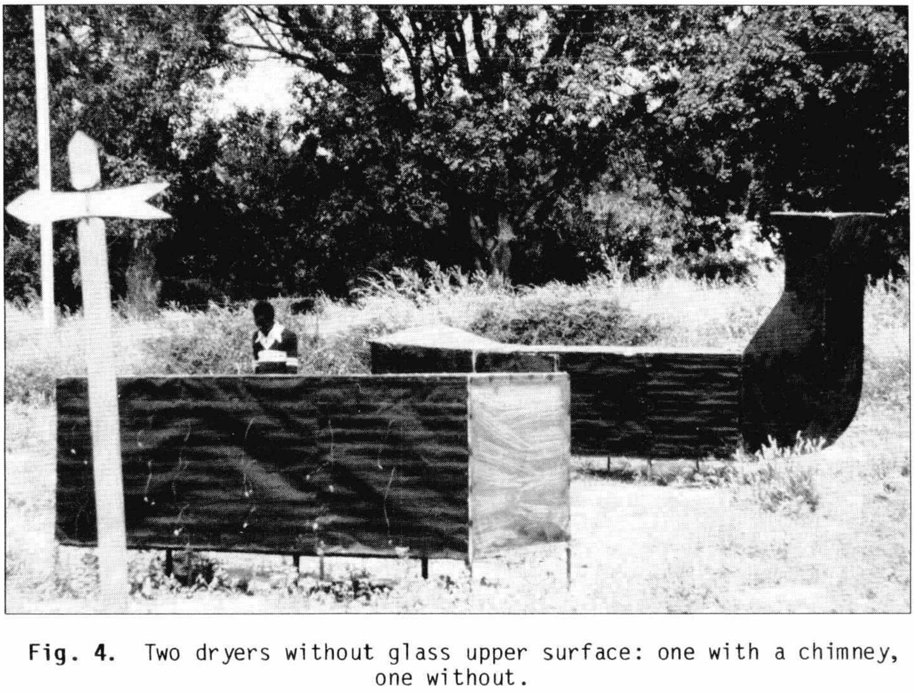

Fig. 4. Two dryers without glass upper surface: one with a chimney, one without.

was devised so as to allow the moisture content of the grain to be monitored, as well as to determine whether air could flow easily through the mass of grain.

Results and Discussion

Crib Drying

Observations on the 10 cribs installed in a rural environment and at the Centre showed that the drying time was between 5 and 6 weeks, or 2 weeks less than the traditional drying time. Nevertheless, the drying time is still relatively long compared with that of other drying methods, conventional or solar.

The main advantage of crib drying is that both drying and storage are much more efficient than with traditional methods. Raising the dryer above the ground ensures better ventilation and hence more rapid drying. It also prevents rodents and most insects from reaching the crop. In crib drying, the surface exposed to insects, birds, and other animals is significantly reduced and, at the same time, airflow through the product is increased. If the frequency of attack by these predators is proportional to the exposed surface area (which remains to be proved), we would expect postharvest losses to be reduced if larger masses of crop are dried on smaller surfaces.

The useful life of such a dryer is estimated to be 10 years. Based on this estimate, economic analysis shows a cost recovery from drying/storage of 1 kg of millet grain of 8-10 XOF[1], which represents 11.5-14.3% of the official sale price of millet (70 XOF/kg). To warrant the construction of such a dryer purely on economic grounds, it must be able to reduce losses directly by 11.5-14.5%. The secondary advantages, for example, rapid release of parcels of land and better distribution of harvesting for mechanical threshing, are less tangible in the eyes of the user (Diop 1979).

Solar Drying

Values for air speed and the exterior (ambient) and interior temperatures at various times of the day for each of the four dryers are given in Tables 1-4. The observations were made over 4-6 days. If the dryer is efficient, this period should be adequate for reducing the moisture content of the grain to a sufficiently low level to ensure good preservation.

The temperature difference between the exterior and interior of the dryer rarely exceeded 10°C (Tables 1-4). This difference is quite small compared with temperature gradients of 30°C or more that have been obtained with some types of dryers under climatic conditions that are much less favourable that those in Senegal (Diop 1979). This occurred because there is, actually, no solar collector feeding hot air properly to the dryer; thus the interior temperature of the dryer is not much higher than the ambient. Moreover, when the dryer is

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[1] In 1986, 220 XOF (franc de la Communauté financière africaine) = 1.00 CAD (Canadian dollar).

Table 1. Dryer without chimney but with glass upper surface.

Time	Air speed (mm/sec)	Temperature (°C)		
		Exterior	Interior	Difference
20 June 1978				
0840	202.14	22.00	29.38	7.38
0950	200.57	28.00	35.83	7.83
1040	201.43	33.00	38.57	5.57
21 June 1978				
1000	212.38	32.00	38.52	6.52
1155	229.19	35.00	40.52	5.52
1600	230.10	39.00	47.00	8.00
1700	223.43	38.00	42.05	6.05
1740	218.62	31.00	38.79	8.79
22 June 1978				
0845	220.43	27.00	31.31	4.31
0945	221.19	28.00	36.43	8.43
1145	220.38	33.00	38.81	5.81
1200	205.86	34.00	42.14	8.14
1630	242.33	38.00	38.98	0.98
1720	224.57	39.00	38.98	0.02
23 June 1978				
0830	205.95	27.00	28.48	1.48
0930	228.48	27.00	32.76	5.76
1030	238.76	28.00	38.57	10.57
1130	241.62	32.00	40.31	8.31
1310	205.43	34.00	42.93	8.93
1340	223.19	37.00	43.50	6.50

completely filled with ears of grain, the plate that acts as an absorbing surface is totally covered by the product to be dried and is, therefore, useless.

To determine whether there were any signifiant differences between the four types of dryer, a multiple linear regression model was developed. The model is based on the following assumptions: that the interior temperature of the dryer (dependent variable) depends on a number of factors including the time of day, the air speed, the ambient temperature, and whether the dryer is equipped with a chimney or glass upper surface or both. The multiple linear regression model not only provides a means of validating these assumptions, and possibly quantifying the importance of each factor (independent variable) in the expression for interior temperature (dependent variable), but also of comparing the various types of dryer. The model can be expressed in mathematical form as:

Table 2. Dryer without chimney but with sheet metal upper surface.

Time	Air speed (mm/sec)	Temperature (°C)		
		Exterior	Interior	Difference
20 June 1978				
0826	203.81	22.00	30.50	8.50
0830	200.48	27.00	36.76	9.76
1030	191.43	28.00	38.71	10.71
1735	200.14	28.00	38.90	10.00
1755	200.00	28.00	38.33	10.33
21 June 1978				
0820	200.43	27.00	29.05	2.05
0900	203.52	27.00	33.62	6.62
1000	240.00	33.00	38.62	5.62
1530	237.48	41.00	42.83	1.83
1630	231.71	39.00	43.48	4.48
1730	218.38	37.00	39.07	2.07
22 June 1978				
0800	214.76	26.00	27.10	1.10
0900	217.95	28.00	30.48	2.48
1000	221.86	29.00	36.21	7.21
1110	205.86	33.00	38.86	5.86
1210	213.00	34.00	40.38	6.38
1555	237.38	39.00	43.00	4.00
23 June 1978				
0805	217.52	21.00	27.93	6.93
0905	209.19	23.00	29.19	6.19
1005	233.25	28.00	33.64	5.64
1105	259.76	32.00	36.24	4.24
1205	208.43	33.00	37.90	4.90
1230	201.62	33.00	39.07	6.07

$$Y = B_0 + B_1(x_1) + B_2(x_2) + B_3(x_3) + B_4(x_4) + B_5(x_5) + e$$

where

Y = interior temperature
x_1 = time of day (from 0800 to 1800 hours)
x_2 = air speed
x_3 = ambient temperature
x_4 = presence of chimney on dryer (1, with chimney; 0, without)
x_5 = use of glass upper surface (1, with glass; 0, without)
e = error constant.

Table 3. Dryer without chimney but with sheet metal upper surface.

Time	Air speed (mm/sec)	Temperature (°C)		
		Exterior	Interior	Difference
27 June 1978				
1150	203.33	28.00	32.21	4.21
1615	201.29	34.00	41.00	7.00
1725	206.33	34.00	38.36	4.36
28 June 1978				
0830	258.81	27.00	29.29	2.29
0840	238.30	27.00	30.55	3.55
0930	316.48	28.00	33.45	5.45
0940	298.50	28.00	35.35	7.35
1030	333.24	33.00	37.43	4.43
1040	319.70	33.00	38.15	5.15
1130	332.81	33.00	39.52	6.52
1140	333.70	33.00	41.30	8.30
29 June 1978				
0956	218.00	28.00	32.00	4.00
1147	266.00	32.00	38.45	6.45
1623	234.00	33.00	37.00	4.00
1715	250.00	26.00	34.25	8.25
30 June 1978				
0858	237.14	27.00	29.98	2.98
1032	224.76	31.00	37.69	6.69
1155	268.57	33.00	40.50	7.50
1245	272.86	37.00	44.93	7.93
1507	299.05	37.00	44.95	7.95

Neither of the coefficients B_4 and B_5 is significantly different from 0 ($\underline{P}$ = 0.95, Table 5). In other words, the presence or absence of a chimney or of a glass upper surface has no significant influence on the dryer interior temperature.

However, time of day (x_1), airspeed (x_2), and ambient temperature (x_3) contribute significantly ($\underline{P}$ = 0.95) to the variations in interior temperature (Y). It should also be noted that time of day and exterior temperature are strongly correlated ($\underline{r}^2$ = 0.70). Of all the independent variables, the ambient temperature seems to have the greatest influence on interior temperature (Diop 1979). In future studies, the influence of solar radiation intensity (solar power on the dryer interior temperature) should also be investigated.

Table 4. Dryer without chimney but with glass upper surface.

Time	Air speed (mm/sec)	Temperature (°C)		
		Exterior	Interior	Difference
19 June 1978				
0810	200.00	26.00	28.71	2.71
0925	200.00	28.00	32.55	4.55
1035	254.76	29.00	36.21	7.21
1140	266.67	32.00	39.71	7.71
1253	250.95	32.00	38.10	6.10
1408	220.95	32.00	40.14	8.14
27 June 1978				
1110	206.43	27.00	35.07	8.07
1540	200.00	37.00	41.07	4.07
1710	203.95	34.00	37.88	3.88
28 June 1978				
0805	220.95	23.00	28.21	5.21
0905	207.05	27.00	33.38	4.38
1005	222.29	29.00	36.31	7.31
1105	346.62	29.00	39.64	10.64
1505	258.81	35.00	42.55	7.55
29 June 1978				
0835	205.71	29.00	29.40	0.40
1040	231.43	29.00	36.74	7.74
1515	301.90	33.00	38.48	5.48
1650	262.38	33.00	35.60	2.60
30 June 1978				
0830	214.29	26.00	29.83	3.83
1000	244.76	28.00	35.33	7.33
1130	265.71	33.00	39.83	6.83
1245	255.24	34.00	45.17	11.17
1420	260.48	37.00	47.33	10.33

Conclusions

The crib-dryer is of particular interest because it affords a more effective way of drying and storage than the traditional methods used by the farmers.

The performance of the solar dryers investigated at CNRA in Bambey was very low, particularly in view of the intense periods of sunshine experienced in Senegal. This is mainly due to the poor design of the dryer itself. Because the dryer lacked a high performance solar collector, its efficiency was almost as low as that of the

Table 5. Analysis of variance for linear regression of interior against five variables.

	Degrees of freedom	Sum of squares	Sum of χ^2
Regression	5	1551.79	310.36
Error	80	467.18	5.84
Total	85	2018.97	
		$R = 0.77$	$F = 53.15$*

Coefficient	Corresponding variable	Standard deviation	Value of t[a]
$B_0 = 4.863$	--	--	--
$B_1 = 0.299$	time of day	0.1245	2.4*
$B_2 = 0.0217$	wind speed	0.00825	2.63*
$B_3 = 0.7575$	exterior temperature	0.0894	8.48*
$B_4 = -0.854$	use of chimney	0.613	-1.39 NS
$B_5 = 0.904$	use of glass	0.537	1.68 NS

[a] * = significant at $P = 0.95$; NS = not significant.

crib-dryer. The dryer design was actually that of a "drying box" in which the product itself acts as the absorber (Fournier 1980). For this reason, it is of little significance whether the dryer has a chimney or a glass upper cover. If the dryer were well designed, a chimney could increase the flow of hot air through the dryer and hence improve its drying characteristics. On the other hand, the efficiency of covered plate colletors is higher than that of bare plate collectors only up to a flow rate of 300 m^3/hr. Above that rate, the temperature of the absorber is so low that the radiative losses are small whereas the losses from the cover assume relatively greater importance. The efficiency of the bare collector is then higher than that of the covered collector (Fournier 1980).

The study on these particular solar dryers should, therefore, be generally reworked, with emphasis placed on the design of a high performance collector. Only in this way can the advantage of Senegal's high solar energy be usefully exploited.

Prospects

Agricultural development in Senegal will require more widespread use of crop dryers even though, at present, these dryers are not justified for most of the cereals that are found mainly in the north and north-central regions.

Because solar energy is so readily available, research should focus on the design of solar dryers. "Compared with natural drying, even the most rudimentary solar techniques can reduce average drying times by 50%. Aside from quantitative benefits, the quality of the product is almost always improved. The high temperature inside the dryer eliminates the risk of infestation. Equally, the initial protein content is virtually all recovered" (Fournier 1980).

Research on dryers should, therefore, be continued to perfect a high performance hot air generator that can be fabricated from locally available materials: sheet metal, corrugated metal sheet, plastic film, etc. The performance of the dryer should be measured against the following parameters: temperature gradient between the exterior and interior, drying curve of the product, drying time of the product, germinal power of seed, nutritional and organoleptic quality of the product, useful life of the dryer, and the cost of drying.

From an economic standpoint, the criterion of profitability dictates the most widespread possible use of the dryer. The range of drying products should, therefore, be diversified to spread over the whole year (Fournier 1980).

At all events, preliminary studies should clearly demonstrate the economic viability of such techniques and their superiority over methods now in use. Because drying is essentially the first stage in postharvest production, it is clear that changes at this stage should be accompanied by corresponding changes at the later stages of threshing, storage, and processing if the efficiency of the overall postharvest production chain is to realize its full potential.

Future Research on Solar Drying

As was mentioned earlier, the use of solar dryers for drying cereals in central and north-central Senegal is not economically justifiable. Current price levels and the disorganization of the cereal production network do not warrant any additional investment by the producers. They would adopt such an approach only if prices were higher and there were an outlet for surplus production.

This is not intended to imply that all research on solar dryers should stop. The producers in the south and south-east of the country are faced with real drying problems for their crops (rice, maize, sorghum, and sanio). With the coming of the Diama dam, the double culture system that is envisaged will necessitate the use of dryers by producers. Finally, some foodstuffs such as fish and vegetables require adequate drying for good preservation. Research on drying techniques for these products is clearly justified, but it should be predicated on the real needs and technoeconomic capacities of the potential users.

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