Effects of Direct Sun Drying of Maize Grains on Perforated and Unperforated Surfaces

[1]Silayo*, V.C.K. and J.L.Woods[2]

[1]Department of Agricultural Engineering and Land Planning, Sokoine University of Agriculture, P.O Box 3003, MOROGORO TANZANIA

[2] Department of Agricultural and Environmental Sciences, University of Newcastle, Newcastle upon Tyne, NE1 7RU, U.K

Abstract

Sun drying of maize grains on unperforated and perforated surfaces was conducted under simulated solar radiation intensity of about 800 W/m and in the field, where solar radiation intensity was variable. The drying depths employed were 10, 20, 30 and 40 mm under simulated solar radiation conditions and 20 and 40 mm in the field. The response variables measured were weight loss at all depths and moisture content and temperature distributions in the 40-mm depth bed. The results in terms of overall drying rates indicate that, at depths greater than 10 mm, the perforated surface was superior ($P < 0.05$) to the unperforated and at 40 mm the effect was about double that of the control. Changing of drying depth from 10 to either 20 or 30 mm on the perforated surface did not affect the specific drying rates significantly ($P < 0.05$) except on 40 mm depth. On the unperforated surface the overall specific drying rates decreased significantly ($P<0.05$) with change of drying depth from 10 to 20 mm and above. Lower moisture gradients were achieved on the perforated surface and despite the higher drying rates temperatures in the bed were lower than on the unperforated surface. In order for high drying throughput to be achieved, drying depth of about 30 mm on perforated surfaces is recommended. Sun drying in the field yielded results that were similar to those obtained under simulated solar radiation conditions despite the fluctuating nature of terrestrial solar radiation intensity. Further work in the field, focusing on the effect of aperture size of perforations and the gap size between the drying surface and the ground floor for perforated surfaces is needed.

Keywords: Sun drying, simulated solar radiation, unperforated surface, perforated surface

Introduction

Sun drying still accounts for a large proportion of all dried crop products. Techniques used range from hand turning on a wooden mat to large scale concreted yards with mechanized spreading, turning and gathering. Despite this, the physical processes involved are not well understood. Simultaneous thermal and moisture diffusion have been suggested to contribute largely to sun drying (Brooker *et al*., 1992; Silayo, 1995). The work of Bassey (1981), Sodha *et al*. (1985) and Naam (1986), have also given some insight into the phenomenon. However, compared with some detailed studies of more sophisticated solar drying systems presented by Exell (1980), Garg and Sharma (1990) and Bala and Woods (1993, 1994 a & b), the analysis of sun drying systems is still inadequate. Since sun drying is widely practiced by rural communities, particularly in the devel-

*Corresponding author

oping countries, improvements in its management may increase its usefulness.

The main objective of this study was therefore, to compare the effectiveness of sun drying of grains on perforated against unperforated surfaces, in terms of drying rates and moisture content and temperature distribution through the depth of grain. The focus was on maize grain, which is the major staple food in Tanzania. The experiments were conducted under controlled conditions in the U.K. using a laboratory solar simulator rig, and the observed phenomena were verified under field conditions in Tanzania.

Materials and Methods

Prior to the drying experiments (under simulated and field conditions), dry maize (*Staha* variety) was re-wetted to moisture content of about 22.5 % wet-weight basis, so as to have uniform initial moisture content for the experimental materials. The amount of re-wetting water used was calculated using the relationship (Silayo, 1995)

$$w = m_i\left(\frac{M_f - M_i}{100 - M_f}\right) \qquad (1)$$

where

w = amount of re-wetting water, g

m = initial weight of grain, g

M = initial moisture content of grain, % wet-weight basis

M = desired final moisture content, % wet-weight basis

The solar simulator consisted of nine tungsten halogen lamps (each with 1 kW capacity), arranged in a square grid. The rig was designed and fabricated for the purpose of this study. The irradiation capacity of the simulator ranged from 500 to 800 W/m as measured by Solarimeter (Model No. 101820D, CASSELA, LONDON) on a flat surface, depending on height from the grid. The solar simulator was installed in a laboratory building with minimum openings in order to minimize the influence of fluctuating weather in the external environment. Experiments with the solar simulator were done at the radiation intensity of 799 W/m.

Under the simulated solar radiation conditions, drying experiments were performed on a tray with a diameter of 40 cm. Two types of materials were used in the bottom of the tray: an unperforated solid insulation material (unperforated surface) and later on a honeycomb base that was porous (perforated surface) enough to allow passage of air from underneath. The experiments were done for grain depths of 10, 20, 30 and 40 mm on both the unperforated and perforated surfaces and replicated three times. In order to monitor weight changes, the tray was mounted on a weighing balance (Sartorius 6100plus). For the 40 mm depth treatment sample, the tray was instrumented with a thermocouple system (type-T) placed at the centre of the sample in order to measure temperature within the grain and on the grain surface. Additional experiments were conducted for 40 mm depth sample in order to monitor moisture content distribution. These were also replicated three times.

Under field conditions, similar experiments were repeated on both the unperforated and perforated surfaces at Sokoine University of Agriculture for the 20 and 40 mm depth treatments. The purpose of the field trials was to verify the results obtained under simulated solar conditions.

The variables measured were weight loss (± 0.1 g) with time and initial and final moisture content of grain for the four treatments (10, 20, 30 and 40 mm depths), under the simulated solar conditions and two treatments (20 and 40 mm depths) under field conditions. Other factors investigated were moisture content and temperature distributions along the 40 mm grain depth for both experimental conditions (laboratory and field). Weight loss was determined on half-hourly interval by recording the changes in grain weight. Moisture content of the grain was determined using the ventilated oven method at 130 C for 38 hours (ISO, 1980-E; BS 1981). Temperature distribution was measured throughout the depth of the grain using seven thermocouple wires (type-T) at 6.5 mm intervals (starting from the surface). Two extra thermocouples were used to measure temperature at 2 and 6.5 mm below and above the grain surface, respectively. This was done to assess the effect of radiation exchange between the grain surface and the radiation source. Thermocouple readings were changed from mV to C scale using the standard type-T thermocouple calibration tables. For moisture content distribution through the 40 mm

Table 1. Mean specific drying rates on the unperforated and perforated surfaces obtaned under the simulated solar irradiance of 799 W/m

Grain depth (mm)	Specific drying rates x 10 (Kg/[kg.m^2 [MJ.m^{-2})]		% age difference in specific drying rates.
	Unperforated Surface	Perforated Surface	
10	4.76^a	4.33^a	-9.0
20	3.86^c	4.23^a	9.6
30	2.36^d	3.58^a	51.9
40	1.61^e	3.16^b	95.9

Means with different superscripts in a row and in a column imply significant difference at 5% level.

Between the unperforated and perforated surfaces, the results also indicated that at 10 mm grain depths, the specific drying rates were not significantly different ($P > 0.05$). At greater depths, the specific drying rates for the perforated surface were significantly greater ($P < 0.05$) than that on the unperforated surface. This difference became more pronounced with increase in depth. For the deepest bed, the perforated drying system gave about twice the specific drying rates in comparison with the unperforated one.

The observations made on drying depths and drying surfaces (Figs. 1 and 2, Table 1) imply that sun drying of grains at greater depths is generally inefficient, particularly on unperforated surfaces. Also, sun drying on perforated surfaces can be done at depths ranging from 10-30 mm, but for enhanced throughput, 30 mm depth performs best. Unperforated surfaces are suited to 10 mm or less drying depths. The improved drying performance on the perforated surface was due to the effect of buoyancy of air through the perforations and the grain mass, in addition to moisture and thermal diffusion through the grain (Brooker *et al.*, 1992; Silayo, 1995). This would bring about a convective heat and mass transfer mode in the grain, leading to increased moisture loss.

Drying uniformity

The final moisture content (Fig. 3) and temperature distributions (Fig. 4) through the 40 mm grain depth were also compared for perforated and unperforated surfaces. Use of perforated Surface resulted in more uniform drying with low

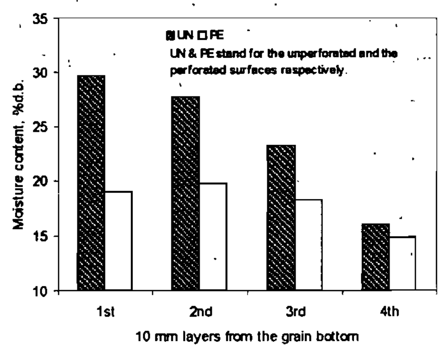

Figure 3: Avege moisture content of 10mm thick layers of maize grain in 40 mm depth after six hours of drying at the simulated solar irradiance of 799 W/m^2

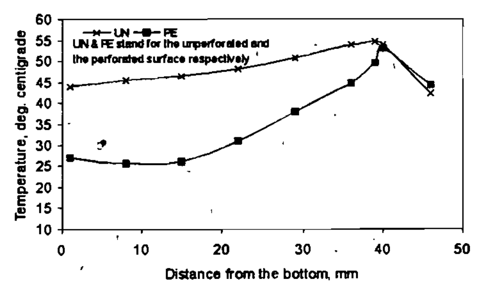

Figure 4: Temperature across 40 mm depth of maize grain at the fourth hour of drying at the simulated solar irradiance of 799 W/m

grain depth, 10 mm strata layers were sampled from the tray at the end of drying, followed by moisture content determination.

Solar radiation intensity, which is the primary sun drying controlling factor, was measured using the solarimeter. In addition, other environmental factors that have influence on the drying process were measured. These included wind velocity by cup anemometer (M/16008, CASSELA, LONDON), ambient temperature by mercury-in-glass thermometer and relative humidity by measuring wet-bulb and dry-bulb temperatures using a sling hygrometer. All the parameters were measured for both simulated and field conditions except wind velocity that was measured only in the field.

Results and Discussion

Laboratory results

Drying characteristics

Results for the simulated solar radiation experiments at the intensity of 799 W/m^2 in the laboratory are shown in Figures 1 and 2. The figures show grain weight loss with drying time at different grain depths on both unperforated and perforated surfaces. The results indicate that weight loss increased with drying depth. At the same time the results indicate that the overall specific drying rate (kg/[(kg.m^2)(MJ.m^{-2})] decreased (Table 1). This observation was pronounced on the unperforated surface, which had shown more decrease of the specific drying rates with depth compared with the perforated surface. On the unperforated surface, changing from 10 mm depth to depths of 20 mm and above produced a significant reduction ($P < 0.05$) in the specific drying rates. On the perforated surface, there was a significant reduction in specific drying rates ($P < 0.05$) only on changing the drying depth from 10 to 40 mm compared with changing from 10 to either 20 or 30 mm.

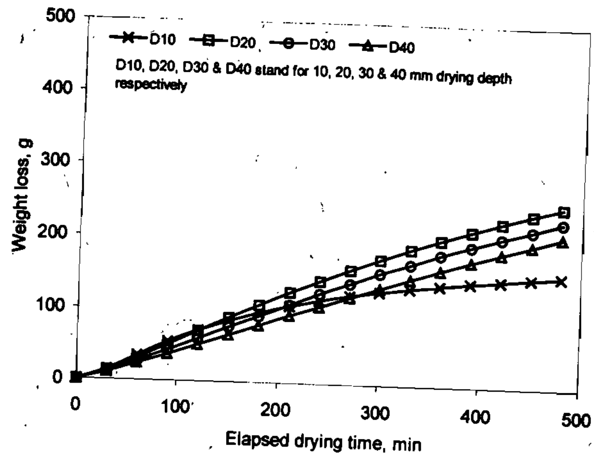

Figure 1: Weight loss by maize grain drying on the uperforated surface at the simulated solor irradiance of 799 W/m^2

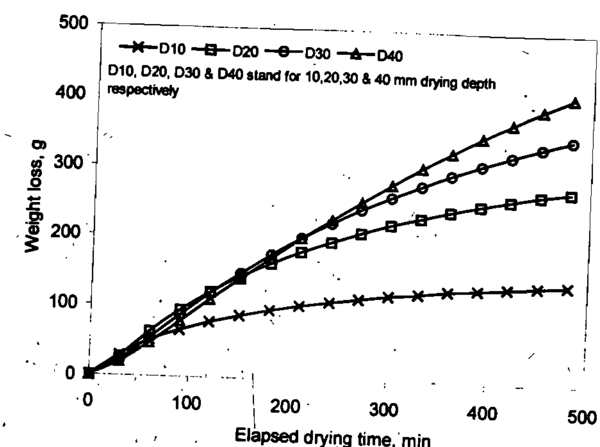

Figure 2: Weight loss by maize grain drying on the uperforated surface at the simulated solor irradiance of 799 W/m^2

moisture gradient between layers, whereas the unperforated surface resulted in non-uniform drying with high moisture gradient across the grain bed. The difference in moisture content of individual layers between the unperforated and the perforated surfaces decreased from the bottom of the bed to the top, which implies that on the unperforated surface only the top layer dried effectively. Temperatures in the grain bed on the perforated surface were relatively lower compared to those in the unperforated surface, despite having the highest drying rates. This was attributed to convective heat and mass transfer in the grain bed for samples on the perforated surface due to passage of air through the perforations (Silayo, 1995).

Field results

Due to the fluctuating nature of terrestrial solar radiation intensity, the field sun drying curves have been presented on the basis of integral solar radiation or insolation as shown (Fig. 5). As in the case of simulated solar radiation conditions, field results show that at the same grain depth, samples on the perforated surface treatment yielded higher($P<0.05$) specific drying rates relative to the unperforated surface (Table 2). In another observation, change of depth from 20 to 40 mm resulted in a significant reduction ($P < 0.05$) in specific drying rates on both the unperforated and the perforated surface as in the simulated solar radiation conditions. However, contrary to the tratments under simulated solar conditions, the percentage difference in specific drying rates between the unperforated and the perforated drying surfaces did not increase with increasing drying depth. The reason for this discrepancy was not clear but the fluctuating nature of weather in the field might have contributed.

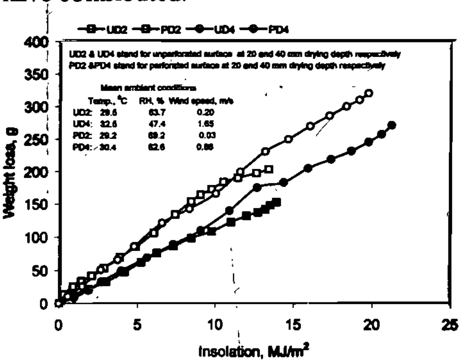

Figure 5: Weight loss by maize grain during sun drying in the field under variable solar radiation intensity

Table 2.Mean specific drying rates on the unperforated and perforated surfaces obtaned in the field under the variable solar radiation intensity [2]

Grain depth (mm)	Specific drying rates X10 kg/[$(kg.m^2)$] $(MJ.m^{-2})$]		%Age difference specific drying rates.
	Unperforatedsurface	Perforated Surface	
20	3.90	5.38	38.1
40	2.27	2.88	27.1

Means with different superscipts in a raw and in a column imply significant difference at 5% level.

The final moisture content distributions (Fig. 6) in the field also showed similarities to those observed under the simulated solar conditions, but for some reasons, their mean moisture levels did not show a clear trend between the two conditions and the drying surfaces. Temperature distributions (Fig. 7) during drying under field conditions were similar to those for the simulated solar conditions,

only within the bottom layers. The discrepancies shown in the top layers could be due to complexities brought about by the combined uncertain fluctuations of solar radiation intensity and air velocity, which contributed to surface convective heat and mass transfer processes. However, such effects could not be easily quantified.

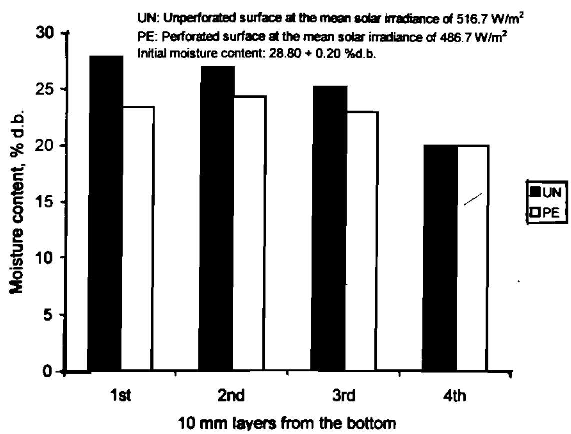

Figure 6: Average moisture content of 10 mm thick layers of maize grain in 40 mm depth after six hours of sun drying in the field under variable solar radiation intensity

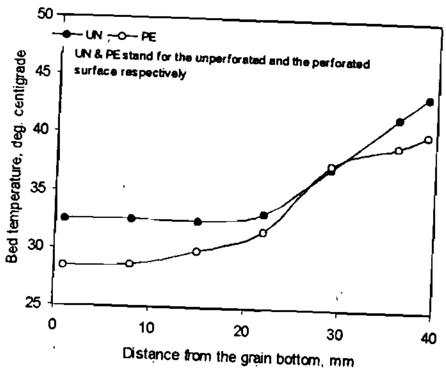

Figure 7: Temperature across 40 mm depth of maize grain at the fourth hour of drying during sun drying in the field under variable solar radiation intensity

Conclusions and Recommendations

It can be concluded that sun drying on perforated surfaces provides higher drying rates than unperforated, particularly for deep grain beds. Lower moisture gradients and lower temperatures are achievable on perforated surfaces. These may slow down the reduction in seed viability during drying. Nevertheless further studies are needed for verification. In practical terms, it can be recommended to use grain depths of 10 to 30 mm on perforated surfaces for maize grain, whereas for unperforated surfaces the recommended depth would be 10 mm. For an enhanced throughput on perforated surfaces, drying depth of 30 mm is recommended for maize grain. Field sun drying yielded results that were similar to those obtained under the simulated solar conditions. Further studies in the field are required to involve many variations on types of unperforated surfaces and aperture sizes of perforations for perforated surfaces.

Acknowledgment

The research work was jointly funded by Sokoine University of Agriculture and the Overseas Development Administration through the British Council. Their cooperation and dedication to the success of this work are highly appreciated.

References

Bala, B.K. and Woods, J.L. (1993). Simulation and optimization of a natural-convection solar dryer. *Proceedings of the Annual Conference of the American Solar Energy Society*. Washington D.C., p.419-424.

Bala, B.K. and Woods, J.L. (1994)(a). Simulation of the indirect natural convection solar drying of rough rice. *Solar Energy*, 53(3): 259-266.

Bala, B.K. and Woods, J.L. (1994)(b). Simulation of the performance of polythene and glass covered natural convection solar dryers: a comparison. *In Renewable Energy: Climate change, energy and environment, Part III*. Ed. A.A.M. Sayigh, Pergamon.

Bassey, M.W. (1981). Solar energy as a heat source in crop drying in Sierra Leone. *In Food Drying: Proceedings of the Workshop held in Edmonton, Alberta*. Ed. G. Yaciuk, IDRC, 1982.

Brooker, D.., Bakker-Arkema, F.W. and Hall, C.W. (1992). Drying and Storage of Grains and Oilseds. Van Nostrand Reinhold.

BS (1981). Determination of Moisture Content of Maize (milled and whole). British standards, BS 4317: Part 15.

Exell, R.H.B. (1980). Basic design theory for simple solar rice dryer. *Renewable Energy Review Journal*, 1: 1-14.

Garg, H.P. and Sharma, S. (1990). Mathematical modelling and experimental evaluation of a natural convection solar dryer. *Proceedings of the First Renewable Energy Congress*, Pergamon Press, p.904-908.

ISO (1980-E). Maize-Determination of Moisture Content (on milled grains and on whole grains). The International Standards Organization, ISO 6540.

Naam, Y.I., Park, M.E. and Ha, Y.W. (1986). Effects of drying methods at different harvesting times on grain moisture and quality of barley. *Research report of the rural development administration: Crops, Republic of Korea*, 28(2): 129-136.

Silayo, V.C.K. (1995). Sun drying of grains. *PhD thesis, University of Newcastle upon Tyne*.

Sodha, M.S., Dang, A., Bansal, P.K. and Sharma, S.B. (1985). An analytical and experimental study of open sun drying and a cabinet type dryer. *Energy Conversion and Management*, 25(3): 263-271.