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# Performance Evaluation of an Indirect Solar Dryer for Sheanut Kernels

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**Abstract:** The shea tree produce sheanut kernels from which shea butter is extracted. The average dimensions of the kernels are 4 cm in length and 3 cm by width. Due to its big size (4×3 cm), natural sun drying of kernels is not. Drying tests carried out in an empty indirect solar dryer, gave temperatures above 60°C but were reduced to about 50-55°C when loaded. At airspeeds of 1 and 1.4 m $sec^{-1}$ there was no significant difference in the moisture contents of the samples on the different trays. The acid and peroxide values of the butter indicated that butter obtained from the dried kernels could be classified either as category 1 or 2 butter irrespective of the drying conditions to which the kernels were subjected. Hence, the indirect solar dryer can be used to produce butter of recommended properties for cosmetics, pharmaceuticals and in food.

**Key words:** Solar dryer, characterization, sheanut kernels, food, butter

## INTRODUCTION

Open sun drying has been used as the principal method of food drying by individual farmers in the humid tropics for centuries today. Produce dried by this method include fruits, vegetables, grains as well as tubers. The shea tree that produces sheanut kernel from which shea butter is extracted grows exclusively in Subharran Africa though the butter is used worldwide. Sundrying of sheanut kernels is a key step in the processing of the kernels to butter. This is because at harvest sheanut kernels contain about 45-60% water on wet bases and are therefore highly pruned to degradation. During the drying process, the kernels are spread on bare ground and exposed directly to sun rays. Unfortunately this activity is carried out in the rainy season when the availability of sunshine is erratic. The high relative humidity of the air within this time increases the drying time and consequently the risk of acidification of the oil is high. Sun drying of raw nuts for 5-10 days reduces the moisture content to about 15-30% which is higher than the 7% moisture content recommended for storage (Bup *et al*., 2012). The method of sun drying which is popularly used in major shea producing countries to reduce this moisture content, though relatively cheap is long and exposes the dried kernels to rain and attack by micro-organisms and insects. Womeni reported that the treatment of shea kernels in a deep fat drying process significantly reduces the moisture content within a very short period of time and improves the quality of its butter. However, the deep fat frying method will obviously add to the huge consumption of wood which is already being experienced in the boiling of nuts and oil extraction stages. Wood consumption also poses a problem of forest depletion. According to Lmre and Palaniappan (1996) in the developing countries and in rural areas the traditional open-air drying methods should be substituted by the more effective and more economic solar drying technologies.

From the foregoing, coupled with the high cost and absence of electricity in shea producing localities (which are mostly rural), a study that will propose the integration of an indirect solar dryer for shea kernel production becomes very appealing since solar energy is virtually free and collection and use poses little or no environmental problems. Though direct solar dryers have been built and used in major shea producing countries such as Ghana and Mali scientific information on the

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performance of these solar dryers is lacking. The use of forced convection indirect solar dryers to dry sheanut kernels has not been reported in the literature. In addition, most of the direct and indirect solar dryers in use function on a natural convection mode which limits the uniform distribution of available air in the dryer. This gives a product which is not uniformly dried. Such a product can be easily attacked by moulds during storage. Indirect solar dryers have the additional advantage that they protect the product being dried from direct sunrays which have the capability of degrading the product.

**Objective:**

- Optimise an indirect solar dryer with variable airspeeds for the drying of sheanut kernels
- And evaluate some quality parameters of shea butter extracted from nuts dried in the dryer

## MATERIALS AND METHODS

**Sheanut kernels:** The sheanut kernels used in the drying process were obtained from Tchabal village in Ngaoundere Cameroon. The kernels were stored in a freezer at -18°C from whence they were withdrawn for analysis.

**Description of the indirect solar dryer:** The indirect solar dryer employed in this research, was re-dimensioned with the aid of an information sheet (Table 1) established for sheanut kernels using results from the literature (Bup, 2003; Kapseu *et al.*, 2007). This re-dimensioning and construction work was done in collaboration with the Centre for Appropriate Technology (CAT) Bamenda, a Non Governmental Organization (NGO) that deals in renewable energy for sustainable development. The laboratory dryer was re-dimensioned to handle 5 kg of sheanut kernels. The solar dryer Fig. 1 can be viewed as consisting of three main components: a solar collector, a drying chamber and an air evacuating system.

The solar collector (or absorber) is a flat box made of wood in the inner portions and covered with a 4 mm thick transparent glass material having a thermal conductivity of 0.9 Wm $K^{-1}$ and density of 2.39 g/$cm^3$. The inner walls of the collector are lined with an undulating aluminium sheet (to increase surface area of absorption) and are painted black to promote energy absorption by the phenomenon of Black Body Radiation.

The drying chamber can take a maximum of three trays (at a time) on which food is placed. It is constructed such that it protects the food from animals, insects, dust and rain. The chamber walls are made of plywood to prevent heat losses.

Table 1: Information sheet used in the redimensioning and construction of the indirect solar dryer

| Parameters | Value of the parameter |
|---|---|
| Capacity of the dryer | 5 kg of shea kernels |
| Maximum permissible temperature | 60°C (Kapseu *et al.*, 2007) |
| Air flow | Natural ventilation |
| Initial moisture content | 65% |
| Final moisture content | <7% (Lovett, 2004) |
| Trays spacing | 15 cm for uniform temperature within the trays |
| Height of collector from the ground | 45 cm for easy accessibility to the dryer |
| Tilt angle | 17.5° from (latitude±15°) |

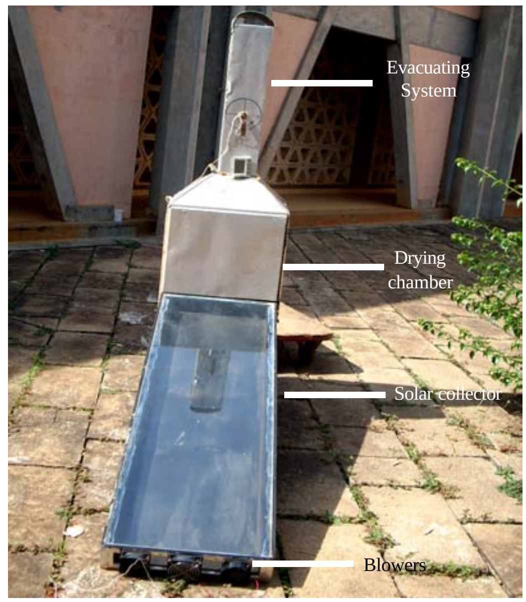


Fig. 1: Indirect solar dryer showing its principal components

The drying chamber is mounted in such a way that it receives air from the solar collector at its bottom. The upper portion of the drying chamber is conical in shape and leads to the evacuating system (the chimney). The cone like portion of the chamber helps to concentrate and channel the air leaving the drying chamber into the evacuating system from where it is sent out to the environment.

The evacuating system is an extension from the cone and opens to the exterior upwards. The evacuating system enhances the rate of air flow, through the chimney effect: heated and less dense air rising in the drying chamber is sucked out of the dryer through the evacuating system by some type of suction mechanism. The outer walls of the evacuating system are covered with aluminium sheet.

**Performance evaluation of the indirect solar dryer:** The performance of the indirect solar dryer (Fig. 1) was evaluated in order to determine optimum conditions for drying sheanut kernels. This evaluation was done in the months of August to September 2006 and April to November 2007 at the campus of the University of Ngaoundere. Shea kernels are harvested in the months of April to August and processing may go up to November (Bup, 2003). The dryer was tested under natural and forced convection runs when empty and when loaded with cooked sheanut kernels (Yaldiz and Ertekin, 2001).

**Natural convection studies:** For natural convection studies, the air flow in the dryer was natural and based on the principle that heated air becomes lighter, rises through the drying trays and goes out through the evacuating system by the chimney effect.

Three different tray heights were tested 15, 30 and 45 cm from the solar heater or collector (Rossello *et al.*, 1990). The performance of the dryer was determined without load by measuring ambient temperature ($T_{amb}$) and relative humidity ($RH_{amb}$), the temperature ($T_{in}$) and relative humidity ($RH_{in}$) at the entrance into the drying chamber as well as the temperatures on tray 1 ($T_1$), tray 2 ($T_2$) and tray 3 ($T_3$) in the dryer.

All of these readings were recorded at 30 min. intervals each day within the test periods. Figure 2 presents a sketch of the dryer indicating the positions at which these measurements were carried out.

**Temperature, relative humidity and airspeed measurements:** The temperature, relative humidity and airspeed measurements were done with the help of a Mini Thermo-Anemometer (Model, 45158 Extech Instruments, China). The Mini Thermo-Anemometer is a pocket size instrument of precision 0.1 with protective, water resistant fold-up housing that gives a simultaneous display of airspeed or relative humidity and temperature. These ambient temperature and relative humidity measurements were usually carried out under a shed to avoid the influence of direct sunrays on the reading. Ambient temperature gave an indication of the amount of heat absorbed by the collector that was subsequently transmitted to the drying chamber. El-Beltagy *et al.* (2007) demonstrated the direct dependence of incident radiation on ambient temperature. Hence, higher ambient temperatures were directly related to incident radiation falling on the collector surface and consequently to higher drying air temperatures.

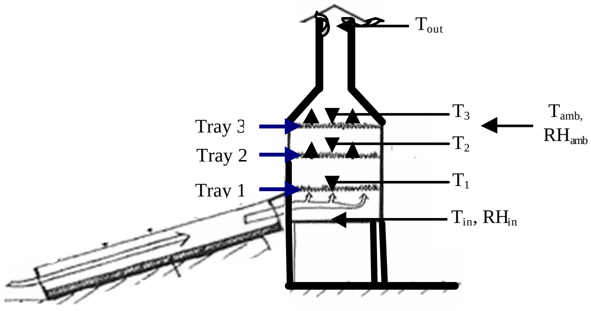


Fig. 2: A sketch of the dryer showing points at which temperature measurements were made

**Temperature distribution in the dryer:** Four thermocouples were used to record temperatures at the entrance into the dryer ($T_{in}$) on tray 1 ($T_1$), tray 2 ($T_2$) and tray 3 ($T_3$). These readings were used to evaluate the temperature distribution at different points in the dryer. The thermocouples were linked through a data logger to a computer to record these readings directly.

The relative humidity of air entering the drying chamber ($RH_{in}$) was measured using a Thermo-Hygrometer (novo Ref 16755, France).

Under no load condition, the readings were first taken maintaining the collector of the dryer either in the East, North or West direction throughout the day. After this, other experiments were carried out in which the dryer was rotated such that the collector of the dryer faced 3 different directions (East from 8.00 am to noon, North from noon to 2.30 pm and West from 2.30 pm to 5 pm) on the same day. It was then observed that by rotating the dryer through three directions on the same sunny day, highest temperatures were obtained in the dryer almost throughout the day. Thus, rotating the dryer through the 3 directions on the same day was retained to track the sun in order to maximize the temperatures in the dryer for all the test runs.

**Forced convection studies:** Forced convection studies were carried out on the dryer in an attempt to determine optimum conditions that reduce temperature gradients that could exist between the drying trays as much as possible. Forced convection was ensured by the installation of 3-12 Volts blowers at the collector inlet (Fig. 1) which took in air from the environment and blew to the product. To vary the airspeed one, two or all of the three blowers were made to function at a time and their respective airspeeds measured thereby providing three different airspeeds at which experiments were carried out.

These blowers functioned well when they were driven by solar cells obtained from the Department of Electrical Engineering, Energetics and Automation of the National School of Agro-Industrial Sciences (University of Ngaoundere) at ambient temperatures as low as 19°C.

Thus, solar cells can be used to run the blowers in the absence of electricity. However, during the experimental runs, the blowers were driven by electricity in order to render data obtained under different conditions comparable. The performance of the dryer running under natural and forced convection modes was equally evaluated with and without load.

**Determination of some properties of the butter of the indirect solar dried kernels:** Sheanuts obtained from Tchabal Ngaoundere and cooked at 80±5°C for 120 min were manually cracked and the kernels cut into 5, 10 and 15 mm thick slabs using a Tommy Slicer (Model Siemens, Erlangen, Germany). To test the effect of airspeed, the 5 mm thick slices were dried under natural convection at 0.6, 1 and 1.4 m $sec^{-1}$ while for the the evaluation of the effect of particle size the 5, 10 and 15 mm thick slices were dried at an air speed of 1.4 m $sec^{-1}$. During the test period, average environmental conditions varied as follows Temperature ($T_{amb}$) 19-27°C, Relative humidity ($R_{amb}$) 50-90%. The corresponding average air drying conditions in the drying chamber were 29-51°C and 31-65%, respectively. For each drying run 300 g of the samples were dried to moisture contents <7% before oil extraction. A block diagram for the drying process is presented in Fig. 3.

**Oil content:** The samples obtained after drying were ground using a kitchen type manual grinder to give a paste that was used in the extraction process. For each grinding process, the adjusting knob of the grinding compartment of the manual grinder was fixed to maximum in an effort to obtain a uniform particle size distribution for all the samples. The total lipid content was determined by the Russian Method (Bourley, 1982).

**Acid value:** The acid value was determined by the method described by Pacquot and Hautfenne. The percentage Free Fatty Acids (FFA) calculated as oleic acid was obtained from the relation:

$$FFA(\%) = \frac{\text{Acid value} \times 282}{56.1 \times 1000} \times 100 \quad (1)$$

**Peroxide value:** The peroxide value was determined by the method of Pacquot and Hautfenne.

**Moisture content of the oil:** The moisture content of the butter was determined by drying a given quantity of the butter to constant mass in an Infrared oven (Model XM 60, Precisa instrument AG, Switzerland) at 105°C within 2-4 min. The equipment directly records the moisture content of the butter.

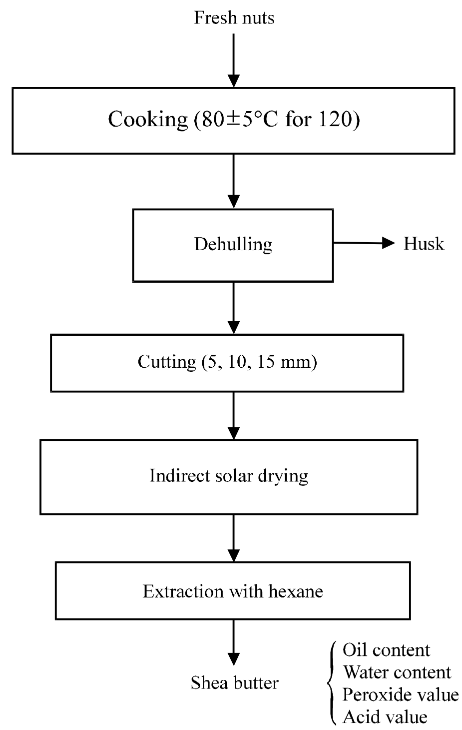


Fig. 3: Block diagram for the process of drying sheanut kernels to obtain butter

## RESULTS AND DISCUSSION

**Performance evaluation of the indirect solar dryer:** The performance of the constructed dryer (Fig. 1) was evaluated in order to determine optimum conditions (temperature and airspeed) for the drying of sheanut kernels. The respective differences between the ambient temperature and relative humidity with the corresponding values at the entrance into the dryer were calculated from the equations:

$$\Delta T = T_{in} - T_{amb}$$

$$\Delta RH = -(RH_{in} - RH_{amb})$$

**Performance evaluation of the dryer under Natural convection**

**Temperature and relative humidity in the dryer when empty under natural convection:** The variation of air temperature and relative humidity with solar time under no load condition for a selected day is presented in Fig. 4 and 5. All curves were fitted on SigmaPlot (SigmaPlot 2004 for windows Version 9, Systat Software Inc.) using a polynomial equation of the form $y = y_0 + ax + bx^2 + cx^3$ with regression coefficients ranging from 0.73-0.91.

The variations for $T_{amb}$ and $T_{in}$ were 22.7-30.8 and 28.1-60.3°C, respectively for the selected day. Togrul and

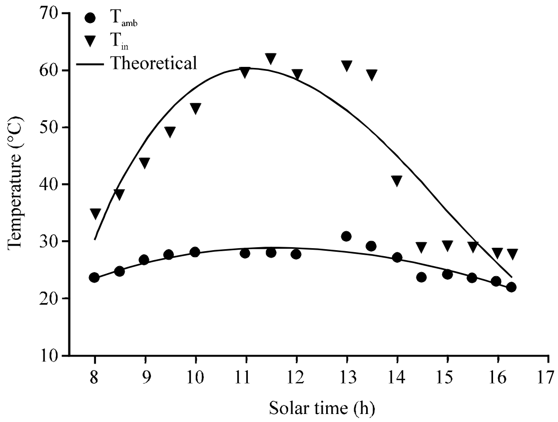


Fig. 4: Variation of temperature with solar time under natural convection without load

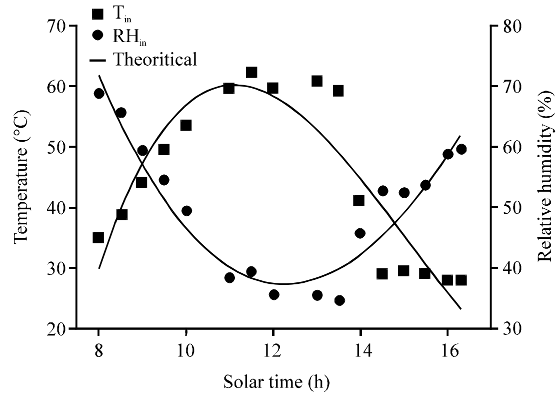


Fig. 6: Variation of air temperature and relative humidity with solar time under natural convection without load

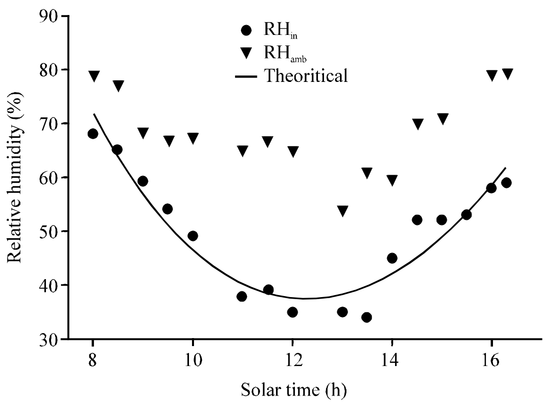


Fig. 5: Variation of relative humidity with solar time under natural convection without load

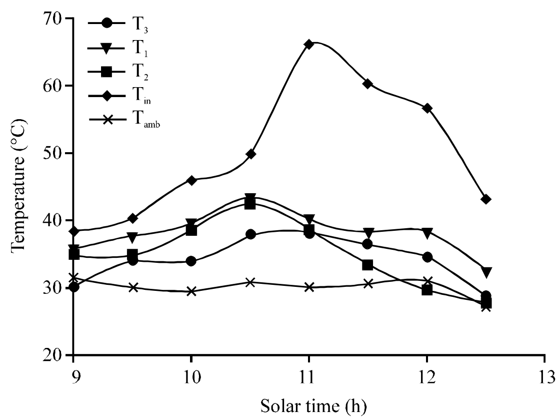


Fig. 7: Temperature distribution in the dryer under natural convection without load

Pehlivan (2002) and Sacilik *et al*. (2006) obtained similar trends in Elazig and Ankara, Turkey conditions, respectively.

Maximum temperatures were obtained between 11:00 am and 1:30 pm. The temperature entering the dryer reached a maximum of about 60°C, under no load condition when the maximum ambient temperature was around 31°C. It should however be noted that temperatures could rise up to 64°C on selected days compared to highest temperatures of 46°C reported by Yaldiz and Ertekin (2001). The variation of $T_{in}$ with time followed the same pattern as $T_{amb}$ indicating that the drying chamber air temperature was highly dependent on ambient conditions as expected. $T_{in}$ was significantly higher than $T_{amb}$ with $\Delta T$ ranging from 5.5-30.5°C. This value was indicative of the drying potential of the air in the drying chamber.

The relative humidities ($Rh_{amb}$ and $Rh_{in}$) decreased as the time of the day elapsed and was inversely proportional to temperature (Fig. 6) with minimum values observed between 11:00 am and 1:30 pm, suggesting that drying rates could be maximum around this time since, a lower relative humidity usually indicates a high capacity of the drying air to carry moisture.

The average air flow rate was approximately 0.1 m $sec^{-1}$ in the dryer and about 0.9 m $sec^{-1}$ outside during the test period.

Figure 7 shows the evolution of temperature distribution on different trays in the dryer under no load condition. As expected, the ambient temperature was lower than the temperature at the drying chamber inlet and the temperatures on the trays. The differences in temperature between the trays (tray 1, 2 and 3) were very small indicating that the temperature within the drying chamber was uniformly distributed. Mwithiga and Kigo (2006), obtained similar trends when they carried out the performance evaluation of a dryer with limited sun tracking capability in Nairobi, Kenya. A statistical test also showed that there was no significant difference between the temperatures on tray 1, 2 and 3 at 95% confidence level. There was however, a significant difference between the temperature at the entrance to the drying chamber ($T_{in}$) and the temperatures on the drying trays $T_1$, $T_2$ and $T_3$, since there was very little or no air flow to carry the inlet heat up the drying chamber. This observation suggested that blowers could be installed so that the drying air entering the chamber could be carried effectively through the drying trays.

**Temperature and relative humidity when loaded under natural convection:** The variations for $T_{amb}$, $T_{in}$, $RH_{amb}$ and $Rh_{in}$ for the days under consideration (Fig. 8) were (27.4-31.6°C), (37.3-48.8°C), (55.1-65.1%) and (41-44%). Maximum temperatures were obtained at about 1:00 am to around 2:30 pm. The temperature entering the dryer reached a maximum of about 50°C, under load condition when the maximum ambient temperature was around 31°C. $\Delta T$ and $\Delta RH$ values ranged from 9.9-19.9°C and 12.1-22.6%, respectively. These differences were less than those obtained under no load condition above perhaps due to the presence of moisture leaving the product that increased the relative humidity and decreased the temperature in the dryer and hence reduced the $\Delta T$ and $\Delta RH$ values. Hence, the drying potential of the air reduced when the dryer was loaded as expected but however, remained relatively high for the drying of biological products.

Figure 9 presents the temperature distribution in the dryer when loaded under natural convection with the sun tracked at 3 sun positions (E, N and S). It was observed that the ambient temperature remained relatively constant throughout the drying period only rising by about 2-5°C. The temperature at the entrance into the drying chamber ($T_{in}$) increased as the time of the day elapsed to reach a maximum at about 1:30 p.m. The temperatures on tray 1 ($T_1$), tray 2 ($T_2$) and tray 3 ($T_3$) followed virtually the same pattern. There was no significant variation ($p<0.05$) in the values of $T_1$, $T_2$ and $T_3$. This meant that the temperature distribution within the three trays remained uniform when loaded under natural convection.

From Fig. 10 and 11, it was clearly observed that the temperature of the air leaving the collector ($T_{in}$) differed significantly from the temperature on the first drying tray ($T_1$) by a magnitude of 7-15°C. This indicated a great loss of energy accumulated at the collectors. This highlighted the need for the incorporation of blowers to carry much of the heat accumulated at the entrance of the dryer up the drying trays. Blowers were therefore installed into the dryer to carry the heat accumulated at the dryer entrance up to the drying trays. Results of this modification are presented in the following studies.

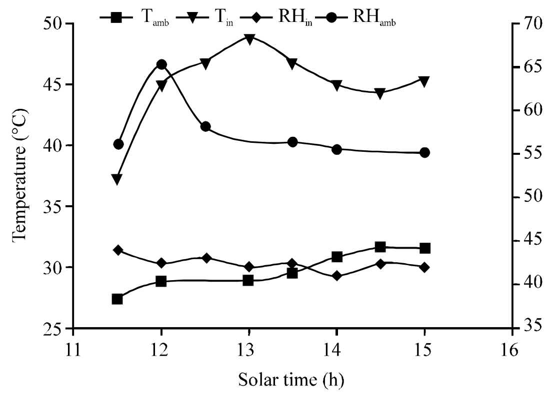


Fig. 8: Variation of air temperature and relative humidity under natural convection with load

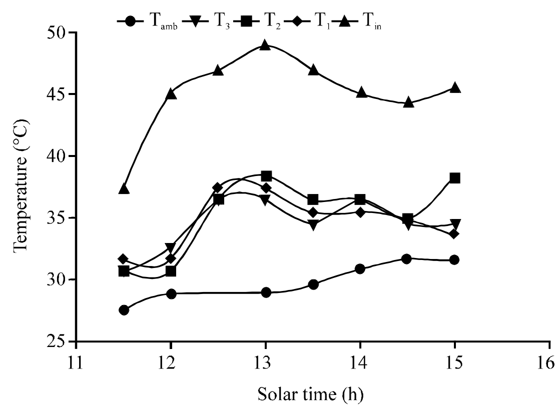


Fig. 9: Temperature evolution in the dryer when loaded under natural convection

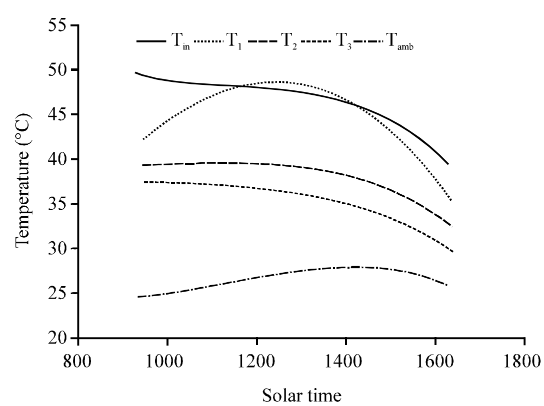


Fig. 10: Temperature distributions in the dryer with blowers functioning at 0.6 m $sec^{-1}$

**Performance of the dryer under forced convection:** The blowers incorporated provided airspeeds of 0.6, 1 and 1.4 m $sec^{-1}$ when 1 or 2 or 3 of the blowers were made to function at a time. Figure 12 shows the temperature

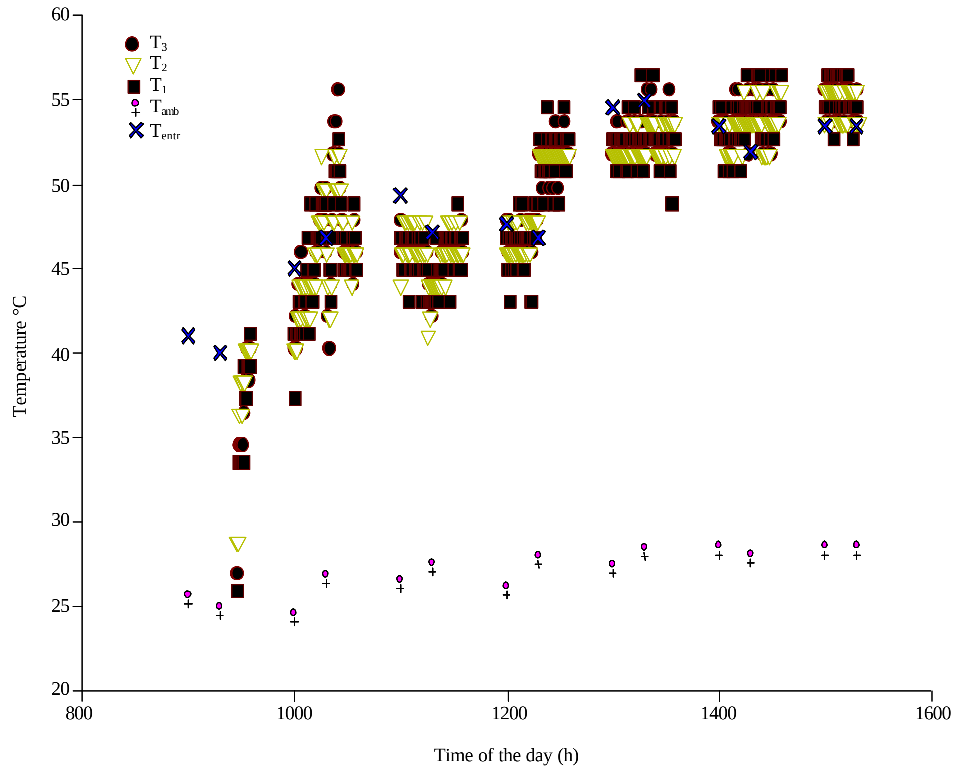


Fig. 11: Temperature distributions in the dryer with blowers functioning at 1 m sec$^{-1}$

Table 2: Some quality parameters of the butter obtained from indirect solar dried kernels

| Treatments | Oil content (% d.b.) | Moisture content (% d.b.) | Peroxide value (meq/kg) | FFA (%) |
|---|---|---|---|---|
| 5 mm natural convection | 47.01±3.5$^a$ | 2.55±0.15$^c$ | 9.46±1.1$^{cd}$ | 2.18±0.34$^b$ |
| 5 mm 0.6 m sec$^{-1}$ | 46.78±2.3$^a$ | 2.88±0.03$^c$ | 11.59±3.1$^{cd}$ | 0.20±0.02$^a$ |
| 5 mm 1 m sec$^{-1}$ | 45.47±4.8$^a$ | 6.16±0.45$^e$ | 14.56±2.7$^d$ | 5.92±0.68$^c$ |
| 5 mm 1.4 m sec$^{-1}$ | 47.29±3.6$^a$ | 2.52±0.03$^c$ | 8.19±0.6$^{bc}$ | 0.75±0.18$^a$ |
| 10 mm 1.4 m sec$^{-1}$ | 47.35±1.2$^a$ | 1.82±0.06$^b$ | 2.50±0.3$^a$ | 0.54±0.22$^a$ |
| 15 mm 1.4 m sec$^{-1}$ | 50.63±2.6$^a$ | 1.21±0.01$^a$ | 3.84±0.2$^{ab}$ | 2.10±0.23$^b$ |

distribution in the dryer at airspeed of 1.4 m sec$^{-1}$. Similar trends were obtained at 0.6 and 1 m sec$^{-1}$ airspeeds.

At 1 and 1.4 m sec$^{-1}$, there was no significant difference ($p<0.05$) between $T_{in}$, $T_1$, $T_2$ and $T_3$. Thus, energy losses observed at the entrance into the drying chamber when there were no blowers as presented in Fig. 11 were greatly reduced or eliminated by the introduction of blowers which provided airspeeds of 1 or 1.4 m sec$^{-1}$. It is easily discernible from Fig. 12 that an airspeed of 1.4 m sec$^{-1}$ provided uniform temperature distribution in the dryer. It was equally observed that with introduction of blowers, maximum temperatures obtained in the drying chamber were generally reduced by about 5-10°C but remained within the ranges recommended for the drying of biological products. Therefore, drying of sheanut kernels could be conveniently carried out at airspeeds of 1.4 m sec$^{-1}$.

**Some quality parameters of the butter obtained from indirect solar dried kernels:** Some properties of the oil extracted from the dried kernels are presented in Table 2. These properties included oil content, moisture content, peroxide value and acid value. The properties were chosen because they represented the main parameters frequently used to classify shea butter into category 1, 2 or 3 (personal communication). Apart from the oil content, there were significant differences in all other parameters of the butter.

The oil content, moisture content, peroxide value and acid value ranged from 44-50, 1.2-6.2 d.b, 2.5-22.6 meq kg$^{-1}$ KOH and 0.20-5.91%, respectively. Given that all the samples were cooked under the same conditions before being treated for drying, the significant differences observed on the parameters of the oil extracted from the 5 mm thick slice (treatment 1-3) were probably due to the different airspeeds, ambient and drying chamber air temperatures and relative humidities under which the experiments were carried out. Treatments 4-6, investigated the influence of particle size (5, 10 and 15 mm) on the parameters of the oil. These slices were

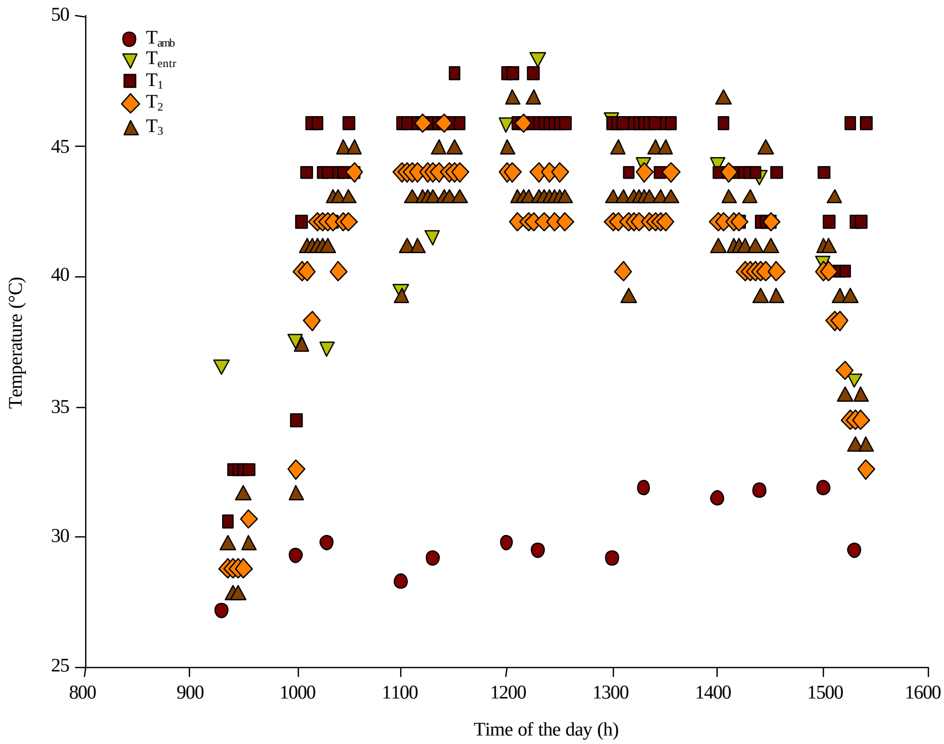


Fig. 12: Temperature distributions in the dryer with blowers functioning at 1.4 m $sec^{-1}$

dried on the same drying tray at the same time, so it was highly probable that particle size had a significant effect on the acid and peroxide values as observed from Table 2. Considering the standards for shea butter the butter obtained from the kernels dried in the indirect solar dryer could be classified either as category 1 or 2 irrespective of the varying air conditions under which the samples were dried. Category 1 butter is the most recommended and is defined for the cosmetic and pharmaceutical industries while category 2 is the second grade normally used in confectionaries and chocolate industries.

## CONCLUSION

The performance of an indirect solar dryer was tested with and without load under natural and forced convection conditions. Temperatures in the dryer rose up to 64°C irrespective of the season when it was running under natural convection with no load in the dryer. These temperatures were reduced to about 50-55°C when the dryer was loaded. At air speed of 1.4 m $sec^{-1}$, there was no significant difference in the moisture contents of the samples on the different trays due to the homogenisation of the air drying temperature in the drying chamber. The acid and peroxide values of the butter indicated that butter obtained from the dried kernels could be classified either as category 1 or 2 butter irrespective of the drying conditions to which the kernels were subjected. Hence, the indirect solar dryer can be used to produce butter of recommended properties for cosmetics, pharmaceuticals and in food.

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