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Effect of Drying Temperature on Proximate Composition and Viability of Maize Dried in a Solar Biomass Hybrid Dryer

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Abstract
Maize is an important cereal produced for food and feed and its nutritional composition and viability could be affected when subjected to inappropriate drying conditions. This study investigated the effects of drying temperature on the proximate composition and viability of maize grains dried at different levels in a solar biomass hybrid dryer. Proximate analysis was performed using standard A.O.A.C. methods. Germination test was done using sterilized Petri–dishes lined with filter papers to determine the viability of dried grains. Overall mean temperature, 43.63 ± 8.6 ˚C in the dryer was 9 ˚C higher than the average ambient temperature. The moisture content (MC) of grains in the dryer reduced from average 17 % to 11 % (w.b.) in 8 h at an average drying rate of 0.64 %/h. The overall drying efficiency was 12.7 % compared to 5.7 % for the open-sun drying process. The viability of grains dried in the dryer (avg. 95%) compared favourably to the viability of sun-dried grains (96%). The results show that, the temperature in the dryer had no adverse effect on the proximate nutritional composition and viability of dried maize grains. The adoption of solar biomass hybrid dryers for use by smallholder farmers is encouraged due to its suitability in providing a viable drying option to open-sun drying.

Keywords: Solar biomass hybrid dryer, maize grains, drying temperature, proximate composition, maize grain viability

Effet de la température de séchage sur la composition proximale et la viabilité du maïs séché dans un séchoir hybride à biomasse solaire

Résumé
Le maïs est une céréale importante produite pour l'alimentation humaine et animale. Sa composition nutritionnelle et sa viabilité peuvent être affectées lorsqu'il est soumis à des conditions de séchage inappropriées. Cette étude a examiné les effets de la température de séchage sur la composition proximale et la viabilité des grains de maïs séchés à différents niveaux dans un séchoir hybride à biomasse solaire. L'analyse proximale a été effectuée en utilisant les méthodes standard de l'A.O.A.C.. Le test de germination a été effectué à l'aide de boîtes de Pétri stérilisées et tapissées de papier filtre afin de déterminer la viabilité des grains séchés. La température moyenne globale, 43,63 ± 8,6 ˚C dans le séchoir était supérieure de 9 ˚C à la température ambiante moyenne. Le taux d'humidité (TH) des grains dans le séchoir a été réduit de

17 % en moyenne à 11 % (w.b.) en 8 h à un taux de séchage moyen de 0,64 %/h. L'efficacité globale du séchage était de 12,7 %, contre 5,7 % pour le séchage en plein soleil. La viabilité des grains séchés dans le séchoir (moyenne de 95 %) se compare favorablement à la viabilité des grains séchés au soleil (96 %). Les résultats montrent que la température dans le séchoir n'a pas eu d'effet négatif sur la composition nutritionnelle proximale et la viabilité des grains de maïs séchés. L'adoption de séchoirs hybrides à biomasse solaire par les paysans est encouragée en raison de leur capacité à fournir une option de séchage viable par rapport au séchage en plein soleil.

Mots clés: Séchoir hybride à biomasse solaire, grains de maïs, température de séchage, composition proximale, viabilité des grains de maïs.

Introduction

Maize is the most important cereal crop in Sub-Saharan Africa, grown in a large range of ecological zones. The grains are the most important part of the maize crop, with enormous uses such as the production of animal feed, human beverages and also serves as a source of income, accounting for 30% - 50% of low-income household expenditures in Eastern and Southern Africa (Bola *et al.,* 2013; IITA, 2009). The grains have a great nutritional value serving as a good energy source, dietary fibre, and calories. According to Badu-Apraku *et al*. (2006) proximate composition of most maize varieties is reported to be between the ranges of 1.2% - 3% for ash, 6.5% - 12.5% for moisture content, 5.3% - 14% for protein, 0.6% - 2.9% for crude, 2.2% - 5% for fat and 66% - 76% for carbohydrate.

The high consumption of maize grains among cereals can be attributed to its nutritional value and relatively low cost. A study conducted by Erastus (2011) showed that in most African countries, 90% of rural households grow maize, and the cultivation is usually dominated by smallholder farmers who produce 75% of the overall production. Thus, maize serves as a source of income generation for many households.

Over the years, maize grains have mainly been preserved through drying. In Ghana, drying of most agricultural produce is carried out through open sun drying method, industrial type mechanised dryers that rely on fossil fuels or electricity and in a few instances, solar dryers. Though open sun drying is weather dependent, labour intensive, unhygienic and time consuming, it is the most common and cheapest method of drying farm produce in sub-Sahara Africa according to Amer *et al*., (2010). Drawbacks such as delayed drying due to poor weather could result in grains becoming mouldy and possibly getting contaminated with aflatoxins (Akowuah *et al*., 2018). The grains' exposure during open-sun drying also results in physical contamination and quantitative loss by birds, rodents, and scavenging livestock. Most smallholder farmers are often forced to sell their produce cheaply because of the unavailability of a suitable method for drying their grains (Armah and Asante, 2006). Again, long exposures to excessive sunshine may cause potential loss of germination, and U.V. radiation may damage the nutritional composition of the grains (Madhlopa *et al*., 2002). Due to the several limitations of open sun drying, recent research works have focused on attempts to bridge the gap between open-sun drying and use of industrial mechanical drying set ups which are expensive to operate. The intermediate solution has always been through the use of solar dryers, which reduce the drying time, increase the drying efficiency and quality of the grains compared to open-sun drying. However, one significant limitation of solar dryers is their use only during hours of adequate solar radiation, which prolongs the drying period, thereby affecting its quality (Akpinar, 2008; Armah et al., 2021). According to Sekyere et al. (2016), these and other drawbacks have limited the commercialisation and adoption of solar dryers in Ghana by farmers.

To address this problem and encourage the scale-up of solar dryers in sub-Saharan Africa, the provision of reliable and readily available energy is required (Neba and Nono, 2017). In view of this, current research in solar dryer technology has focused on the development of hybrid drying systems that rely on solar energy and other renewable energy sources such as biomass (Amer *et al.,* 2010; Gunasekaran *et al.,* 2012; Okoroigwe *et al.,* 2013). However, for the commercialisation of solar hybrid drying systems, information on its performance is necessary to give confidence to investors and adopters of new technologies to ensure successful scale-up and deployment to meet production outputs. This study was therefore carried out to investigate the performance and determine the effect of drying temperature on the nutritional composition and viability of maize grains dried in a newly constructed solar biomass hybrid dryer.

Materials and methods

Study area and dryer description

The drying experiment was conducted at Ejura, one of the major maize producing areas in the Ashanti Region of Ghana. The drying facility is located on the premises of Pens Food Bank Limited, Ejura, at GPS coordinate, 7.3826213, -1.3686575. As shown in Figure 1, the solar-biomass hybrid dryer is designed as a greenhouse-type tent dryer. It consists of three major parts: the drying chamber, solar photovoltaic (PV) system, and a biomass furnace. The dryer has an overall dimension of 13.07 m x 6.28 m x 4.61 m, with the roof and all sides covered with a 0.03 m thickness UV-protected transparent acrylic sheet. It has four layers arranged in a U-shape with a total loading capacity of approximately 4 tonnes.

Each fixed drying tray has an average depth of 0.05m and is made of wood with the base fixed with nylon mesh reinforced with metal

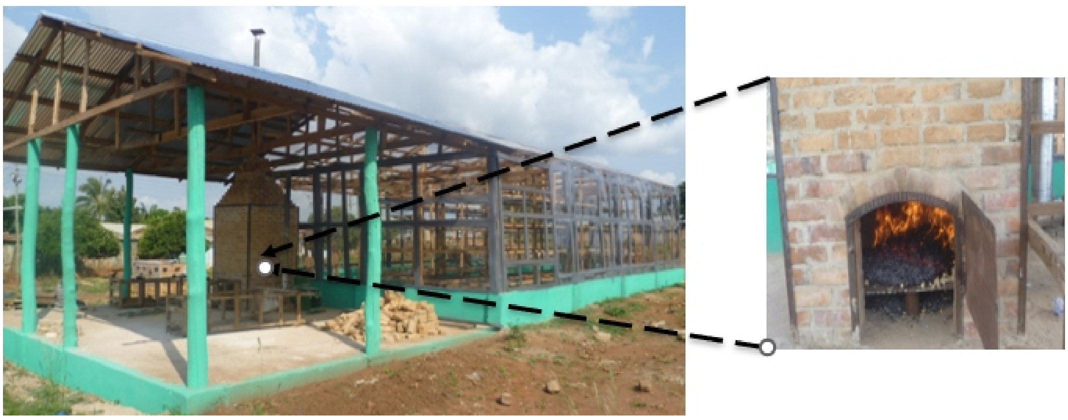

Figure 1: Developed solar biomass hybrid dryer (left) with the furnace (right)

mesh to hold the drying grain. The drying trays are spaced to allow for a smooth flow of drying air on top and beneath the grains, eliminating the need for stirring during drying. To ensure easy collection of grains after drying, the shelves are fixed at an angle that allows the grains to easily flow into an open duct fixed in front of the shelves which allows the dried maize to flow by gravity into a collecting bag below as shown in Figure 2.

A furnace enclosed with a crossflow heat exchanger and utilises biomass feedstock such as maize cobs, dried coconut husk, rice husk, palm nutshell, etc., is attached to the dryer to provide clean hot air, which is channelled into the drying chamber using a blower or induced draught (I.D.) fan. Retrofitting the solar dryer with a backup heat generation system like this ensures that the drying process can continue during periods of no sunshine or cloudy weather. The PV system is installed with a backup battery to ensure possible operation of the dryer in communities with no access to electricity or during night, cloudy and/or rainy periods.

Experimental procedure

The dryer was used to dry 3.7 tonnes of *Obatanpa* maize, a local white maize variety, during the drying experiment and each shelf was loaded with equal quantity of maize. Each layer was loaded with 924 kg of maize. The maize grains used for the study was obtained from a local farmer within the community. The same quantity of maize (924 kg) was dried on a tarpaulin in the open-sun, at the same location close to the dryer during the same period.

Instrumentation and measurements

Solar insolation was measured using a pyranometer (Solar Power Meter, AMPROBE SOLAR-100) every 10 minutes. The air velocity was also recorded at a 10-minute interval using an integral vane digital

Figure 2: Inner view of drying chamber with shelves loaded with maize

anemometer (DFM 8904). Temperature and relative humidity variation of air within the dryer were monitored using Tinytag data loggers (model TGP-4017; Gemini Data Loggers, Chichester, UK.). Five data loggers were placed at each of the drying layers in the drying chamber, as shown in Figure 3.

The mean was determined as the temperature for the layer. The ambient temperature and relative humidity were measured as well. The moisture content of maize grains during the drying experiment was determined using a pre-calibrated moisture meter (Dicky-John mini GAC plus moisture analyser with accuracy of ±0.1%). The initial moisture content of maize grains was determined before drying started, and samples were taken at hourly intervals for moisture content analysis. To ensure uniformity in moisture content measurements, maize grains were sampled from different locations of the three sections at each of the four drying layers and mixed thoroughly before the moisture content reading was taken and recorded. Three measurements were taken at each period and the means calculated for analysis. The same procedure was repeated for grains dried in the open-sun.

Dryer performance assessment

The dryer's technical performance was expressed in terms of its thermal efficiency and drying rate. Thermal efficiency measures the overall efficiency of the drying system. It is expressed as the ratio of the energy required to evaporate moisture from a material to the heat supplied to the drying system. It was calculated using Equation 1 (Ayyappan and Mayilsamy, 2010).

$$\eta_{th} = \frac{m_w\, h_{fg}}{A \times I} \qquad \text{Equation 1}$$

Where, η_{th} is the thermal efficiency of the dryer, m_w is the mass of water evaporated in time t, h_{fg} is the latent heat of vapourization of water (kJ/kg), A is the area of the dryer (m^2) and I is the solar intensity in W/m^2.

Figure 3: Location of temperature and relative humidity sensors at the 2^{nd} layer in dryer

Drying rate as a performance parameter in assessment of dryers indicates the rate at which moisture is removed from a certain quantity of produce being dried. It was calculated using Equation 2 (Zhao *et al*., 2019).

$$DR = \frac{m_t - m_{t+dt}}{\mathrm{dt}} \qquad \text{Equation 2}$$

Where, *DR* is the average drying rate (%/h), M_t and M_{t+dt} is the moisture content at time *t* and *dt*, respectively, and *dt* is the drying time (h).

Quality assessment test

The proximate nutritional composition and grain viability test were conducted on the maize grains after drying to compare the quality attributes of the grains dried in the solar-biomass hybrid dryer and compared to the maize grains dried in the open-sun.

Nutritional value test

Proximate nutritional composition analysis was carried out on sampled dried grains according to the procedure of the Association of Official Analytical Chemists (A.O.A.C., 1990) for moisture, ash, crude fat, crude fibre, and crude protein contents. The carbohydrate was calculated by the difference method (A.O.A.C., 1990) by subtracting the sum (g/100g dry matter) of crude protein, crude fat, ash, and fibre from 100g.

Germination test

A germination test was conducted after drying to investigate the effect of the drying temperature in the dryer on the viability of dried grains and was compared to the viability of grains dried in the sun. It was carried out at the Food and Postharvest Laboratory of the Department of Agricultural and Biosystems Engineering at the Kwame Nkrumah University of Science and Technology, Kumasi. Dried maize grains were sampled from different positions at the three sections at each layer of the dryer. For each layer, 100 clean grains with no signs of defect were carefully picked from of the sampled dried grains and counted into sterilized Petri-dishes, lined with filter papers. An equal amount of water was sprinkled on it and covered. This was replicated three times for each layer. Emergence counts started from the fourth day and continued until there was no visual observation of seedling emergence. The percentage of germinated seeds was calculated using Equation 3 (Azadi and Younesi, 2013),

$$(\%)\ \text{Germination} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds in sample}} \times 100\%$$

Equation 3

Statistical analysis

All statistical analyses were carried out using the GenStat Statistical Software (Version 12). Data obtained where necessary were subjected to Analysis of Variance (ANOVA), and the significance level of differences in means was checked at a significance level of 5% ($p \leqslant 0.05$). Results were represented using the mean values obtained.

Results and discussion

Temperature variation with time

The transfer of heat to moist products by conduction and convection from the ambient air mass at a temperature above that of the product is the primary requirement of the drying process during solar drying (Amer *et al*., 2010). The air temperature variations in the solar biomass hybrid dryer during the drying period of seven (7) sunshine hours are presented in Figure 4. Drying air temperature varied across the different levels (L1 – L4) in the dryer. The results show that drying temperature increased from the bottom (L1) across the upper levels (L2, L3, and L4) of the drying chamber with the maximum temperature, 53.9 °C recorded at L4 followed by L3 (50 °C), L2 (43.9 °C) and L1 (40.1 °C). These maximum temperatures were recorded during the peak drying period around 12:00-13:00 GMT when solar insulation was at a maximum of about 1,062 W/m^2. Comparably, the maximum temperature recorded under ambient conditions was 35 °C which was 18 °C less than the maximum recorded at level 4.

The mean temperature recorded for level 4 (L4) was 49.35 ± 3.64 ˚C. The mean temperatures recorded at L3, L2 and L1 in the dryer were 46.07 ± 2.89 ˚C, 40.66 ± 2.04 ˚C and 38.45 ± 1.62 ˚C, respectively. Comparatively, the overall mean temperature across all the levels in the dryer (43.63 ± 8.6 ˚C) was about 9 ˚C more than the average ambient temperature (35.04 ± 3.3 ˚C).
The high temperatures recorded in the dryer compared to the ambient temperature were due to the transparent material (Perspex) that was used to overlay the drying chamber. Tonui *et al.* (2014) reported that the Perspex material allows the absorption of more solar energy due to direct solar insolation. It also prevents heat escape by acting as a heat trap for infrared (thermal) radiation by confining the heated air. The air density differences due to the buoyancy effect, which resulted in the stratification of hot and cooler air in the dryer, also contributed to the increasing temperature trend from L1 to L4 in the dryer (Akowuah *et al.,* 2018). The closeness of L4 and L3 to the roof of the dryer which received more of the direct solar insolation through the roof compared to the lower layers (L1 and L2) resulted in the relatively high temperatures at the upper layers. Hallak *et al.* (1996) reported on a similar observation of drying air temperature increasing in the higher

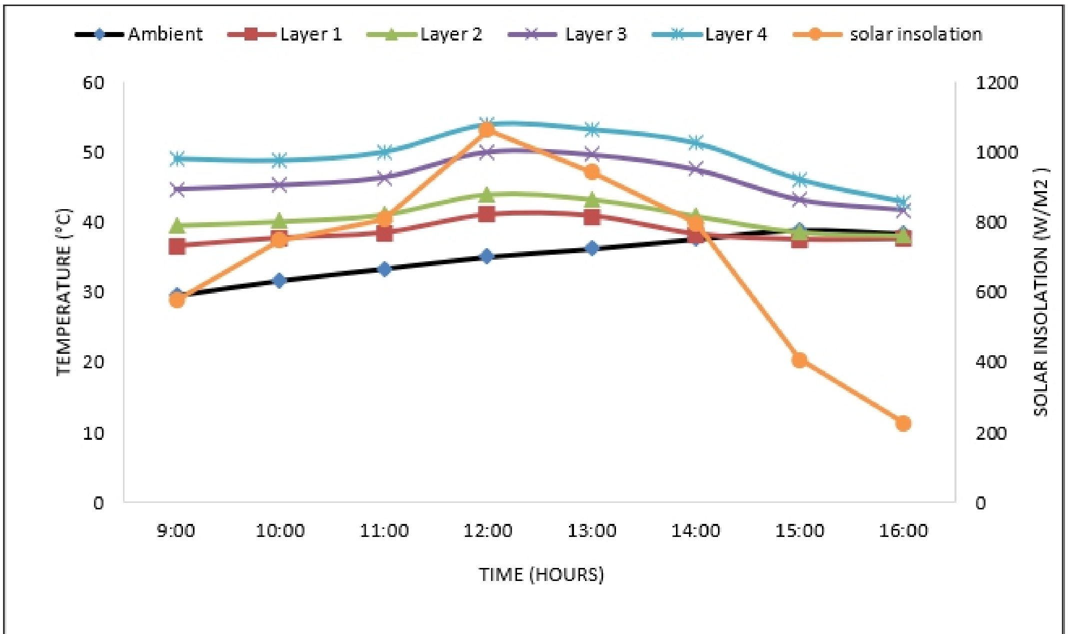

Figure 4: Temperature and solar insolation variation during drying

compartment of a solar dryer. Other authors (Tibebu, 2015; Bolaji, 2005; Svenneling, 2012) have reported similar results where the ambient temperature was comparatively low than temperatures in a solar dryer.

Effect of drying temperature on moisture content with time

Drying was carried out between the hours of 14:00-17:00 GMT on Day 1 and was continued in Day 2 until drying was completed between 9:00-14:00 GMT, as shown in Figure 5. The grains were dried from an average initial moisture content of 20.5% on dry basis (17% w.b.) to a final moisture content of 13.4% dry basis (11.9% w.b) within eight sunshine hours. Maize grains dried at layers 4 and 3 dried in 6 sunshine hours to moisture contents of 12.5% and 13.3% dry basis, respectively. However, maize grains at layers 1 and 2 dried to 14.2% and 13.9% dry basis, respectively in 8 sunshine hrs of exposure in the dryer.

Variation in grain moisture with time at the different drying levels (L1-L4) was influenced by the drying temperature which varied in an increasing order from the bottom (L1) across the upper levels (L2, L3 and L4). The reduction in drying time at the upper levels was due to the relatively high temperatures observed which increased the available energy required for the evaporation of moisture from the grains. Achint *et al.* (2017) reported a similar observation in their work which involved the drying of corn in a solar cabinet dryer. On average, it took eight sunshine hours to dry approximately 3.7 tonnes of maize from 20.5% to 13.4% dry basis (17% - 11.9% wb). After the first day of drying, grains dried using the open-sun were covered at night with a tarpaulin until drying started the next day. The moisture content had increased slightly by 0.1 from 17.1% (db) to 17.2%. The slight increase in the moisture content of grains covered overnight due to reabsorption of moisture by condensation

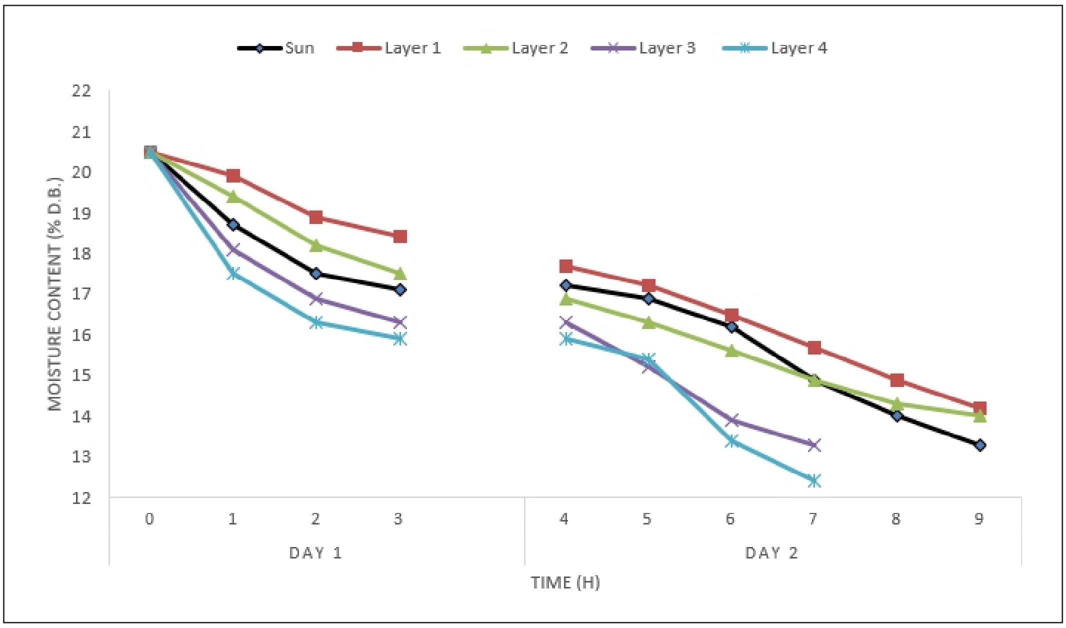

Figure 5: Variation of moisture content at different levels in the SBHD. versus the open-sun

highlights the potential for grains to get infested by moulds when dried using the open sun method which is often practiced by smallholder maize farmers in Ghana. No rewetting was observed in grains that were left on the drying shelves in the solar dryer overnight. Moreover, there was a rather reduction or stability in moisture content of grains left overnight in the dryer. This could be attributed to the lower humidity of the surrounding air mass in the dryer relative to that in the grains caused by the high temperature from the trapped heat recorded during the day.

Generally, moisture loss was achieved gradually during the drying process through the convective airflow. Moisture removal from the grains resulted from the absorbed heat by the grains from the surrounding air mass (Amer *et al*., 2010). In grain drying, heat gained by the product must be enough to vaporize the moisture it contains to its surrounding environment until the moisture content of the product is in equilibrium with the surrounding air (Bitog *et al*., 2009). Grains dried at L4 recorded the lowest moisture content due to the direct incident radiation on the grains causing an increase in grain temperature aside the drying air temperature.

Drying rate

Figure 6 shows the variations in drying rate measured during the effective drying hours within the two days of the drying experiment. Averagely, drying rate of 0.6 %/h, 0.7 %/h, 1.0 %/h, 1.2 %/h and 0.8 %/h were recorded for maize grains dried at layers 1, 2, 3, 4, and the open-sun, respectively. After the first hour of drying, maize placed at layer 4 recorded the fastest drying rate (3 %/h) followed by layer 3 (2.4 %/h), the sun drying (1.8 %/h), the layer 2 (1.1 %/h) and then layer 1 (0.6 %/h). The drying rate decreased gradually in all the layers in the drying chamber and the sun over the drying period. Layer 4 recorded the highest drying rate than all the other layers

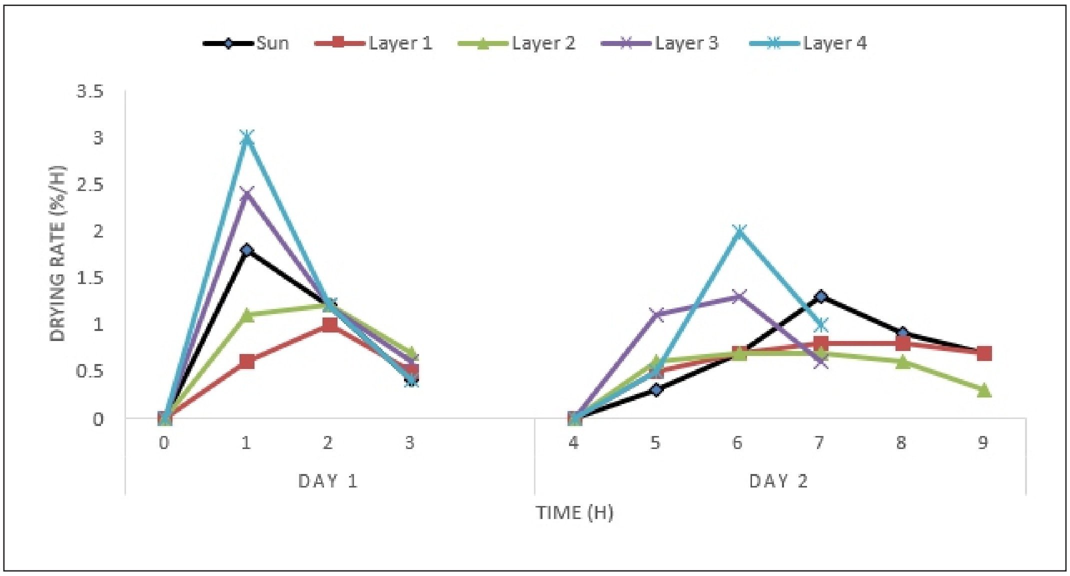

Figure 6: Variations in drying rate at the different levels against the open-sun drying process

during the drying period. The faster drying rate in layer 4 and 3 could be attributed to the closeness of the layers to direct solar incident radiation, which caused the air around these layers to gain high temperature with lower humidity leading to faster drying compared to grains dried at layers 2 and 1, and the open-sun. The rate of drying may depend not only on temperature but also on the relative humidity, initial moisture content of the product, air velocity, and the nature of the product (Dhanushkodi *et al.,* 2015; Zhao *et al*., 2019).

The faster drying rate recorded at layer 4 of the drying chamber was due to the high temperature and lower humidity, which is a major factor determining the rate at which moisture evaporates from the surface of grains (Chakraverty, 2000; Fu *et al*., 2015). The low drying rate recorded in the lower levels (L1 and L2) of the drying chamber was therefore as a result of the low temperature from the differential insolation caused by the shielding of the lower levels from direct irradiation moving from layer 4 to layer 1 and higher relative humidity recorded in layers 1 and 2 during the drying process. Grains dry naturally when the relative humidity of the air is below the equilibrium moisture content of the grains. Thus, the grains gain moisture when the relative humidity of the air is above the equilibrium level (Okano, 1998).

The drying rate accordingly decreased with a decrease in moisture content of the grains dried across the different layers as the drying progressed, as shown in Figure 6. The higher drying rates observed at the start of the drying process across the different levels was due to the high initial moisture content and it slowed towards the end of the drying process as the grains lost moisture. This is corroborated by Stiling *et al*. (2012) who reported that grains with high initial moisture content experience a rapid fall in moisture loss, but as the drying process continues and the grain loses moisture, the drying rate slows down

Thermal efficiency

The drying efficiency recorded for the drying of maize grains in the solar dryer was determined as 12.7% compared to 5.7% recorded for the open sun drying process. The dryer's overall low thermal efficiency could be attributed to the low rate of moisture removal at the lower levels (layers 1 and 2). The low rate of moisture removal at the lower levels of the dryer was due to the low temperature and the relatively high humidity recorded. This could affect the drying capacity which is one of the most important factors in the utilisation of grain dryers. Solar dryers by their design and principle of operation normally record low drying efficiency. According to Brenndorfer *et al*. (1987), for natural convection solar dryers the drying efficiency ranges from 10-15%. The drying efficiency (12.7%) is very close to the average drying efficiency of 13% reported by Barki *et al*. (2012) when they evaluated the performance of an efficient solar dryer for drying grated cassava. Schiavone (2011) also reported a drying efficiency of 10.8% in his study on drying mango in a natural convection solar dryer. However, Ayyappan and Mayilsamy (2010) reported a thermal efficiency of 20% for a solar tunnel dryer for drying copra. Compared to the drying efficiency of the open-sun method, the solar dryer provided the better alternative for drying the maize grains.

Proximate analysis

The nutritive value of maize is a very important quality factor since the grain is considered one of the main food and feed grains in Ghana. According to FAO (1992), the chemical composition and nutritive value of maize do not lose their susceptibility to change when the grain is harvested. However, the subsequent post-harvest activities such as processing or storage may cause the nutritional quality of maize to decrease significantly. Lasek *et al.* (2012) also reported that within the same corn grain cultivar it cannot be assumed that the proximal content will be similar. However, other factors, such as the harvesting date, the drying process, the storage condition, etc. may interfere with the proximal composition.

The results of the proximate composition of maize dried at different layers and different temperature conditions in the solar dryer is presented in Table 1. Maize grains sampled from the different layers of the dryer after the drying process showed variations in the percentage composition of the various nutritional components such as fat, protein, and carbohydrate content. In contrast, ash and fibre contents were similar in grains sampled across all the layers as shown in Table 1.

Analysis of the results show that there was a significant difference in carbohydrate content of maize grains dried at the upper layers compared to grains dried at the lower layers and the open sun. Grains dried at layer 4 recorded the highest carbohydrate content of 75.78%. This was due to L4 recording the highest average temperature (49.35˚C ± 3.64 ˚C) in the dryer which resulted in high dry matter content in the form of starch. A similar observation was made by Gumus and Ketebe (2013) when a higher carbohydrate content was reported at the highest temperature (130 ℃) when maize was dried at three different temperatures (110 ℃, 120 ℃, and 130 ℃).

Similarly, there variations were recorded in crude fat of dried grains sampled across the different layers in the dryer. Comparatively, it was observed that the crude fat content was higher for grains sampled at lower layers compared to the upper layers. Fats are insoluble in water but may undergo partial decomposition at higher temperatures. This explains why there was a significant difference in crude fat content between the open-sun-dried maize (2.78%) and maize dried in layer 4 (2.04%) with recorded average temperatures of 35.04 ± 3.3 ˚C and 49.35 ˚C ± 3.64 ˚C, respectively. The recorded crude fat content of maize grains dried are within the expected range of 2 % to 5 % for most maize varieties as reported by Badu-Apraku *et al.* (2006). The analysis of the results showed that varying temperature conditions at the different levels did not result in significant differences in the crude fibre content of dried maize grains sampled from

Table 1: Proximate composition of dried maize

Parameters	Layer 4	Layer 3	Layer 2	Layer 1	Sun drying
Carbohydrate (%)	75.78±2.3^{a}	75.74±1.7^{a}	74.24±3.1^{b}	74.14±0.9^{b}	74.07±1.7^{b}
Fat (%)	2.04±0.2^{b}	2.34±0.1^{ab}	2.05±0.3^{b}	2.58±0.2^{a}	2.78±0.1^{a}
Fibre (%)	2.01±0.1^{a}	2.08±0.2^{a}	2.38±0.1^{a}	2.16±0.3^{a}	2.09±0.2^{a}
Protein (%)	7.57±0.4^{b}	6.85±0.2^{c}	7.95±0.3^{a}	7.32±0.4^{b}	7.56±0.3^{b}
Ash (%)	1.30±0.1^{a}	1.19±0.0^{a}	1.20±0.3^{a}	1.40±0.2^{a}	1.18±0.1^{a}
Moisture (%)	11.30±0.6^{c}	11.80±0.4^{b}	12.18±0.5^{a}	12.40±0.3^{a}	12.32±0.4^{a}

Means with the same superscripts within columns are not significantly different (p<0.05) the different layers in the drying chamber. The crude fibre content ranged from 2.01% in layer 4 to 2.38% in layer 2. These results are within the range of crude fibre content for maize (0.6% to 2.9%) as reported by Badu-Apraku *et al.* (2006). There was no significant difference ($p<0.05$) in the ash content of grains sampled from the different layers as shown in Table 1. The ash content recorded ranged from 1.19 % to 1.40% for grains dried in the dryer and 1.18 % for grains dried using the open-sun drying method. The percentage ash content was within the range 1.4% to 3.3% for maize grains as reported by Enyisi *et al.* (2014). The reported ash content was relatively low and according to Enyisi *et al.,* (2014) this is usually preferred because it may enable long storage by minimising fungal contamination and also serve as an indicator for grain purity. Composition of crude protein for grains sampled at the different layers showed variations across the layers, though the results are within the maize crude protein range reported by Badu-Apraku *et al.* (2006). Maize grains dried in the upper layers recorded significantly lower moisture content than maize grains dried in the lower layers. The lower temperatures recorded at the lower layers resulted in the relative higher moisture content recorded at the lower levels but the values reported are within the accepted range of 12-13 % recommended for safe storage of maize grains. Though the results of the proximate analysis show variations in the nutritional composition (crude protein, carbohydrate, moisture and crude fat) of dried maize grains sampled from the dryer, it can be assumed that the drying temperature effects in the dryer were positive in maintaining the quality of the dried maize as the results reported fall within the acceptable range for proximate composition of most maize varieties, ash 1.2%-3%, moisture content 6.5%-12.5%, protein 5.3%-14%, crude 0.6%-2.9%, fat 2.2%-5% and carbohydrate 66-76% as corroborated by the findings of Badu-Apraku *et al.,* (2006); Boateng *et al.,* (2012); and Ikya *et al.,* (2013). The variations in the proximate composition of grains could be attributed to the temperature variations recorded at the different levels, which induced different heat levels. This is corroborated by Brooker *et al.* (1992) who reported that the feed efficiency and nutritive value of maize grains dried at 50 °C was affected and got worse when higher air temperature was used for the drying. Coradi *et al*. (2020) also reported that high temperatures cause alterations in the chemical constituents of grains, such as lipids, carbohydrates, and proteins.

Effect of drying temperature on germination of dried grains

The germination test indicated no significant difference in germination between maize grains dried in the solar dryer and grains dried in the sun. However, grains dried in layer 3 recorded the highest germination (96.10%), followed by the sun drying (95.85%), layer 4 (94.67%), layer 2 (94.33%), and layer 1 (93.0%), as indicated in Table 2. Excessively high temperature may kill the germ and result in reduced germination ability of seeds. However, the temperatures within the drying chamber did not influence the viability of the maize grains dried in the solar dryer. Therefore, it can be deduced that the drying conditions in the dryer did not affect the germination potential of the dried maize. Owolade *et al*. (2005), who studied the effect of drying method in their work, reported lower germination percentage (38%-89%) using an artificially Thermax batch-type seed drier at 45 ℃ compared to maize dried under the sun (79%-98%) and under a shade (84%-98%).

Seed moisture content and drying temperature have been reported to be the most important factors influencing seed viability. In their study, Azadi and Younesi (2013)

Table 2: Germination test for maize dried using the S.B.H.D

Drying chamber layer	Germination (%)
Layer 1	93.00±6.10b
Layer 2	94.33±5.20ab
Layer 3	96.10±6.00a
Layer 4	94.67±7.50ab
Sun-Drying (Control)	95.85±4.10a
LSD (5%)	2.180

**Values followed by the same letters are not significantly different at ($p < 0.05$)*

reported that seed moisture and warm temperature exposure are the principal determinants for seed viability. Drying under a high temperature may destroy seed viability.

Conclusion

In this study, the effect of drying temperature on the proximate composition and viability of a local white maize variety dried in a solar biomass hybrid dryer has been successfully investigated. About 3.9 tons of white maize from an initial moisture content of 17% (wb) to a final moisture content of 11.9 % (wb) was achieved within an 8-hour drying period at a drying rate of 0.64 %/h at an overall drying efficiency of 12.7% which was better than the 5.7% recorded for the open sun drying process. At an overall mean temperature of 43.63 ± 8.6 ˚C recorded across all the levels in the dryer, the proximate nutritional composition and the viability of the dried maize grains were not adversely affected by the temperature conditions in the dryer. Overall, the solar hybrid dryer can be effective in drying maize grains with many benefits including shorter drying time, protected drying environment and reduced post-harvest losses at the smallholder level.

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