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Fabrication and performance evaluation of a wooden cabinet dryer for value addition of fruits for micro-, small and medium-scale enterprises (MSMEs)

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ABSTRACT
Dried fruits contribute immensely to breakfast menus and snacks for most people. A wooden cabinet dryer was fabricated and used to dry mango, pineapple and papaya to assist processors and micro-, small and medium-scale enterprises (MSMEs) gain economic advantage of dried fruits and reduce the high postharvest losses of fruits. The performance assessment of a wooden cabinet dryer was conducted to determine its effect on the weight of fruits (4.8–12.0 kg), yield (12.4–14.4%) and drying temperature (65°C) over a period of six to eight hours. Additionally, the efficiency (13.49–14.38%) of the wooden cabinet dryer was based on the full capacity load of the three fruits (40.0–50.0 kg), initial moisture content (82.60–84.20% w/b), final moisture (13.50–15.80% w/b) and drying time (10–12 h). The proximate composition of the three fruits was observed for protein (2.8–3.9 g/100g), ash (1.9–3.4 g/100g), fat (0.2–4.3 g/100g), carbohydrate (90.9–92.4 g/100g) and energy (387.5–414.0 Kcal/100g). The drying efficiency of the wooden cabinet dryer was highest for drying pineapple among the three tropical fruits and has the potential of reducing the operational cost associated with processing dried fruits.

Keywords: Wooden cabinet dryer; value addition; mango; pineapple; papaya
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Introduction

Mango, pineapple and papaya are some of the world's largely produced and traded fruit crops in both fresh and processed forms with a high concentration of vitamins (RHODA, 2008). In the dried form, the concentrations of vitamins are higher and usually are included in breakfast cereals and confectionery. These fruits are of particular interest due to their widespread production, dual-seasonal availability, nutritional content and inclusiveness in other food preparations. These fruits are highly nutritious and provide a rich source of β-carotene, ascorbic acid, pectin, tannins and minerals such as calcium, iron and phosphorus (RHODA, 2008; Nakasome & Paull, 1998; Subhadrabandhu & Otham, 1995).

Postharvest losses associated with these fruits has led to the development of many processing, preservation, value addition and storage technologies to reduce these losses. Due to their high moisture contents and chemical composition, fruits generally stay in their natural state for only a few days, after which they begin to deteriorate. In order to preserve or add more value to raw fruits, technologies such as canning, juicing, drying has been previously used (Fellows, 2000). In Sub-Saharan Africa, preservation of fruits by drying provides livelihood opportunities for people in rural, peri-urban and urban areas, including producers of raw materials, commodity traders, food processors, vendors and exporters. In Ghana, during seasons of fruits glut, losses of 30 to 50% has been estimated for fruits due to spoilage, which reduces the economic returns on the harvest (WACOMP, 2019).

One of the methods available to address this situation is by drying the fruits. According to Mohsen-Ranjbaran *et al.* (2014) and Tettey (2008), apart from increasing shelf-life and making products available all year round, drying also adds more value to agricultural products, which is important in the food industries. Drying reduces moisture content and inhibits water activity, microbial and chemical degradation mechanisms and minimize costs of transporting food (Ghaffari & Mehdipour, 2015; Okos *et al.,* 1992). Dried fruits are convenient and retain most of the nutrients of fresh fruits and are therefore considered healthy. Interestingly, dried fruit products are increasingly becoming popular and form a large proportion of the export products from many tropical countries.

The wooden cabinet dryer is important to the fruits value-chain for sustainable increases in income for actors in the sector. Essentially, drying which is a form of removal of water from a food material using different forms of energy involves simultaneous heat and mass transfer which subsequently results in evaporation of moisture from the food material (Tsotsas & Mujumdar, 2012; Mujumdar, 2006; Chemkhi *et al.*, 2005). Several drying methods have been applied to food systems based on economic returns, environmental concerns and resultant quality (Demir & Sacilik, 2010; Latapi & Barrett, 2006; Goula & Adamopoulos, 2003: 2005; Babalyk & Pazyr, 1997; Okos *et al.,* 1992). Subsequently, drying of pineapples, papaya and mangoes utilizing solar drying, conventional drying and microwave drying have been reported (Tsotsas & Mujumdar, 2012). Even though throughputs are high and final products of these drying methods were of good quality, these methods required high capital investments and high energy consumption, and their operational costs were relatively expensive. Additionally, the cost factor of fruit drying techniques and energy sources are major challenges in many developing countries. In areas where electrical energy is unreliable or expensive, sun drying is the main drying technology employed. However, this method of drying fruits resulted in poor quality products (Tunde-Akintunde & Oke, 2011). This challenge stimulated the development of a wooden cabinet dryer suitable for use in rural and urban areas to dry fruits.

The principle of operation of the wooden cabinet dryer was by natural convection in which Liquefied Petroleum Gas (LPG) supplies the heat through the drying chamber to effect drying. Moisture, humid air, and flue gases exit the drying chamber through a chimney. The wooden cabinet dryer has the potential of reducing the operational cost associated with processing dried fruits. Additionally, it is an important initiative, which was anticipated for enhanced fruit processing, especially in rural communities where the bulk of raw fruits are produced. However, in order to promote the wooden cabinet dryer technology for adoption, there was a need to test its performance in order to provide a clearer understanding of its drying mechanism, moisture distribution and moisture removal from fruit products. Therefore, the aim of the study was to fabricate a wooden cabinet dryer powered by liquefied petroleum gas and evaluate its performance for fruits drying for micro-, small and medium-scale enterprises (MSMEs) for adoption and commercial production of dried fruits for both local and foreign markets.

Materials and Methods

The wooden cabinet dryer

The main features of the wooden cabinet dryer include a drying chamber fabricated using a three-layered plywood, a brick mount and a cylindrical metallic chimney. The drying chamber was lined with a 1.0 mm thick aluminum sheet to enhance heat distribution. In order to prevent the flame from direct contact with products, a 3.0 mm metal sheet separates the bottom tray from the gas burner. The drying chamber consist of two chambers and contains 12 rows of drying racks. The wooden cabinet dryers were made of local plywood and burnt bricks, which were sourced locally in peri-urban and urban areas (Fig. 1). Total expenditure for the fabrication of the wooden cabinet dryer was 3,270.00 USD and could be fabricated easily (Table 1). Two wooden cabinet dryers were fabricated on the premises of two micro-, small and medium-scale enterprises (MSMEs) in Madina and Taifa townships in Accra for the study (Fig. 2).

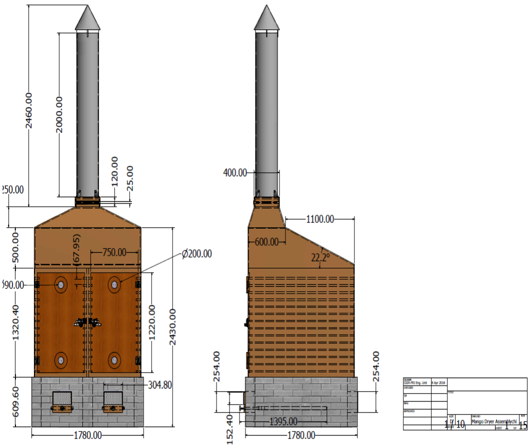

Fig. 1: Schematic presentation of the wooden cabinet dryer (A: Front view; B: Side view)

A. Close B. Open

Fig. 2: Wooden cabinet dryer (A: Close; B: Open)

TABLE 1
Cost calculation for developed wooden cabinet dryer per unit

Sl. no	Hard ware item	Quantity	Unit price (USD)
1	1 x 12 x 16 Redwood	6 pcs	20
2	2 x 12 x 16 Redwood	1	40
3	¾ Plywood	12 pcs	25
4	Burnt bricks	500 pcs	0.50
5	Steel sheets 2mm	1	60
6	Aluminum foil	4 sheets	30
7	Wooden trays	20	10
8	Temperature probes	2	120
9	Humidity probes	2	120
10	Bartoline wood preservative	6 gallons	18
11	Wood glue (fevicol)	6 gallons	12
12	Galvanized mesh	8 rolls	95
13	Door locks and hinges	3 pairs	18
14 15 16	Oil paint Thinner Abrasive, brushes, nails, rivets, hinges, fibre glass, plastic mesh	4 gallons 4 gallons	12 12
17	Service charge	-	-
	Total Expenditure		*3270*

Fabrication considerations

The wooden dryer has an advantage over other dryers as it is made of local plywood and brunt bricks which can be sourced locally in a rural, peri-urban and urban areas. The design considerations for the fabrication of the wooden dryer (Fig. 1) were as shown in Table 2.

TABLE 2
Design considerations for fabrication of the wooden cabinet dryer

Parameters	Values		
External Dimension	Length (1.78 m)	Breath (1.78 m)	Height (2.65 m)
Drying	65 – 70 ºC		
Duration	5 – 8 h		
Moisture content	14 – 18 % w/b		
Shelf-life of products	6 – 12 month		
Recovery	20 %		
Recommended	50 kg fresh fruits		
Dried	10 kg		
Liquefied petroleum gas (energy)	27.19 kg		
Solar powered extraction fan	20 W		

Performance evaluation of the wooden cabinet dryer

Heat distribution within the drying chamber was monitored by positioning probes (Almemo Datalogger, ALMEMO® 2890-9, GDU-12S DATALOGGER UNIT with NiCr-Ni thermowire T 190-0 temperature sensors connected, Germany) within the chamber. Heat generated within the brick mount, which houses the Liquefied Petroleum Gas (LPG) burner was also recorded using the data logger. Equations 1 – 3 were employed to determine the efficiency of the dryer;

Heat Supplied, Q = Mass of fruits x Latent heat of evaporation of water

$= M_f \times \Delta H_w$ ……..Eq. 1

Dryer Efficiency =

$$\frac{\text{Energy/heat utilized in removing moisture from fruit}}{\text{Total energy/heat available in the drying system}} \quad \text{Eq. 2}$$

$$\text{Dryer Efficiency} = \frac{M \times \Delta H_w}{F_c \times H_{lpg} \times t} \quad \text{Eq. 3}$$

M = Mass of moisture removed (kg)
ΔH_w = Latent heat of vaporization of water = 2743 kJ/kg
Fc = Fuel Consumed (kg/h)
H_{lpg} = Calorific value of lpg (kJ/kg)
t = drying time (h)

In determining the efficiency of the wooden cabinet dryer, drying was set as a ratio of water to moisture removed from the fruits by evaporation. Hence, the latent heat of evaporation supplied to the fruits under consideration was to turn every kilogram of moisture/water into vapour. The slices of fruits were spread evenly and thinly of one layer of thickness on the drying racks of the wooden cabinet dryer, which aided the evaporation of moisture from the fruits.

Fresh fruits

Freshly harvested and firm-ripe mango (var. Kent), pineapple (var. MD-2) and papaya (var. Solo Dwarf) were obtained from a certified grower in the Eastern Region. The fruits were transported to the premises of the two MSMEs in Madina and Taifa townships in Accra and left overnight to cool to room temperature before drying.

Fruit processing

The mangoes, pineapples and papayas were washed in potable water and sanitized in chlorine solution for five minutes before processing. Sanitized fruits were peeled using a sharp stainless steel knife. The mangoes were de-stoned before slicing, whereas the core of pineapple was removed using a stainless steel coring device. In the case of papaya, the seeds were scooped out of the fruit using a spatula. The prepared fruits were sliced into chunks measuring approximately 3 cm by 5 cm. The chunks were spread in a thin layer on drying racks before loading into the pre-heated wooden cabinet dryer at low capacity and high capacity loaded levels.

Proximate composition of dried fruits

Moisture, protein, fat, ash contents of the dried fruits were evaluated using approved methods according to AOAC (2000), determined on a dry weight basis (dwb). Carbohydrate was estimated by difference while energy was calculated using the Atwater Factor (AOAC, 2000).

Statistical analysis

The data obtained from the studies compared using Analysis of Variance (SPSS 17.0.1), assuming a probability level of $p < 0.05$. Significantly different means were separated by Duncan's Multiple Range Test. The results were reported as mean ± standard error (m ± SE).

Results and Discussion

Drying of fruits

The wooden cabinet dryer effected drying by natural convection and as the Liquefied Petroleum Gas (LPG) supplies heat, moisture, humid air, and flue gases exited from the drying chamber through a chimney. The wooden cabinet dryer evolved on the weight of pineapple, mango and papaya fruits used (4.8–12 kg), yield (12.4–13.0%), drying temperature (65°C) and drying time (6–8 h) as presented in Table 3. A sampling of the wooden cabinet dryer at the low capacity level when the wooden cabinet dryer was not full shows percentage yield was highest for mango (14.4%) and lowest for papaya (12.4%) (Table 3). Appropriate drying method often enabled dried products to be stored for several months without the risk of spoilage when properly packaged. In food industries, the majority of commercial flow dryers were designed on thin-layer drying principles.

According to Chakraverty & Singh (1988), thin-layer drying simulation was the best criterion to model food drying process. Subsequently, in studies by Xia & Sun (2002), the authors' utilized simulation models of drying process to improve on existing drying systems and predicting airflow over the dried product. Drying of agricultural products was a highly energy-intensive process, accounting for 10–20% of total industrial energy use in most developed countries (Hebbar & Rastogi, 2001; Wang & Sheng, 2006; Sharma *et al.,* 2005; Volonchuck & Shornikova, 1998). Interestingly, conventional air-drying was the commonly used drying method in the food industry.

In developed economies, convective dryers such as drum dryers, belt dryers and fluidized bed dryers, which transfer heat to food product by hot gases are often found in commercial drying plants for processing numerous industrial agricultural products such as mango, banana, pineapple, coconut, spices and herbs (Kudra & Mujumdar, 2002). However, these facilities are lacking in most developing countries for drying agricultural products due to their high cost. Subsequently, low-cost convection dryers such as the wooden cabinet dryer have great potential in small farming communities even without electricity availability for drying agricultural products (Kudra & Mujumdar, 2002; Fellows, 2000; Zanoni *et al.,* 1999).

In convection drying latent heat of evaporation is required to remove water or other solvents within the fruits but it is a challenging task facing real thermodynamic barriers (Kemp, 2012; Krokida & Bisharat, 2004). Further, the evaporation load will be less than 50 % of the actual process of energy consumption in terms of fuel supplied. The numerous causes for this difference included additional energy required to break bonds and release bound moisture, heat losses in the exhaust for convective dryers or through the dryer body, heating solids and vapour to their discharge temperature, steam generation and distribution losses and condensate losses as well as losses in non-routine operation of startup, shutdown or low load periods as reported earlier by Kemp (2012).

TABLE 3
Drying parameters of fruits from the wooden cabinet dryer

Fruit	Quantity dried (kg)	Yield (%)	Tempera-ture (°C)	Time (h)
Pineapple	12.0	13.0	65	8
Mango	4.8	14.4	65	8
Papaya	8.4	12.4	65	6

Evaluation of wooden cabinet dryer efficiency

At a full dryer load of sliced pineapple, mango and papaya (50 kg, 48 kg, 40 kg, respectively), gas flow rate (1.5 kg/h) and drying time (10–12 h), the efficiency of the wooden cabinet dryer for pineapple, mango and papaya were 14.38%, 13.59% and 13.49%, respectively. Pineapple fruit that was most efficient (14.38%) to dry in the wooden cabinet dryer had initial moisture content of 84.20% and final moisture content of 15.80% achieved at a drying time of 12 h, ambient temperature of 29.5%, ambient relative humidity of 76.2%, Liquefied Petroleum Gas consumption level of 1.5 kg/h and calorific value of 46,100 kJ/kg (Table 4). The initial moisture content of the three fruits ranged from 82.60–83.50% and was reduced to a final moisture content range of 13.50–15.80% at a drying period of 10–12 h, using a calorific value of LPG of 46,100 kJ/kg (Table 4).

The drying conditions and efficiency of the three fruits are presented (Table 4). These observations are similar to studies by Ruis-Celmaa *et al.* (2009) and Zanoni *et al.* (1999), where the drying rates of tomato were found to increase with increasing temperature, thus reducing the drying time. In improving their technology, the operations were optimized in terms of energy consumption to reduce environmental impact, which subsequently could be applied in any studies on food drying (Kudra, 1998; Kemp & Gardiner, 2001; Kudra & Mujumdar, 2002).

TABLE 4
Drying conditions and efficiency of the wooden cabinet dryer for drying mango, pineapple and papaya

Factor	Fruits		
	Mango	**Pineapple**	**Papaya**
Initial weight, kg	48.0	50.0	40.0
Initial moisture content, % (w/b)	83.50	84.20	82.60
Final weight, kg	6.9	6.5	6.0
Final moisture content, % (w/b)	14.40	15.80	13.50
Ambient temperature, ^{o}C	29.5	29.5	29.8
Ambient relative humidity, %	76.2	76.2	75.8
Average Drying temperature, ^{o}C	65.0	65.0	65.0
Drying time, h	12	12	10
LPG consumption, kg/h	1.5	1.5	1.5
Calorific value of LPG, kJ/kg	46100	46100	46100
Efficiency %	13.59	14.38	13.49

Proximate composition of dried fruits

The proximate composition of the three fruits studied were in the ranges of protein (2.8–3.9 g/100g), ash (1.9–3.4 g/100g), fat (0.2–4.3 g/100g), carbohydrate (90.9–92.4 g/100g) and energy (387.5–414.0 Kcal/100g) (Table 5). Energy (414.0 Kcal/100g) and fat (4.3 g/100g) content of the dried pineapple fruit was highest, whereas carbohydrate (92.4 g/100g), protein (3.9 g/100g) and ash (3.4 g/100g) were highest in mango and papaya. Generally, results from the chemical analysis showed a good concentration of nutrients after drying the fruits (Kemp & Gardiner, 2001; Kemp, 2012). This observation suggests that processing the fruits in the wooden cabinet dryer was not detrimental to the macronutrients of protein, carbohydrates, fat and ash as observed for other drying technologies (Kemp & Gardiner, 2001; Kemp, 2012).

TABLE 5

Proximate composition of the wooden cabinet dried fruits

Fruit	Protein (g/100 g)	Ash (g/100 g)	Fat (g/100 g)	Carbohydrate (g/100 g)	Energy (kcal/100 g)
Mango	3.9±0.01[b]	3.4±0.03[b]	0.2±0.01[a]	92.4±0.64[b]	387.5±2.17[a]
Pineapple	2.8±0.01[a]	1.9±0.01[a]	4.3±0.01[b]	90.9±0.21[a]	414.0±2.45[b]
Papaya	3.9±0.02[b]	3.4±0.01[b]	0.7±0.01[a]	92.0±0.35[b]	389.8±2.30[a]

Means bearing different superscripts are significantly different ($p < 0.05$)

Feasibility for commercialization of the wooden cabinet dryer

The wooden cabinet dryer is an appropriate drying technology that is able to reduce the post-harvest losses of fruits and provides better alternative drying technology for fruits that are not detrimental to the macronutrients of the fruits. It was built with local wooden materials that were sourced from the community at reduced cost. It was energy efficient compared to electrical mechanical dryers used in previous studies reported by Ruis-Celmaa *et al.* (2009), Kudra & Mujumdar (2002), Kemp & Gardiner (2001), Zanoni *et al.* (1999) and Kudra (1998). Additionally, it provided value-added products of fruits with extended products shelf-life and has the potential to created new markets for dried fruits and increased incomes for the actors in the fruits sector. The wooden cabinet dryer is ideal for up-scaling and worth of investment for primary beneficiaries such as producers, micro-, small and medium-scale enterprises, processors of fruits by way of value addition and improved incomes. The primary beneficiaries will be producers, micro-, small and medium-scale processors of fruits by way of reduction of post-harvest losses, value-added fruit products and improved incomes. The fabrication cost of the wooden dryer and its accessories including service charges was 3,270.00 USD, far lower compared to the electrical mechanical dryer at a cost of 8,571.00 USD.

The key advantage of the wooden cabinet dryer powered by liquefied petroleum gas over the electrical mechanical dryer, for adaption by farmers, fruit vendors, and processors and micro-, small and medium-scale enterprises (MSMEs) included its low cost of fabrication materials, locally available wooden materials, low operating cost, easy to be set-up both indoor and outdoor. Additionally, total breakdown of the wooden cabinet dryer was rare due to absent of operating motors, it was user-friendly and can be easily adapted in rural and remote areas where there is no electricity supply as often the situation in sub-Sahara Africa.

Conclusion and Recommendation

The efficiency of the wooden cabinet dryer was averagely 13.82%. Proximate analysis of mango, pineapple and papaya used in the assessment showed a good concentration of macronutrients after drying. Moisture content of the three fruits was also reduced to reasonable levels (<10% w/b), which would enhance keeping properties of the dried fruits. These findings suggested that the wooden cabinet dryer was effective for processing fruits into dried fruits in order to add more value and extend their shelf-life. The wooden cabinet dryer has the potential of reducing the operational cost associated with processing dried fruits and appropriate for adaption by farmers, fruit vendors, and processors and micro-, small and medium-scale enterprises (MSMEs) in rural, peri-urban and urban communities.

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