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RESEARCH ARTICLE

Analysis of Designs and Performance of Existing Greenhouse Solar Dryers in Kenya

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ABSTRACT

Solar drying offers a convenient, cheaper and environmentally friendly way to dry food. In Kenya, solar dryers have been developed and introduced by different actors. However, their technical and economic performance is unknown. This study assessed the technical performance of existing greenhouse dryers in Kenya, by focusing on their design, use and performance. The data was further analysed to identify the correlation between identified parameters. The study was conducted in parts of Eastern and Central regions in Kenya. A total of 18 dryers were sampled from 50 identified dryers. The average size of greenhouse dryers was 8.12 m long, 3.95 m wide and 2.37 m high. The study also analysed designers, selection of construction, internal configuration, and cost of dryers. Generally, a good consideration was noted in these aspects. 24% of dryers experienced losses over 10%. Major causes of losses were cold weather, spillage and poor ventilation. Most dryers achieved good quality products, with 29% getting less than 50% of grade 1. On average, the drying rate was 13, 56, 48 and 64 hours for mangoes, bananas, cassava and butternut, respectively. These drying rates relate well with other studies. Overall, correlation analysis showed consistence in dryer design, use and performance.

Keywords: Analysis, design, greenhouse dryers, Kenya, performance

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INTRODUCTION

Drying of perishables like fruits and vegetables is a common post-harvest practice in Kenya. In 2009, the country exported about 4000 metric tonnes of dried vegetables, with the highest export being experienced in 2007 when 40,000 tonnes of vegetables were exported (MoA, 2010). The export of dried vegetables has been on the increase (HCDA, 2010; KHCP, 2013). In Kenya, drying is also carried out on roots and tubers, coconut, amongst other commodities. Drying of bananas for flour making is also picking up. Drying has an enormous potential to preserve perishable crops including fruits and vegetables and to reduce losses that was estimated at about 11% and 7% for fruits and vegetables, respectively (GoK, 2007). Deterioration in the weight, volume considered under the quantitative and losses of nutrient value, color, texture defined as the qualitative losses. Drying with artificial drying with fossil fuels or electricity is expensive and has been estimated through calculations at US$ 0.02-0.03/kg of raw produce to be dried or about US$ 0.20-0.30/kg for dried fruits or vegetables. Recently, attempts have been made to develop solar equipment to improve upon the sun-drying techniques, which lead to better use of available solar radiation, reduction in drying time and cleaner and better quality product, free from dust, dirt and insect infestation. This equipment is called solar-drier (Kuchi et al., 2014).

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Solar drying is fast becoming an important alternative for farmers in developing countries, such as Kenya, as the dryers can generate relatively high air temperatures and low relative humidity, both of which are conducive to improved drying rates (FAO, 1994; Whitfield, 2000). The utilization of solar energy for drying applications provides effective, hygienic and economical alternative to the traditional sun drying methods typical to post-harvest processing in Kenya. There has been a number initiative to develop and promote solar dyers in the country. These numerous types of solar dryers have yielded varying degrees of technical and economic performance. However, the dryers have never been reviewed in a bid to analysis and assess their technical and economic performance; a comprehensive review of the various designs, details of construction, usage and operational principles and the economic performance of the wide variety of the designs of these solar-energy drying systems. This study sought to assess the existing designs and technical performance of greenhouse solar dryers in Kenya.

MATERIALS AND METHODS

The study involved assessing the design of existing dryers by looking at the configuration including the mode of airflow, shape, the dimensions (length, width and height), the openings and their sizes, the layers and size of drying area, number of beds or trays, the dimensions; expertise used in design and fabrication; construction including the materials used and cost; and facilities to control or improve dryers' performance. The study was conducted from 26th April to 18th May, 2016. It was conducted in parts of Eastern and Central region in Kenya and focused on enterprises engaged in processing of fruits and vegetables; a few enterprises engaged in drying of roots and herbal products were also analysed. A total of 18 enterprises were surveyed (Fig. 1). The sample was from 50 earlier identified contacts and enterprises using solar dryers. The selection of the enterprises was based on geographical variation, variation in designs, type of crop being dried and willingness of the enterprise to provide crucial information.

Figure 1. Location of surveyed dryers in Kenya.

Preliminary secondary data was gathered from the literature, and the information helped to identify the organisations engaged in promotion of solar dryers so as to get contacts of enterprises involved in solar drying and to provide preliminary background information on solar dryers. Primary data was acquired using developed questionnaires that targeted fruits and vegetables. The information gathering also included direct observation and measurement, and key informants interview; that is, staff of Agricultural Technology Development Centres (ATDCs) and agencies involved in promotion and financing of solar installation.

The data gathered was analysed using SPSS and presented in a descriptive form; using charts and tables. Mathematical calculations were used to determine and assess the technical and economic characteristics of the dryers. The collected data was further analysed to identify the correlation between identified parameters; size of openings, surface area, height, capacity, layers, level of losses and quality of produce.

RESULTS AND DISCUSSION

Dryer types

All the dryers that were surveyed were of the greenhouse type. Of these dryers, 65% were gable roof type while 23% were parabolic with 12% being undefined (Fig. 3). The gable roof was said to be simple in construction as many users were familiar with the construction of the greenhouse used for growing horticultural crops, and which in most cases has almost similar shape. Most (89%) of the dryers had passive (natural convection) type of airflow, with 11 having air forced convection system. None of the dryer had an alternative energy backup system.

Figure 2. Types of solar dryers (left: gable roof dryer; right: parabolic or semi-circular shape).

Dryer designs

The dryer sizes were varied. The dryer length was on average 8.12 m, with the width being 3.95 m. The average height of the dryer was 2.37 m. These dimensions were mostly likely based on ergonomics, intended capacity and usage of the dryer. The dimensions are consistent with other studies, for example Akinjiola and Uthamalingam (2012) identified a width-to-length ratio of 1:2 of floor area as ideal for passive greenhouse dryers for optimum heat gain. According to the study, narrower greenhouses will experience more heat loss than those that are wide because of their smaller ratio of perimeter to floor area, while wider structures also tend to be taller and provide improved ventilation and interior air circulation. Other studies have come up with relative similar sized dryers. For instance, Janjai (2012) developed a higher capacity greenhouse dryer of 8.0 m in width, 20.0 m in length and 3.5 m in height. Almuhanna (2012) greenhouse design had gross dimensions 2 m long, 1 m wide and 1.21 m high at the eaves

The dryer outlets were less than the inlets; with the averages being 2.00 m^2 and 3.43 m^2, respectively (Table 1). The outlets and inlets are key design parameters, but there seemed not to be an identifiable consideration in the sizing of the outlets or the inlets. 16.7% of the dryers had no inlets (0 m^2 inlets) and this would definitely limit air movement and affect dryer performance. However, in terms of relative sizes of inlet and outlets, other studies also showed a bigger inlet than outlets. Barnwal and Tiwari (2008) developed a greenhouse dryer that had an inlet of 2.55 m^2 and outlet of 0.605 m^2. The outlet for forced mode of the same dryer was 0.005 m^2.

Table 1. Average dimensions of the dryers.

	Length (m)	Width (m)	Height (m)	Inlet (m^2)	Outlet (m^2)	Surface Area (m^2)
Average	8.12	3.95	2.37	3.43	2.00	86.70
Range	3.1-21.7	1.9-8.15	1.8-3.35	0-13.5	0.00785-9.225	14.60-240.01

The main designers of dryers were the government staff (47%) with 87.5% of these being from the ATDCs in the region; Ruiru and Siakago, and 12.5% being from the Kenya Industrial Research and Development Institute (KIRDI). The two institutions have qualified engineers for such tasks. Other designers were hired or contracted designers (12%), owners (18%) and others such as donors and other supporting institutions (23%). The dryers were mainly constructed by local artisans (56%). Others involved in construction were the government departments (5%), owners (17%) and other players including NGOs (22%). 11% of dryers had one layer, 39% had two layers, 11%, had three layers, and 33% had four layers of trays or beds. 6% of the dryers had no trays installed. Most of the dryers with one or two layers had beds instead of trays. Most dryers had 1 to 6 trays or beds; and mainly beds, while 28, 11 and 6% had 16 to 36, 48 to 72, and 200 trays, respectively. The size of trays and beds was on average about 1 m in width; while the lengths of the trays were also on average about 1 m. The length of the beds depended on lengths of the dryers; with most beds leaving about 0.5 m on the two ends of the dryer.

The dryer's frames were mainly wooden (67% of the dryers), with the rest having metallic (galvanised or aluminium coated) frames. For the floor, 29% had concrete floor that had a black colour, while 24% had concrete with no painting. 18% of the dryers had wooden floor, while 29% had earth floor. The mesh of trays was mainly plastic (83% of the dryers), while 11% and 6% had galvanised and aluminium or stainless steel respectively. The side walls were mainly made from wholly polythene glazing (89%), with 5% and 6% having either the polythene glazing and black polythene or half polythene glazing and half galvanised sheet respectively. The colour of polythene glazing was mainly clear (56%), while 33% had yellow coloured polythene, 5% had both clear and yellow coloured polythene and for 6% of the dryers this was not defined. Therefore, majority had quality enhancing materials, but earth floors and wooden frames could compromise products quality. Most of the dryers did not have facilities to control or improve drying. Only 5.6, 5.6, and 5.6% of the dryers had chimney, collector and fan respectively. 16.7% had other facilities like turbo ventilators and thermometers.

Cost of dryer

The cost of putting up the dryers varied (Table 2), with 33.3% being in the range of US$ 250-500, and 44.5% being in the range of US$ 1,500 to 4,000. The cost of dryer depended on the size, materials used and the additional facilities installed, with those with concrete floors and metallic frames being more expensive. The range of costs gives an alternative choice for the different categories of entrepreneurs.

Table 2: Cost of putting up the dryers.

Range (US$)	Percentage of dryers
100 to 150	5.6
250 to 300	16.7
450 to 500	16.7
800 to 1000	11.1
1500 to 2000	27.8
3000 to 4000	16.7
4500 to 5000	5.6
Total	**100**

Technical performance of the dryers

Losses during drying

The level of losses during drying varied; with 35% having losses below 1% and 23% had losses between 1 and 5%. Additionally, 18%, 12% and 12% had losses of between 5 and 10%, between 10 and 30% and over 30%, respectively. Major contributors to losses were; delayed or cold weather, poor ventilation and others causes like spillage, where 53.4, 31.3 and 85.7% of those reporting rated these causes as important to very important. On the same rating for those who were reporting, rainfall or leakage, dryer inefficiency and market challenges were cited by 13.3, 6.3, and 12.5%, respectively as contributors to losses (Table 3).

Table 3. Source of losses during drying.

	Rating and % of enterprises reporting				
Source	**Not important**	**Little importance**	**fairly important**	**Important**	**Very important**
Rainfall/leakage	66.7%	20.0%	0.0%	0.0%	13.3%
Cold weather	26.7%	0.0%	20.0%	26.7%	26.7%
Poor ventilation	50.0%	6.3%	12.5%	0.0%	31.3%
Delayed selling/lack of market	68.8%	12.5%	6.3%	0.0%	12.5%
Dryer inefficiency	43.8%	31.3%	18.8%	6.3%	0.0%
Others (e.g. spillage)	0.0%	14.3%	0.0%	28.6%	57.1%

Drying rates of the dryers and quality of dried products

Quality was evaluated by assessing the realisation of grade 1 (best grade) from drying. Figure 2 indicates that about 70% of dryers achieved over 80% of grade 1. Only 29% achieved grade 1 of less than 50%. This relates with above level of losses; where only about 24% of dryers experienced losses of more than 10% during drying.

The drying rate varied per crops and it was also different for specific crops as indicated in table 4. As from table 4, mangoes on average dry faster than other produce; with an average of 13 hours where most drying occurred within 10 hours and below. This is followed by cassava that takes an average of 48 hours (2 days) and with most drying occurring at 48 hours and below, and bananas that take an average of 56 hours and with most drying occurring at 48 hours and below. Butternut has an average drying time of 64 hours, and with most drying occurring at 72 hours and below. The variations within same crops could relate to varied dryers efficiencies and the location of dryers. The best drying rates can be used to compare or benchmark the performance of other developed dryers.

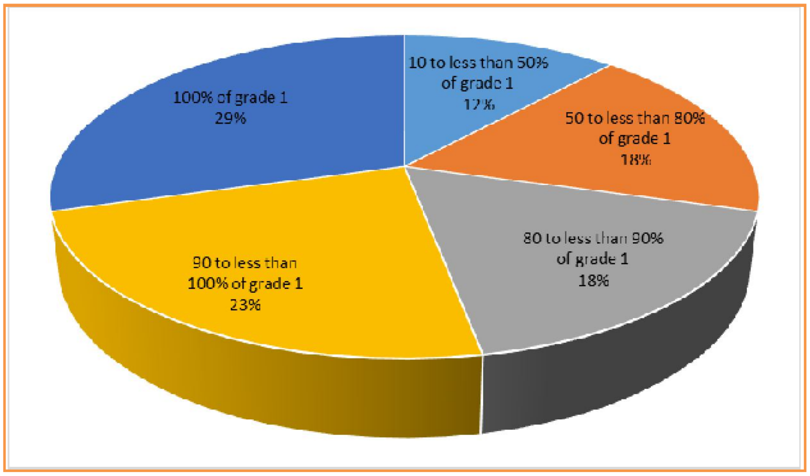

Figure 3. Percentage of dryers achieving the various proportion ranges of grade 1.

Table 4. Drying time (hours) for various produce

Measure	Mangoes	Bananas	Cassava	Butternut
Average	13	56	48	64
Range	7 to 24	24 to 216	24 to 72	48 to 72
Most occurrence	10 and below	48 and below	48 and below	72 and below

The drying rates are consistent with other studies. Sahu et al. (2016) in his review of greenhouse solar dryer indicate relative same ranges of values for drying through various dryers. In more specific analysis, Janjai *et al.* (2009) found out that for banana the drying time was 4 days (96 hours) in the active mode greenhouse drying, while in sun drying it took 5 to 6 days under similar conditions. A related study by Janjai et al. (2011) gave a drying rate 5 days (120 hours) for drying banana in an active mode greenhouse dryer. Mercer (2012) predicted the drying rate of mangoes and found out that it would take about 2 days under forced convection, 2.5 days under natural convection and 4 days under sun drying. Aliyu and Jibril (2009) found out that the drying rate for cassava chips, of 3 cm thickness, in an indirect passive solar dryer was 4 days, while for sun drying it was 6 days. A direct natural convection solar dryer by Ogheneruona and Yusuf (2011) gave a drying rate of two days for tapioca. Whereas these studies were in different environments and since other drying parameters such as thickness would also vary, the surveyed dryers compared well, and in a number of cases better in performance than other dryers analysed in the review. For the surveyed dryers, the analysis of design configuration showed variations and this amongst other factors would be attributed to the varied drying rates.

Dryer design, use and performance relationships

Statistical analysis undertaken to assess the relationship between various parameters on design, use and performance indicated some consistence with theory and as expected. On design configuration, the inlet and outlets were positively correlated and significant at 0.01%. The outlet and surface area and inlet and surface areas were also positively correlated and significant at 0.05%. In terms of usage, the capacity of the dryer and the surface area were positively correlated and significant at 0.05%. There were other relationships in design and usage that were as expected, though not significant. The height was positively related to surface area, to capacity and to number of layers.

The analysis also showed that for performance the percentage of grade 1 realised was negatively correlated to level of losses and was significant at 0.05%, implying that high quality was achieved simultaneously with low losses. There were also other relationships that were not significant, but were as expected on dryer performance. The number of layers was directly related to the level of losses, implying that high number of layers could have been limiting air flow rates and drying rates. The height was negatively correlated to the percentage of grade 1, and this could be attributed to less direct and indirect heating due to the bigger gaps between the glazing material and produce.

Some of the relationships, however, suggested that the designs were developed without consideration of the required inter-relationship; for example, the number of layers was negatively related to surface area, though this was not significant.

CONCLUSION

All The study has identified design configuration of greenhouse dryers in Kenya that could guide in new dryer designs. From this study, an average size of dryers was obtained as 8.12 m long, 3.95 m wide and 2.37 m high. The relative sizes are comparable to other studies and recommendations. Average dryer outlets and inlets also relate with the literature, with dryers having bigger inlets than outlets. A number of dryers were found to have been designed by institutions with qualified staff, a fact that could be attributed to the rated average good performance of the dryers. The dryers had one to four layers, but the statistical analysis indicates that high numbers in some dryers could have affected the performance due to high losses incurred. Most dryers had been constructed using right materials for dryers and food processing. However, use of earth floors and wooden frames in some dryers could compromise quality. The study also indicates that the cost of dryers varied leading to varied choice and ultimately an opportunity for higher adoption of greenhouse dryers. In terms of performance, the level of losses was on average low with only 24% of the dryers experiencing losses over 10% during the drying process. The major causes of losses were cold weather, spillage and poor ventilation. Most dryers achieved good quality of dried products, with only 29% getting less than 50% of grade 1 product. The drying rates varied per crop, but were also different within same crop, a fact that could be attributed to the different geographical locations of dryers and varied performance due to how well the designs were. On average, the drying rate was 13, 56, 48 and 64 hours for mangoes, bananas, cassava and butternut, respectively. Further, correlation analysis showed consistence in design, use and performance of the dryers.

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