Technical and economic analysis of small-scale maize dryers in Kenya

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ABSTRACT Maize is the major staple food in Africa, but is affected by high levels of post-harvest losses and aflatoxin contaminations. One of the factors is poor maize drying. Several interventions are being proposed to improve on maize drying, including solar dryers. Some of these are considered efficient and sustainable to improve storage of maize. However, their levels of technical and economic performance have not yet been explored or compared to the traditional open-air drying, that is common in Sub-Saharan African (SSA). Therefore, this study estimated technical and economic performances of different small-scale maize dryers in Kenya. Five small-scale maize dryers (EasyDry M500, Dehytray, solar POD dryer, Greenhouse dryer and hybrid energy dryer) were included in the on-station experiments and their technical performance (capacity, time of drying) and economic performance (purchase cost, labor and other variable costs) measured. EasyDry M500 was the cheapest with a cost of KES. 165/bag or KES. 21/bag/%; followed by Solar POD dryer, KES. 229 and Greenhouse dryer, KES. 242/bag. The other dryers were very expensive; Dehytray, KES. 2,463/bag and Hybrid dryer at highest cost, KES. 5,155/bag. EasyDry M500 was the most efficient dryer with a Benefit-Cost Ratio (BCR) of 3.7, Greenhouse, 2.4 and Solar POD, 2.2.

Key words: Aflatoxin, economics of drying, Cost -Benefit Analysis

1. Introduction

Maize is the leading cereal crop in Sub-Saharan Africa (SSA) due to its ability to adapt to diverse agro-ecological conditions and it's relative resistance to pests and diseases (CGIAR, 2016; Nyoro et al., 2007). Maize production is highly seasonal, and the harvest in one season can last only for a few weeks, therefore, maize requires to be properly stored to spread its consumption throughout the year, as well as, to give room for other commercial actors along the maize value chain to bargain for better prices (Groote et al., 2019). However, to achieve this objective, maize farmers and other chain actors need to sufficiently invest in post-harvest drying technologies in order to safely preserve quality during storage (Mugabi & Driscoll, 2016).

However, maize, like other cereal crops, usually suffers considerable losses due birds, insects, weather and pests, and therefore, harvesting is usually done before maize is fully dry (Reykdal, 2018). Maize is usually harvested with a high moisture content ranging from 19% to 25% (Tonui, 2017), which provides an ideal condition for grain germination, insect infestation and multiplication, and growth of molds. The marketing boards and major maize millers therefore require maize to have a moisture level of 13.5% or below (Muyanga, 2014). Therefore, maize drying becomes a fundamental step in maize value chain as it allows maize to be stored and be put into various uses later, including milling for flour, malting for beverage industry and preparation of seeds for subsequent productions (Reykdal, 2018).

In Kenya, grain drying activities are usually accompanied by severe environmental challenges including high relative humidity and unexpected rainfalls in many of the maize growing regions that make it difficult to dry maize sufficiently (Amir et al., 1991). These regions tend to experience two rainy seasons, March to May is the long rains and October to December, the short rainy season. Between the two rainy seasons, maize needs to be harvested and dried, and the onset of rains can very short (Mbebe et al., 2019; Walker & Davies, 2017). Consequently, these difficult weather variations have resulted to high volumes of post-harvest losses and aflatoxin contaminations contributing to frequent cases of food insecurity in the Kenya.

In the past, many African farmers used traditional methods such as sun drying (commonly referred as open-air drying) and on-field drying (Schulten, 1982). Open-air drying, which is still the most common method for most farmers, involves spreading maize on the ground, bare or on a cover such as tarpaulins, concrete slabs or even a thin polythene sheet and expose maize to direct sunlight. On-field drying implies leaving the crop standing in the field until it is fully dry.

However, despite these methods are inexpensive, they are quite undependable and unhygienic as they are characterized by insufficient maize qualities due to exposure of maize to rain, dust, foreign objects, poor handling, non-uniform drying, as well as, losses due to theft and consumption birds and stray animals (Mbebe et al., 2019; Udomkun et al., 2020a). Furthermore, on-field drying exposes the crops to attack by insects, rodents, wild animals, strong winds and occasional rain showers, which can damage the grains, increase molds and reduce the maize quality considerably.

Maize is primarily grown as livestock fodder in most part of the world, in Sub-Saharan Africa (SSA), 95% of maize grown goes directly to human consumption. In Kenya, particularly, maize is the most important staple food crop, as well as, representing 3% of Kenya's gross domestic product (GDP) and 21% of the total value of primary agricultural commodities produced in Kenya (Mutiga et al., 2019). Maize is the most important agricultural enterprise in the Kenya's strategic food reserve and it provides livelihood to about 98% of Kenya's 3.5 million smallholder farmers (Emmanuel, 2016). In addition, the maize sector employs directly or indirectly large numbers of the households in Kenya and its failure will significantly affect the national food security.

While achieving food security still remains a dream for most developing countries in Sub-Saharan Africa (SSA), reducing losses and food wastages, including post-harvest losses, along maize value chain, can positively impact food availability (Sawicka, 2020; Udomkun et al., 2020b). The overall post-harvest losses in Sub-Saharan Africa (SSA) are estimated to be 40%, but can go up to 80% under extreme weather conditions (Osodo, 2019). In maize specifically, the losses are estimated to be 20% of the total national maize production (Onyango & Kirimi, 2018). Therefore, reducing post-harvest losses is considered as the only viable solution to achieving food security without putting much pressure on the available scarce resources (Kikulwe et al., 2018).

Additionally, substandard drying methods have contributed to frequent incidences of mycotoxins contaminations such as aflatoxin which is a major food safety and public health concern in SSA (Udomkun et al., 2020b). Aflatoxin contaminations have increased in African region, particularly in East Africa, where it is now being considered an epidemic (Monda & Alakonya, 2016). The World Health Organization (WHO)s indicates that up to 28% of liver cancer cases globally are directly related to high consumption of aflatoxin contaminated foods and ranked as the third leading cause of cancer deaths globally (Chen et al., 2013).

In response, several interventions have been considered by both the national governments and donors to effectively address challenges arising due to insufficient drying; One of those interventions is the development of improved maize dryers such as solar dryers and biomass-burnt dryers to help reduce post-harvest losses and improve on maize quality (Groote et al., 2019; Mbebe et al., 2019). Effective maize drying necessitates the establishment improved drying technologies that can focus more on maize quality, lower cost, reduce drying time, as well as, maintaining consumer's tastes and preferences.

In the recent years, development of improved grain dryers has been a top subject for many agricultural engineers, applied economists and agribusiness analysts. Mechanization of post-harvest drying techniques have commenced and several attempts have been developed to diversify maize drying through research and innovations (Ndirangu et al., 2018). This could be due to availability of affordable solar panels, batteries and solar powered ventilators, and also skillful man power (Mbebe et al., 2019). Despite these efforts, there is little literature on the technical economic efficiencies of these new dryers, which have makes it difficult to compare their performances to that of traditional open-air drying (Groote et al., 2019; Ndirangu et al., 2018). Most of the available literatures exist in grey and have focused on on-farm grain drying in developed countries (Mbebe et al., 2019).

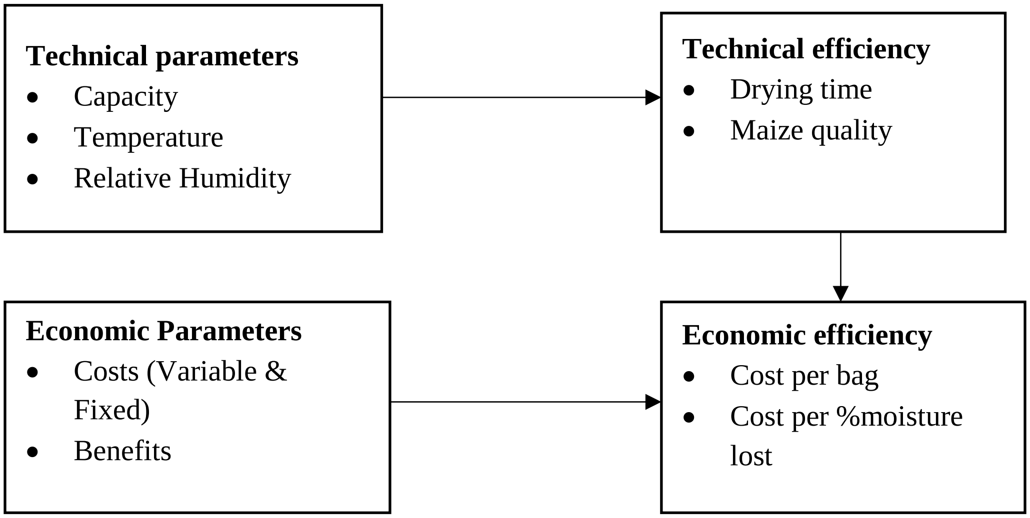
Therefore, this study aims to: 1) identify the small-scale maize dryers available in Kenya; 2) to determine the technical and economic performances of various drying technologies. It is therefore a complementary to a previous study on economics of open-air drying (Groote et al., 2019).

2. Methodology

2.1 Analytical Framework

This study works on the assumption that farmers and traders will use technologies that can increase their benefits and reduce costs. Analysis of the technical efficiency of improved maize dryers involved measuring the moisture levels at the different points of time, and calculating the time, and dryer capacity. Economic analysis involves measuring dryer benefits and comparing it to the costs of drying. The conceptual framework is shown in the figure 1 below;

Figure 1. Conceptual framework



We propose to use of benefit–cost approach to estimates the economics of drying using different systems and to advise decisions and policies of post-harvest drying. First, associated dryer costs are outlined, then the assumptions surrounding the estimation of benefits are provided, then the costs are subtracted from the benefits. This will provide reasonable conclusions upon which the feasibility and advisability of post-harvest drying investment decision could be drawn. The inputs and outputs identified need to be identified as positive (benefits) or negative (costs). Inputs are manifested as costs while outputs as benefits. Typical benefits arising from use of improved maize dryers include: Increased profits, reduced cost of drying, improved maize quality (reduced aflatoxin contaminations, reduced foreign matter contaminations), reduced post-harvest losses, increased storage windows.

Total annual fixed cost is estimated by adding the total annual depreciation and interest to maintenance and repair costs, then dividing by the number of bags dried annually to provide the fixed cost per bag of maize dried. This value is added to variable drying cost per bag for labor and handling, and fuel and electricity costs and divided by the number of percentage points of moisture content removed during drying provides an estimate of total cost per percentage point. This value can be used to compare among different drying systems, or to a commercial drying charge.

2.2 Study Location

This study was conducted in KALRO Research Centre in Njoro, Nakuru County, Kenya. Njoro is located 18 km South West of Nakuru town (Figure 2). It lies at an altitude of 1800m above sea level, experiences temperature ranges between 17-22^{0}C, moderate to high solar energy potential area. The amount of available solar energy is season dependent, with the December-February season receiving the highest amount of insolation of 678 kWh/m^2. Harvesting is normally carried out between August and December, depending on the type of grain.

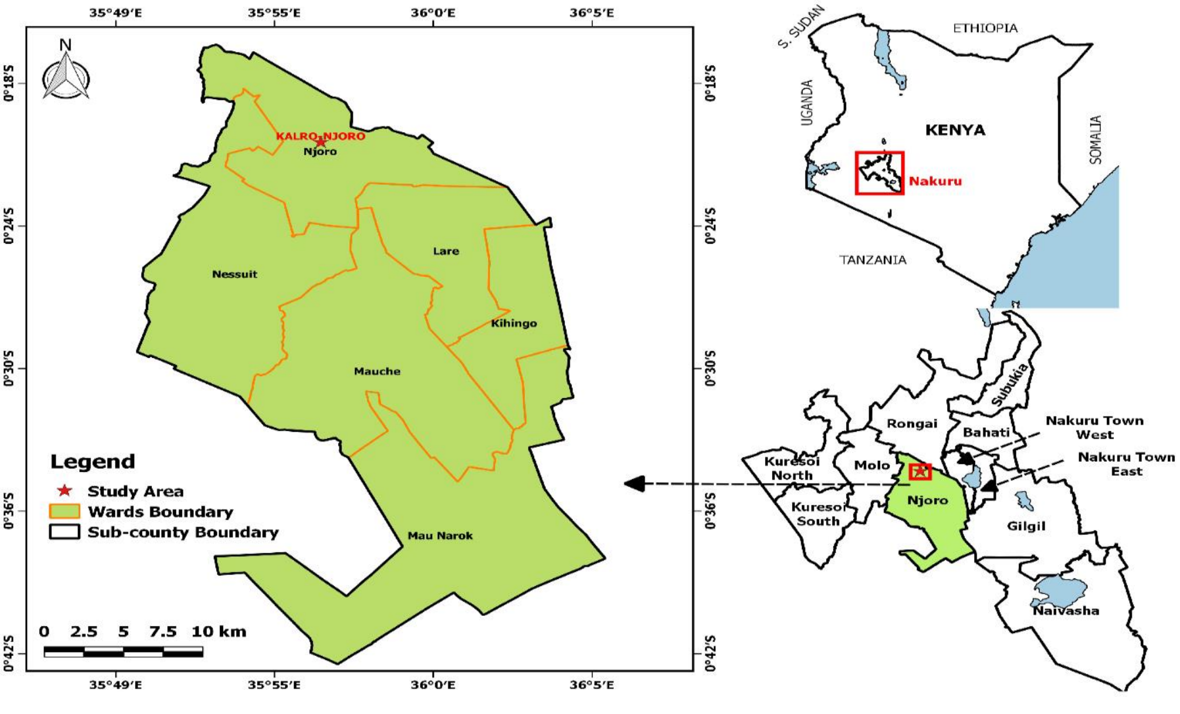


Figure 2. Map of Kalro research center, Njoro, Nakuru County, Kenya. (NCIP, 2018)

2.3 Study design

This experimental study involved trials of new small-scale maize drying technologies in Kenya. First, a pilot study was carried out in February of 2021 to find out which maize drying technologies are currently available for small-scale operators in Kenya. The pilot found that traditional open-air drying was the major technique for drying maize among maize farmers. However, several technologies have been initiated by both national and county governments to improve upon traditional open-air drying. Among the available technologies, we found, the EasyDry M500 and 245XL dryer which were being managed by farmer cooperatives. We also found, the solar pod dryer, the dehytray, the greenhouse dryer and a hybrid energy dryer which were available at the KALRO, Research Centre.

2.4 Experimental procedures and Data Collection

The study used both primary and secondary data. Secondary data was gathered from available literature on the internet, and the information obtained helped in describing small-scale dryers. Next, an experiment was then conducted in March 2021. A team composed of two students (one in engineering and one in economics) and one post-harvest specialist took part in the experiments, assisted by scientist from KALRO, CIMMYT and Purdue University. Two sets of data were collected, one addressing the technical parameters and the other addressing the economic parameters.

Freshly harvested maize grains was collected from farmers in Nakuru County, cleaned manually and loaded in the dryers. Oven drying and digital grain moisture meters were used to determine moisture content before, during and after drying. The grain was dried until their moisture content was reduced to 13% and then the dried grains were evaluated for quality. Temperature and relative humidity in the dryers were also recorded manually at a two-hour interval using a thermometer and hygrometer, respectively. Drying usually take several days so, at the end of the day, maize was unloaded and stored indoors in airtight bags to avoid overnight rewetting.

2.6 Data Analysis

Technical data were first analyzed using descriptive statistics. Both quantitative and qualitative analysis was used to analyze technical performance of each dryer. Cost-Benefit Analysis (CBA) was used to estimate economic efficiency. All the costs incurred in drying the maize were compared against the benefits or value added to maize.

3. Results

3.1. Description of the dryers

Comparing the capacities of the dryers, 5 small-scale dryers were available in Kenya, EasyDry M500 had the largest capacity of 5.5 bags (500kilograms) in one batch. Greenhouse was the second largest capacity, 2 bags per batch. Solar POD, Dehytray and Hybrid were smaller dryers with a drying capacity of 1, 0.08 and 0.06 bags per batch respectively.

Table 1. Types of dryer and their descriptions

EasyDry M500 dryer 	The dryer uses maize cobs as the main source of energy which are burnt to provide heat The dry and hot air is then pushed by a fan that is powered by a 5litres of petrol through the maize bed hanging on a table like structure housed within a canvas bag
Greenhouse dryer 	Greenhouse dryer is made of a steel tube frame covered by a transparent polythene sheet with a bottom made of black metal sheet Solar radiation passes through the polythene sheet and heats the black metal sheet
Solar POD dryer 	The Pico solar crop dryer consists of a series of trays covered by two layers of plastic sheets, fans and a 20 W solar panel backed up by a 12v battery. Maize is placed on five trays (18kgs) with wire mesh bottoms. Fans force the air through the material.

Dehytray dryer

Dehytray is a small and affordable multipurpose dryer developed by Purdue University with the main focus on reducing post-harvest losses and improving maize quality in Senegal and Kenya

It is made of 1 durable black tray that absorbs and radiates heat and allows for maximum air flow, clear acrylic sheets fixed on a yellow frame as the cover, 1 small photo-selective, 1 hygrometer to measure grain moisture levels and 1 food-grade scraper for removing sticky products from the tray and stirring during drying.

Hybrid dryer

A hybrid dryer is an improvement that derives its efficiency from EasyDry M500 and Greenhouse dryer. The dryer uses a furnace fired by biomass including maize cobs. The heat generated is passed through an array of fire tube through the dryer

Open-air drying

In traditional open-air drying, grains are laid out and spread on a bare ground or on a clean ground cover such as tarpaulins, concrete slabs, and a thin polythene sheet, exposing it to the effects of direct sunlight and wind until the desired moisture content is achieved

3.2 Time of drying and Moisture reduction levels

Average time taken by each dryer to reduce moisture content from 20.56 to 13% was recorded for the three days of trials. EasyDry M500 was the fastest dryer, three hours. EasyDry M500 depends on external heat provided by burning cobs/biomass, therefore, had a uniform drying time without break. The other solar dryers took as follows; Dehytray, five hours; Solar POD, six hours; hybrid, seven hours; Greenhouse dryer, eight hours and finally, open-air took the longest, 10 hours. (Figure 3). Moisture reduction is shown in (Figure 4)

Figure 3. Graph showing total drying time in sun hours

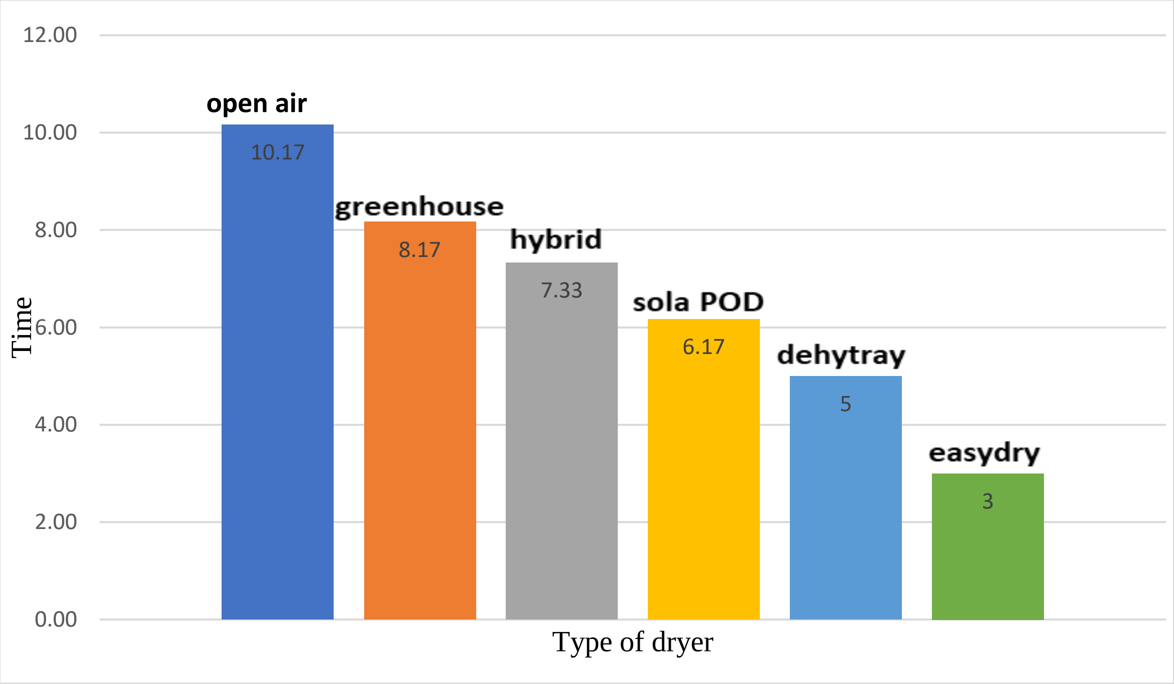
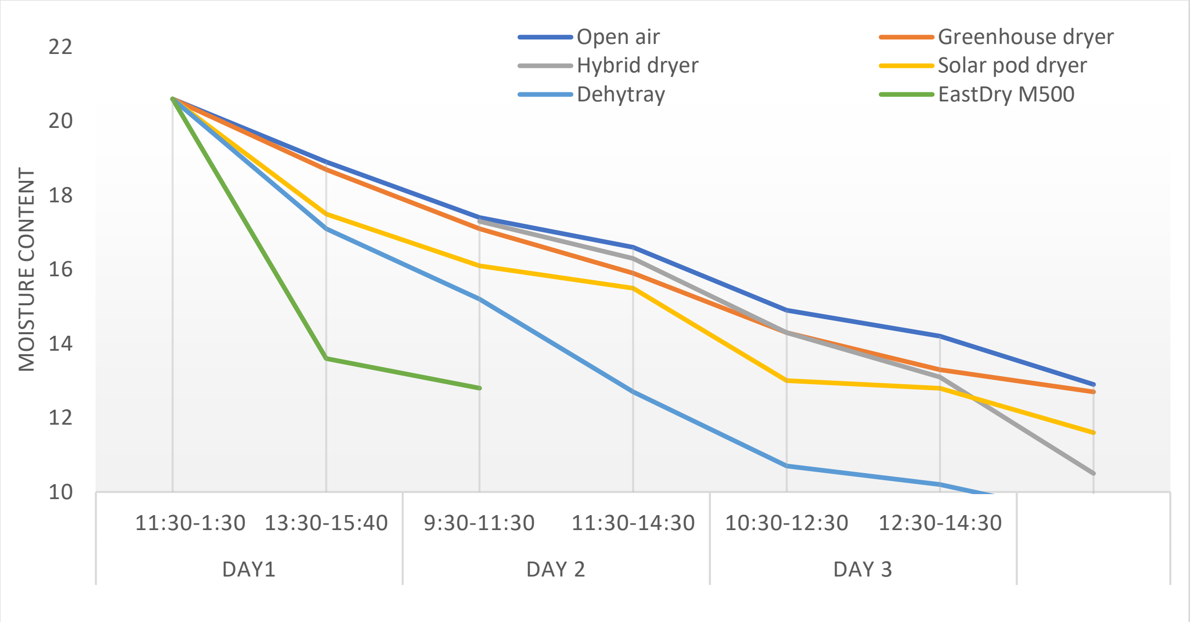


Figure 4. Graph showing rates moisture reduction against time for each dryer



3.3 Cost of drying maize

The total cost of drying maize per bag was calculated by adding annual fixed costs to annual variable costs for each dryer. The average costs, depreciation and interest, of EasyDry M500 was lowest at KES.44/day, and a reasonable useful life was estimated to be 5years when properly maintained. The annual cost of maintenance was estimated to be KES.20/day. An average fixed cost per bag was KES.3/bag. The total variable cost per bag of maize dried was at KES.161, fuel being the highest variable cost at KES.88, and labor cost at KES.48/bag. The total cost of drying bag of maize was KES.165 or cost per percentage point of moisture removed, KES.21/%.

Greenhouse dryer was the second inexpensive dryer. Its fixed cost and variable cost per bag of maize dried was KES. 12/bag and KES. 216 respectively, summing to a total of KES.229 per bag of maize dried. The major cost in drying maize using Greenhouse dryer was labor cost at KES.153/bag. The average cost per percentage point of moisture reduced was KES. 30 /%.

Cost of drying a bag of maize using a solar POD dryer was KES. 242. Fixed costs included; deprecation and repairs & maintenance at an average of KES. 11 and KES.7 per day respectively. Average fixed cost per bag was estimated to be KES.18. Like other solar dryers, variable cost was majorly labor at an average of KES.153/bag. Cost of reducing moisture content per percentage point was found to be KES. 32 per percentage point of moisture reduced, the third most efficient dryer tested.

The rest of the dryers found to be very expensive as their costs for drying a bag of maize was too high. Dehytray with a total cost was KES.2,463/bag of maize and point KES.16 for every percentage point of moisture removed. In Hybrid dryer, the total cost for drying a bag of maize was found to be KES. 5,155 and average cost per percentage point of moisture removed to be KES.681. These total costs were compared against traditional open-air drying (conducted by DeGroote). Open-air had a fixed cost of KES.20/bag, labor cost added up to KES.113/bag and total cost per bag summed up to KES.133/bag (Groote et al., 2019).

Table 2. Drying parameters

Category	Parameters	EasyDry	Greenhouse	Solar POD	Dehytray	Hybrid
Capacity/batch	Bags	5.5	2.0	1.0	0.1	0.1
Time/ batch	Hours	3.0	8.2	6.2	5.0	7.3
Batches per day		3.0	1.0	1.3	1.6	1.1
Bags/day	Bags	16.5	2.0	1.3	0.1	0.1
Capacity per year (3months)	Bags	1485.0	176.3	116.8	11.2	5.5
Life span capacity	Bags	7425.0	881.6	350.3	33.6	27.3
Petrol usage/batch	litres	5	-	-	-	-
Capital cost/bag	KES.	11.4	37.4	42.8	178.6	623.3
Annual cash flow	KES	653,400.	77583.7	51373.0	4928.0	2400.0
Payback period	Years	0.1	0.4	0.3	1.2	7.1

Table 3. Costs of drying

Category	Parameters	EasyDry	Greenhouse	Solar POD	Dehytray	Hybrid
Costs						
	Capital cost	85,000	33000	15000	6000	17000
life span	Years	5	5	3	3	5
Fixed costs	Depreciation/day	44.4	16.7	11.1	5.1	8.3
	Repairs & Maintenance/day	20.5	8.0	3.6	1.5	4.1
	Total fixed cost/ day	65.0	24.6	14.7	6.5	12.4
	Total fixed cost/ bag	3.9	12.6	11.4	52.6	205.3
Variable costs	Labor cost/bag	48.5	153.1	389.2	6,171.4	4,950.0
	Petrol cost/bag	88.7	-	-	-	-
	Transport/bag	24.2	204.2	-	-	-
	Total variable cost/ bag	161.5	216.7	231.3	2,410.7	4,950.0
Total cost per bag		165.4	229.3	242.6	2,463.3	5,155.3

3.4 Benefits of drying maize

This study used difference in the price of wet maize at farm gate and the price of dry maize in the markets to estimate the market value added by drying. The price of wet maize at farm gates was KES.2,160 per bag, adjusted for moisture level to represent the price of the equivalent 1kg maize at 13% moisture. The final market price, farmers/traders sold their maize was KES.2,920 per bag. This represents an increase in the value of maize per bag by KES.790.

The efficiency of the drying operation for each dryer as calculated as the cost per percentage moisture reduced, that is, drying costs divided by the number of points of moisture reduced. EasyDry M500 was considered the most efficient, KES.21 per percentage point of moisture reduced. Greenhouse dryer was second with an efficiency of KES.30 per percentage point of moisture removed. Solar Pod at KES. 32.09/point. Both dehytray and hybrid were not efficient as they exhibited higher cost per points, KES.325.84 & KES.681.92 respectively

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3.5 *Benefit-Cost Analysis*

To calculate the benefit-cost ratio (BCR) of the dryers, we took benefits per bag (difference in price of dry maize at the market minus the price of wet maize) minus total cost of drying one bag, then divided by the total cost of drying one bag of maize. Three dryers; EasyDry M500, greenhouse and Solar POD dryer were considered economically viable since they had BCR of more than 1 **(**3.78, 2.44, 2.26 respectively), indicating that the dryers are worth being utilized by small-scale operators. The other dryers; dehytray and the hybrid had BCR of less than 1 (-0.68 and -0.85 respectively), indicating that their costs exceeded their benefits, therefore, the dryers should not proceed to utilization as they derive less benefits compared to their costs

Table 4. Benefit Cost Ratio

Parameter	EasyDry	Dehytray	Solar POD	Greenhouse	Hybrid
Total cost per bag	165.4	2,463.3	242.6	229.3	5,155.3
Benefit per bag	790	790	790	790	790
BCR	3.78	-0.68	2.26	2.44	-0.85
Moisture reduced	7.56	7.56	7.56	7.56	7.56
Cost per moisture reduced	21.88	325.84	32.09	30.33	681.92

5. Discussion and Conclusion

Our results show that the cost of reducing moisture content from 20% to 13% was lowest cost for Easy Dry M500 (KES.165), Greenhouse (KES.229), Solar POD (KES.242), Dehytray (KES.2,463), and Hybrid (KES.5,155). Drying cost per bag was highly influenced by the dryer capacity and the length of duration required to reduce moisture levels to about 13%. The smaller improved maize dryers had higher cost of drying maize per bag than larger dryers and even open-air drying.

Technically, EasyDry M500 was considered to the most efficient, it can dry a batch of maize (500kilos) in three hours, which is seven hours faster than traditional open-air drying. In addition, the capacity of the EasyDry M500 dryer is convenient for small-scale farmers, which some studies have found to be harvesting about 10-15bags per season, since it can only take a day to dry the wet maize. The other solar dryers were not technically efficient since they had small capacities meaning farmers have to wait long to dry all harvested maize. However, when modified, they could be used by small-scale farmers and traders. Economic analysis found that EasyDry, solar POD and greenhouse dryers to have a benefit-cost ratio (BCR) of greater than one indicating that the dryers are worth being utilized by farmers since their benefits are higher than costs hence it is profitable to use them. The other dryers (Dehytray and hybrid) had a BCR smaller than one showing that their costs are higher than their benefits, therefore, farmers will spend much more to use them. The reason is that the dryers are small and require much labor to dry one bag of maize. Further, EasyDry M500 was the most efficient in drying, compared to traditional open air drying. Cost per moisture reduction for EasyDry was KES.21/point of moisture reduced, five shillings less than open air drying with KES.26/point.

Canada, in comparison, hot air dryers are used to lower moisture content from 21% to about 15% at a cost of $7.80/ton, or KES.75.82 per a 90kg bag of maize. Maize drying in Canada is therefore KES.85 cheaper, more than 50% drying of maize with EasyDry M500 in Kenya. However, it is difficult to compare cost and efficiency across continents due to wide differences in technologies and resources, as the Canadian cost only included energy not labor or equipment, while the solar energy used in Kenya is free but labor is the highest cost.

Finally, new and improved drying technologies should focus on cost and capacity which a dryer can hold per batch as this will be very important factor in farmers adoption or utilization.

Farmers will often those technologies that suits their conditions, and therefore, will want dryers that can reduce both cost or increase profits and reduce the time needed to dry their produces. To be more competitive, these technologies should be able to dry at least 16.5 bags per day, like for the case of EasyDry M500.

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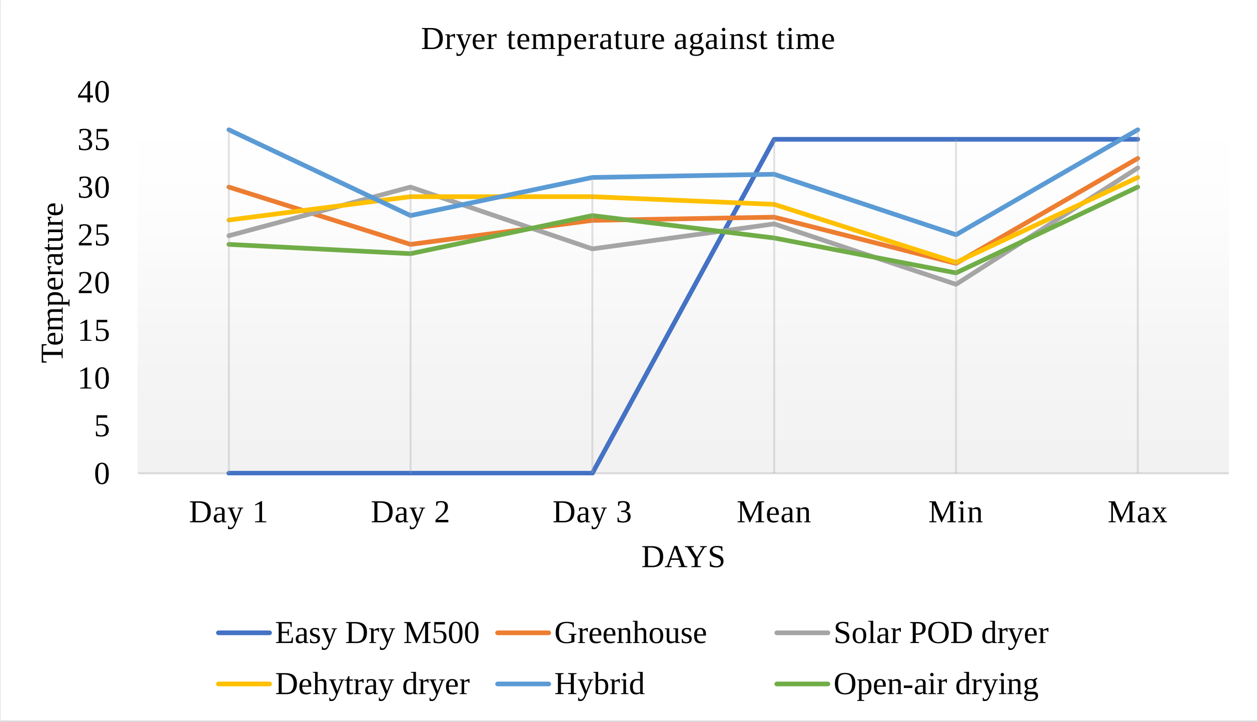
6. Appendix: Supplementary materials

6.1 Dryer temperature

Drying trial was spread in 3 days due to weather variations and total sun hours were recorded. Thermometer was used to record temperature outside and inside the dryer. Day 1 of drying we recorded 3 sun hours and temperature was measured at 2hours interval. EasyDry had a constant temperature of 35ºC throughout the drying process. Constant temperature was because EasyDry M500 does not rely of solar radiations but rather, the heat was provided by burning biomass which was constant throughout the process. Greenhouse dryer had an average temperature of about 26.83ºC, and a minimum of 22ºC and a maximum of 33ºC during the entire trial period. Dehytray recorded an average temperature of about 28.13ºC, a minimum and maximum temperatures of 22.1ºC and 31ºC respectively. Hybrid recorded an average of 31.33ºC and a minimum and maximum of 25ºC and 36ºC respectively while open air, ambient conditions were used, average temperature being 24.67ºC and minimum and maximum temperatures being 21ºC and 30ºC respectively.

Even though, Dehytray and Solar POD dryer had already achieved the objective of reducing moisture levels to about 13% by the second day, drying continued till the other dryers reached that as shown in figure 5 below.

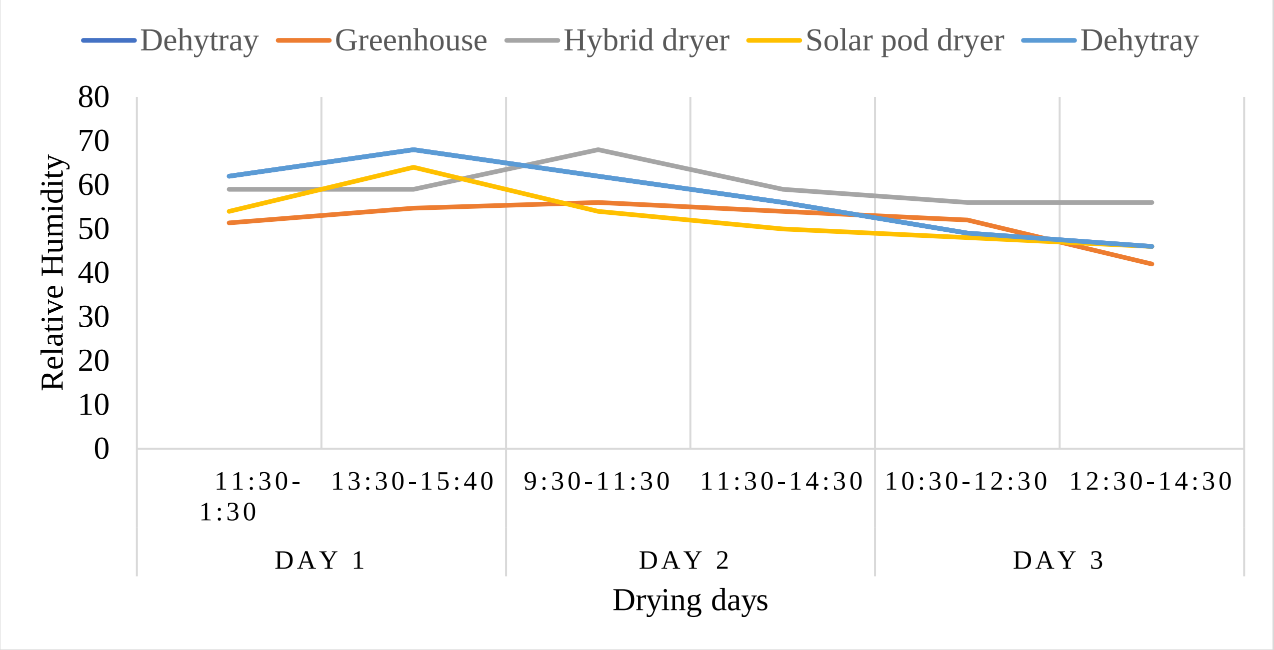
Figure 5. Graphical representation of dryer temperature against drying days



6.2 Relative humidity

Relative humidity was measured using hygrometer. Average relative humidity for the 3 days of the trials were; open-air recorded highest relative humidity, averaging to 62%. Hybrid dryer had an average of 59.5%, Dehytray was 57.17%, solar POD, 52%, Greenhouse, 51.67%and lastly EasyDry M500 which had the least RH of 45%. The average daily RH for dehytray was 59%. (figure 6)

Figure 6. Graph showing of Relative Humidity against drying days



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