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Improving cocoa beans value chain using a local convection dryer: A case study of Fako division Cameroon.

Mobey Emmanuel Tardzenyuy[a,*], Zheng Jianguo[b], Tetteh Akyene[c], Mobey Peter Mbuwel[d]

[a] Donghua University, School of Business & Management, 1882 Yan'an Road West, PO Box 200051 Shanghai, PR China
[b] Donghua University, School of Business & Management, 1882 Yan'an Road West, PO Box 200051 Shanghai, PR China
[c] University of Mines and Technology, Department of Management Studies, P.O. Box 237, Tarkwa, Ghana
[d] University of Bamenda School of Agriculture, P.O. Box 39 Bambili, Cameroon

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ABSTRACT

Cocoa production in south west region of Cameroon, Fako, is faced with several quality challenges. These challenges affect the value of the final cocoa beans produced and the entire cocoa beans value chain. Cocoa harvesting period clashes with the peak wet season in Fako and farmers' only means to dry the produce is to use artificial local dryers. Most farmers' dried cocoa beans suffer deficiencies such as smoke taints, burnt cocoa beans, cracked beans and most abnormal higher than required moisture content of the cocoa beans etc. which in turn affect the cocoa beans value in local and international markets. This paper focuses on optimizing the cocoa beans value chain by using convection dryer to improve moisture content and eliminate defects. Using one-on-one interview, factorial design and design of experiment, a new convention dryer was setup and experimentation carried out. The results showed that setting the convention dryer to these parameters: Temperature 35 °C, Time 96 h, Aeration rate 15 m^3/s and Space/quantity ratio 12 $m^2/50$ kg, the required world standard of 7.0% moisture content of dried cocoa beans is achieved under the prevailing weather conditions. This improves the value of dried cocoa beans by \$2.8/kg in the local and international market as compared to the surveyed values.

Introduction

Cocoa in all its forms has enormous benefits such as, supporting brain health, acting as a good source of antioxidants [2], regulating cholesterol level in the blood, treatment for diabetes and bronchial asthma [3,16]. This help reduce obesity, regulates cardiovascular health, helps treat constipation, prevent cancer, and support skin health [12,30,33,52]. It byproducts such as dark chocolate and cocoa beverages have blood pressure mitigating properties and with great sensory effects [6,13,14,19,53]. In the world, it is estimated that more than fifty million people depend on cocoa for their livelihood [26,57]. In Africa over twenty five million people depend directly or indirectly on cocoa for their livelihood in the entire

* Corresponding author.
E-mail addresses: mobeyt@yahoo.com (M.E. Tardzenyuy), zjg@dhu.edu.cn (Z. Jianguo), atetteh@umat.edu.gh (T. Akyene).

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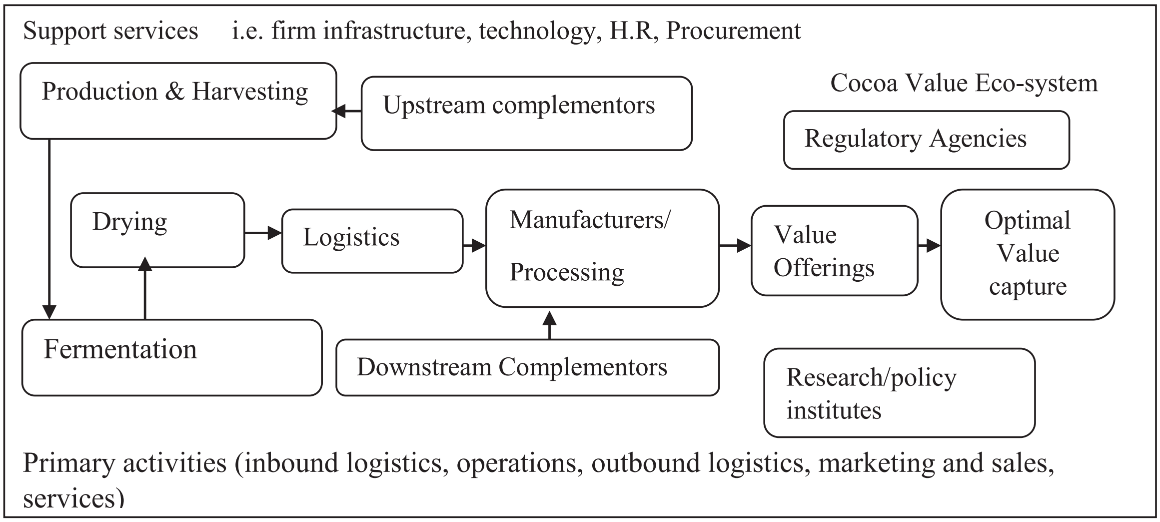

Fig. 1. Reconfigured cocoa value chain (arrows shows critical linkages) [32].

value chain. Cocoa production capacity at the world stage is headed by Africa 68%, Asia 17% and The Americas 15% [27]. In Africa the largest cocoa producing country by volume are Côte d'Ivoire/Ivory Coast which produces 1900 MT, Ghana 850 MT and Cameroon which is ranked third with 250 MT of global supply in the cocoa market [26,44].

The cocoa sector in Cameroon is characterized by smallholder production mainly rural families. The littoral, center, south, south west, and east regions in Cameroon are the main cocoa producing regions with the south west region topping the chart with 58% of the national produce [27,36,41]. With respect to the south west region, the Fako division (district) is the leading cocoa beans producer per quantity of output. Cocoa production in Fako Division is the main economic and developmental activity the natives depends on [48,49]. The Fako Cocoa belts occupies about 37% of total area under cultivation with an annual production growth of 92,619 MT in 2000 to 98,530 MT in 2014 [28,45,55]. This signifies that cocoa production growth in the last fifteen years is 5911 MT averaging 394 MT per year. These breakdowns suggest that several factors (drying of cocoa beans, fermentation, poor harvesting strategies, pesticides contamination and pests infections, and other challenges are limiting cocoa production growth rate in Fako district.

The cocoa harvesting season in Fako division is often done in the peak wet season of the year. The season of cocoa harvest is characterized by high humidity, shorter periods of sun shine and high rain fall at longer periods [49]. This is a natural phenomenon beyond the control of farmers and impacts the post-harvest sun-drying process of the cocoa beans. These conditions force farmers to employ artificial means of cocoa-drying process with numerous quality constraints: (i) Improper drying of the cocoa beans to the required moisture standards, that is, majority of the famers send higher than normal moisture content cocoa beans to the market and this greatly affects the upstream value chain offering, (ii) the moisture content impacts the upstream value chain storage periods and conditions; as cocoa beans with higher moisture are affected by fungi, mold and other bacteria when store at longer periods thus impacting value offering in the next stage of the value chain, (iii) The cocoa beans is subjected to high temperatures at shorter drying periods leading to cracks and disintegration of the bean in artificial local dryers, and (iv) The effect of soot and smoke also affect cocoa beans quality impacting value offering as smoke and heat supply is not separated thus affecting upstream value chain and ultimate value capture in the market.

Cocoa value chain consists of input suppliers, producers or small farm holders, processors i.e. fermenters and drying agents, logistics i.e. traders, exporters and importers, as well as all relating market channels and support services (Fig. 1). The value chain begins with the cultivation and harvesting of the cocoa beans. Harvesting is presided by fermentation, followed by drying and grading, selling to the cooperative or individual buyers in the local market. At each stage in the value chain process value is added [48]. After the cocoa beans has been fermented, the next stage is to dry it to the required moisture standards. Most often wood fired kilns and ovens with numerous quality constraints such as "Smoke off-flavor" [8] are used to dry the cocoa beans. But the current drying practices by stakeholders in the value chain deviate from the desired standards [21] and this does not provide optimal quality (Fig. 3).

Fako, one of the administrative units in the South West region of Cameroon, is a major source of cocoa produce. Ninety percent of the population is rural folks engaged in small-scale agriculture including cocoa production, cassava, bananas and plantains, vegetables etc. as a source of income for many households [4,7]. Cocoa is cultivated on an estimated total surface area of 450,000 Ha that varies from one to three hectares of land [28]. After post-harvest fermentation, the moisture content of about 60% needs to be reduced to 7.0–7.5% by drying. Drying is carried out in two ways i.e. sun drying and artificial drying. Sun drying process is the most cost effective means of drying the cocoa beans. The cocoa bean is spread out on mats, trays or on clean concrete floors specifically made for this purpose as well as wooden or plywood floors in the sun

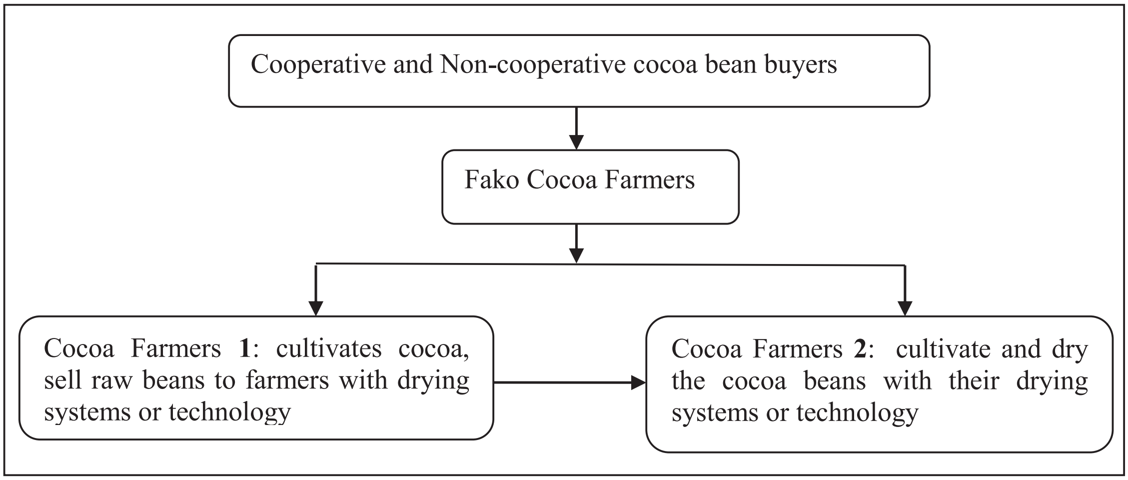

Fig. 2. Farmers interview process.

[15]. The beans is rotated or raked manually to ensure uniformity of drying [23] and always taken care-of when there is weather changes i.e. when it rains. Adequate sunshine for the sun drying of cocoa may take about one week to attain the desired moisture level, but if the weather is dull or rainy, it will take longer and have adverse effects on the quality of the process results [20,21]. On the other hand, most artificial dryers are local convection dryers [15] equipped with air inlets, which allows the convection current of air to flow without letting in smoke or other contaminants to taint the beans. But in Cameroon, most drying platforms are built with slate or cement and are heated at one end by fire [24]. This type of drying may enhance uniform heat distribution but highly loaded with foreign contaminants (Fig. 3) [10].

In Fako district, cocoa beans dryers are constructed with mud bricks and plastered cement walls or walls without plastering with dimension that ranges from 4 m x 3 m x 1.5 m. Equipped with fire wood powered kilns, the drying platform is suspended above the kilns for drying (Fig. 3). The simple advantage is that it is easy to construct and run but these are some of it limitations**.** (i) The drying product is subject to smoke tainting and other fire powered contaminants. (ii) The rotation of the product is intermittent causing some parts of the beans to be burnt and the irrational heat supply leads to roasting instead of drying. (iii) Varied degrees of heat supply leads to bean cracking, (iv) Varied heat supply subject the beans to superficial drying while the seed centers remain wet which leads to rotting after packaging. (v) The dryer is not equipped with devices that determine optimal parameters such as rotation rate, temperature, time, aeration rate and the degree of spread of the drying product that guide and control the drying process. Lack of all these devices lead to defective outcomes in the drying process and impair the value adding processes at the upstream value chain [1].

Although the construction of cocoa beans dryer is made of local materials and easy to run, if the right parameters are adhered to, quality cocoa beans can be produced that optimize quality yields, value offering and value capture in the entire value chain. Thus, this paper focuses on using local convection dryer to dry Fako cocoa beans to the required moisture standards while limiting the impact of smoke and soot and other defects in the process. Solving these problems may improve the cocoa value offerings at the upstream value chain, farmers output and wellbeing during the peak wet harvest season. The rest of the paper is structured as follows: section two touches on the materials and method i.e. one-on-one interview, factorial design, design of experiment, section three covers results, discussion and section four takes a look at the conclusion, limitations and further research.

Material and methods

Interview

One on one interview was conducted with cooperative and non-cooperative cocoa beans buyers to know the challenges they face with dry cocoa beans purchased from cocoa farmers in Fako. Drying quality that affects the price in the market was the key challenge. Further investigations were done to have firsthand information of the situation and degree of effect. The interview with several Fako cocoa farmers revealed that there are two types of cocoa farmers in Fako district: those who cultivate cocoa but sell their cocoa beans to cocoa drying farmers and farmers who cultivate and dry cocoa beans (Fig. 2)**.** Farmers who cultivates and dry cocoa beans, and also dry cocoa beans cultivated by other farmers were used as the research sample. These criteria were used to select farmers for our sample size: they dry cocoa beans using the local dryer and are ready to share their challenges on using the local cocoa beans dryer**;** the farmer's cocoa beans must be of the current season, willing to allow us to measure the characteristics of the dried beans. A total number of 1240 farmers participated in this study. Each farmer's cocoa bean moisture content quality was tested using moisture testing meter model GM 006 AMSTAST

Table 1
Moisture, smoke and mold content in cocoa bean.

Optimal MC (MC)%	Farmers' (MC)%	Value captureto MC Ratio ($/kg)	Optimal MC market price	Impact of smoke (L,M,H)	Impact of mold%	Total (N)
7.0	15	1.6	2.8	L	2.5	176
7.0	14	1.6	2.8	L	2	168
7.0	13	1.6	2.8	L	2	100
7.0	12	1.7	2.8	M	1	190
7.0	11	1.8	2.8	M	1	103
7.0	10	1.9	2.8	M	1	90
7.0	9.0	2.0	2.8	H	1	50
7.0	8.0	2.5	2.8	H	0	70
7.0	7.0	2.8	2.8	H	0	103
7.0	6.0	2.4	2.8	H	0	41
7.0	5.0	1.6	2.8	H	0	149

Note: L = Low, M = Medium and H = High.

Table 2
High and low level parameters of the experiment.

Factor	Factor codes	High level	Low level	Unite
Oven temperature	OT	40	3 5	°C
time	T	96	48	h
Aeration rate	AE-R	30	15	m^3/s
Space /Quantity ratio	S/Q-R	12	6	$m^3/50kg$

INC – (Instrument calibration, Sacramento, CA USA), smoke tainting and mold impact were measured by observation on existing dried cocoa beans ready for the market. The corresponding prices to moisture content were determined with the help of local cocoa traders (Table 1).

Parameters selection

The high/low levels of the parameters were selected based on the values reported in previous studies [29,43,56]. This was also guided by sun drying parameters and techniques from various farmers to provide parameters for artificial drying process. This is based on the fact that sun drying process gives optimal quality of cocoa beans. To arrive at the factor levels, the optimal conditions for sun drying process of cocoa beans were studied and simulated into the parameters for designing the local convection dryer [40,47,50].

Temperature

The highest hourly temperature range of the day for optimal sun drying process were measured for a week and the mean taken into consideration for the given optimal output of cocoa beans dried. To this perspective the high, 40 °C (high level) and low 35 °C (low level) was considered. The optimal temperature provides optimal conditions for evaporation and the cocoa beans drying process (Table 2).

Time

The normal time for sun drying of cocoa beans is six hours daily for seven days that summed up to 42 drying hours with varied temperature ranges. To determine the optimal time for artificial drying, the drying process is in confinement and there is vaporization and condensation within the drying platform, the rate of free exit of the vapor is low, to get rid of the excess evaporation and likely condensations, 96 hrs and 48 hrs was adopted as reported in [46,51].

Aeration rate

The aeration rate in sun drying process is effective because it is open and any vapor is rid off as there is no saturation and condensation, thus there is high rate of free exit of the vapor. With control experiment test runs, the optimal aeration rate for artificial drying system was estimated as reported by [43] i.e. Eq. (1). The meter readings from (TSI Alnor USA, Veloci Calc 9565 Series Ventilation Meter) were considered from the manually calculated readings (Table 2).

$$Equation\ (s)\ Q_a = 60\pi \cdot v\left(\frac{d}{2}\right) \tag{1}$$

Where: d = inner diameter
v = Air velocity m/s
Q_a = Air flow rate in m^3/s i.e. the aeration rate.

Table 3
Experimental run.

Ex. Run	OT °C	T(h)	AE-R(m^3/s)	S/Q-R($m^3/50kg$)
1	35	48	15	6
2	40	48	15	6
3	35	48	30	6
4	40	48	30	6
5	35	96	15	6
6	40	96	15	6
7	35	96	30	6
8	40	96	30	6
9	35	48	15	12
10	40	48	15	12
11	35	48	30	12
12	40	48	30	12
13	35	96	15	12
14	40	96	15	12
15	35	96	30	12
16	40	96	30	12

Space /Quantity ratio

The optimal cocoa beans spread for sun drying process were considered in the controlled experimentation to design the artificial drying platform and the drying mats. With respect to the quantity to be dried, time, the optimal spread of the sun drying process and the potential quantity available in the harvest season was taken into consideration for the dryer design. Thus, the more space the cocoa beans is spread, the faster the drying process. Taking into consideration the fermentation process, the fermentation quantity is done in batches of 50 kg per fermentation box, farmers hold that fermentation quality varies for every fermented batch of the beans, the optimal quality of the fermented batch can only be assured when the cocoa beans has been dried, therefore drying each batch without mixing with the others is the principle. This principle has made farmers to dry the beans based on the same quantity as was fermented. This is mixed later after drying for proper quality grading [3,31], thus the 50 kg quantity is adopted.

Experimental design

The two-level factorial designs (or 2^k) was employed as an effective, efficient method to determine the factors combinations, variations and factor levels that have significant effects for optimal response [38,39]. The high and low level of the parameters were input into Minitab 14 software and the experimental design runs results given (Table 3).

Drying experimentation

In setting up the experiment, a new local cocoa beans convection dryer was constructed with bricks and cement plastered walls with the following dimensions 4 m long x 3 wide x 1.5 m high (Fig. 4).

The tilting frame/platform which supports the heating and combustion chamber is suspended 1.5 m off the ground. To helped control the effect of smoke, the combustion chamber was separated from the drying chamber with 2 m heat/ air conveying duct. Further, dry wood charcoal was used in the heating chamber as it produces no smoke in the process. To facilitate the free circulation of air in the drying chamber, the drying mat is perforated. Besides these control parameters, other parameters that were kept constant includes: The rotation rates of the cocoa beans during the drying process, and the rate of free exit of saturated air was the same as the rate of entry of hot/dry air into the drying chamber. Then, the cocoa bean was selected from 16 independent farmers corresponding to the 16 experiments, dried using the new dryer and data collected, analyzed and presented (Table 4).

Moisture content data

In order to calculate the moisture content of the dried cocoa beans, moisture content formula was adopted as in Eq. [23]. This was achieved by randomly selecting fourteen cocoa beans as stipulated by the weighing apparatus, weighing each at every experiment and taking its average weight before and after drying in the convention dryer and the results used to compute the moisture content percentage MC% (Table 4).

$$MC = \frac{W_o - W_d}{W_o} \times 100\% \tag{2}$$

Where: W_o = original weight, and W_d = weight of dried cocoa beans.

Table 4
Result of the experiments.

Exp N0	OT °C	Th	AE-R m^3/s	S/Q-R m^2/50kg	W_o grams	W_d grams	MC %	MC Optimal target %	Target deviation %	Cracked, Roasted/ burntbeans	Smoke impact L (low)
1	35	48	15	6	2.0	1.812	9.4	7.0	2.4	0	L
2	40	48	15	6	3.0	2.724	9.2	7.0	2.2	0	L
3	35	48	30	6	4.0	3.636	9.1	7.0	2.1	0	L
4	40	48	30	6	2.0	1.82	9.0	7.0	2.0	0	L
5	35	96	15	6	3.0	2.751	8.3	7.0	1.3	0	L
6	40	96	15	6	2.0	1.836	8.2	7.0	1.2	0	L
7	35	96	30	6	4.0	3.676	8.1	7.0	1.1	0	L
8	40	96	30	6	3.0	2.76	8.0	7.0	1.0	0	L
9	35	48	15	12	4.0	3.704	7.4	7.0	0.4	0	L
10	40	48	15	12	2.0	1.854	7.3	7.0	0.3	0	L
11	35	48	30	12	3.0	2.784	7.2	7.0	0.2	0	L
12	40	48	30	12	4.0	3.716	7.1	7.0	0.1	0	L
13	35	96	15	12	2.0	1.86	7.0	7.0	0.0	0	L
14	40	96	15	12	3.0	2.799	6.7	7.0	- 0.3	0	L
15	35	96	30	12	2.0	1.87	6.5	7.0	- 0.5	0	L
16	40	96	30	12	3.0	2.811	6.3	7.0	- 0.7	0	L

Note: Target deviation is given by MC optimal target% minus MC%.

Table 5
Comparative performance of surveyed and dryer's cocoa beans.

Interviewed farmer's market value of cocoa beans				Improved convection dryer's market value			
Farmers moisture content (MC%) (Table 1)	*Value captureto MC Ratio ($/kg)*	*Optimal value capture ($/kg)*	ValueLoss *($/Kg)*	Moisture content MC% (Table 4)	*Optimal value capture ($/kg)*	Value captureto MC Ratio ($/kg)	Valueloss ($/kg)
15	1.6	2.8	1.2	9.4	2.8	2.0	0.8
14	1.6	2.8	1.2	9.2	2.8	2.0	0.8
13	1.6	2.8	1.2	9.1	2.8	2.0	0.8
12	1.7	2.8	1.1	9.0	2.8	2.0	0.8
11	1.8	2.8	1.0	8.3	2.8	2.5	0.3
10	1.9	2.8	0.9	8.2	2.8	2.5	0.3
9.0	2.0	2.8	0.8	8.1	2.8	2.5	0.3
8.0	2.5	2.8	0.5	8.0	2.8	2.5	0.3
7.0	2.8	2.8	0.0	7.4	2.8	2.8	00
6.0	2.4	2.8	0.4	7.3	2.8	2.8	00
5.0	1.6	2.8	1.2	7.2	2.8	2.8	00
				7.1	2.8	2.8	00
				7.0	2.8	2.8	0.0
				6.7	2.8	2.4	0.4
				6.5	2.8	2.4	0.4
				6.3	2.8	2.4	0.4

Note on Table 5: (i) Value Loss ($/kg) i.e.2.81.6 = 1.2 for interviewed farmers or 2.82.0 = 0.8 improved dryer etc. (ii) Italics is surveyed data.

Results and discussions

Results

Pertaining to each experimental run combination results by the factorial design analysis, each combination was used to generate its possible moisture content results (Table 4). The experiment moisture content shows positive trends as the moisture content is reduced from the average 60% [11] at fermentation to 15% high to 5.0% low in the farmer's survey cocoa beans to improved range of 9.4%6.3% moisture content (MC%) column. But there is still a marked deviation from the desired moisture content standards target of 7.0%. The target deviation i.e. MC minus MC optimal target (Table 4) gives the "target deviation" in the farmers' survey results and dryer's results. This gives the degree of anomaly in moisture content and the effect on the value captured. Observing other sources of defects gives good results as cracked, burnt, soot and smoke tainted beans are at zero effect in the drying process. Experiment 13 gave the optimal desired recommended standard value of 7.0% [25,35]. A good feasible region exist that can be considered i.e. the moisture content that falls between 7.07.5% is within the feasible region of acceptance. This sustains the acceptable grinding, storage standards with optimal safety moisture content equilibrium, and with relative humidity range of 6.07.9% [54]. Comparing the farmer's survey data and the convection dryer data, it is noticed that the value loss is higher for the farmer's survey and value capture is higher in convection dryer data. Thus, the results gives the moisture content range in convection dryer data that is offering comparatively good value capture for farmers under the prevailing environmental conditions and experimental parameters (Table 5).

Discussions

A glance at the sixteen experimental runs, only experiment thirteen offers the desired results. To obtain the optimal result that reduces target deviation of the moisture content, the new convection dryer was designed with the desired prevailing parameters and used (Fig. 4).The schematic convection dryer was designed and constructed making sure all the limitations of the local convection dryer (Fig. 3) were corrected. The modified convention dryer was constructed with dimensions of 4 m x 3 m x 1.5 m. The drying mat is perforated and suspended to facilitate the free circulation of dry air and heat as needed. To help control the effect of smoke and soot from the heat conveying and combustion chambers, the latter is separated from the drying chamber with 2 m long ceramic heat/ dry air conveying duct. Dried wood charcoal was used to fire the heating chamber principally to limit the smoke/soot in the drying process. The new design features helped in obtaining optimal parameters i.e. temperature 35 °C, time 96 hrs, aeration rate 15 m^3/s, space to quantity ration of 12 $m^2/50$ kg implying defects such as roasting, smoke taints, fast dry cracks in the cocoa beans instead of drying are eliminated and the desired moisture content attained [42]. Irrespective of the moisture content range of 9.46.3% (Table 5) it still provides better market value added to farmers as compared to market value interview results. Interviewed farmer's market value of cocoa beans (value capture to MC Ratio ($/kg) is the prevailing market price (Table 5). These survey prices were used to calculate the improved convection dryer's market value with $2.8 as the price for optimal moisture content of 7.0% etc. Determining the value loss for farmers surveyed beans and the convection dryer's beans, is simply optimal value capture ($2.8/kg) minus value capture to MC ratio ($/kg). Both the value capture to the moisture content and the value loss of the convection dryer is far better off than what pertain in the farmer's market survey. This means, with the parameters combinations, farmers will gain more money (at least $2.0/kg and highest $2.8/kg) for dried cocoa beans if they sell to the immediate buyers and

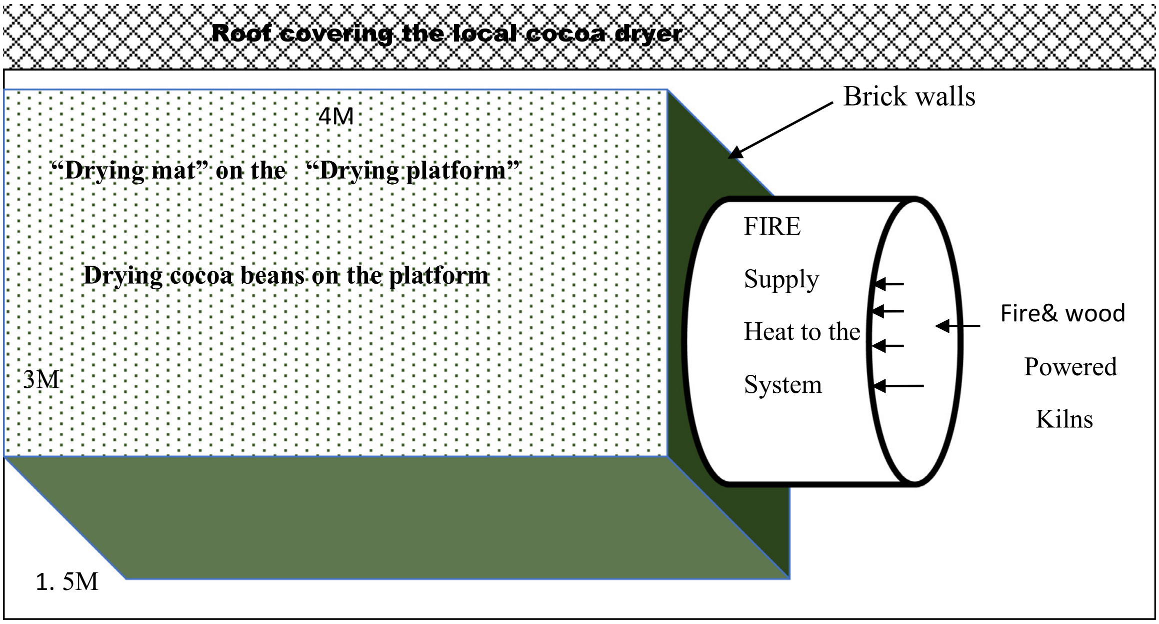

Fig. 3. Local cocoa beans dryer.

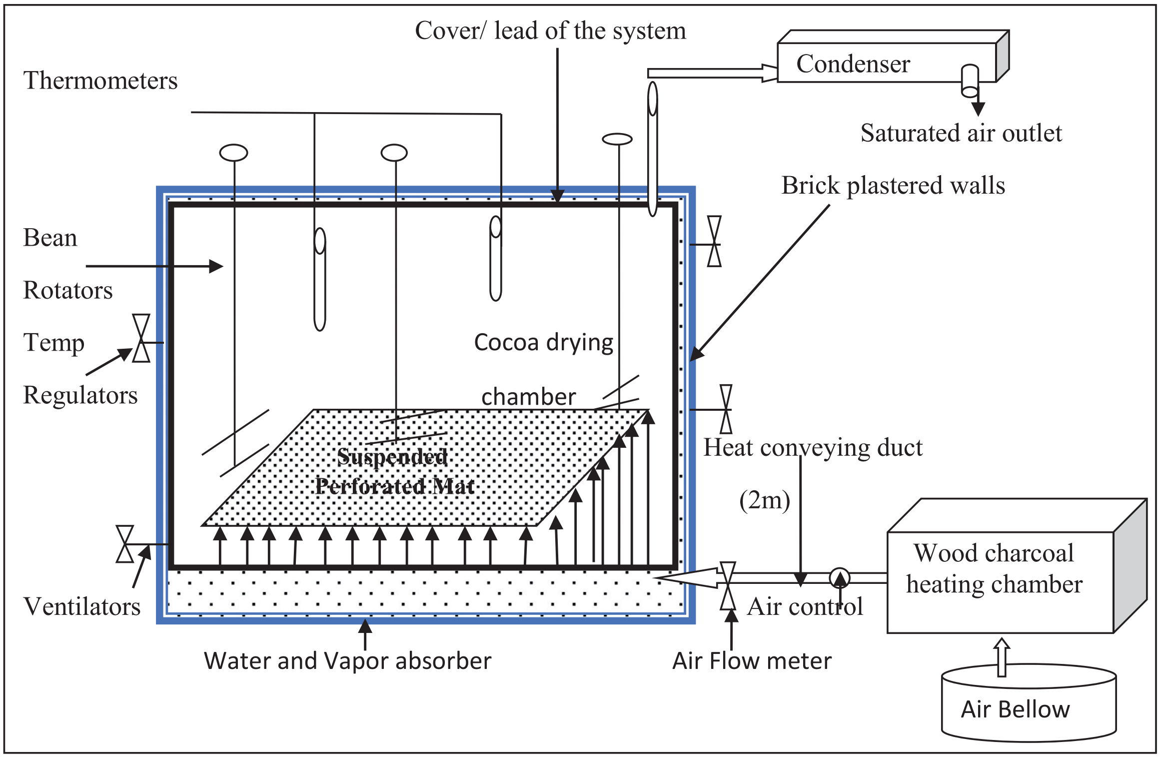

Fig. 4. Designed schematic convection dryer.

immediate buyers selling it in the world market (Table 5). This will boost the living standard of farmers and performance of Cameroon's gross domestic product in the following perspectives.

In upstream value chain, the new convection dryer offers cost effective and optimal drying tool that improves cocoa drying processes. (i) Offering solutions for farmers to dry their beans effectively when sun drying process is impracticable. (ii) Provides the possibilities for farmers to adopt, master /deploy quality tools such as DOE etc. that help develop personal toolkit with convenient application for optimal output. (iii) This also provides opportunities for quality standards adoption and the use of local technology in the industry to manage defects [9]. (iv) Overcome farmers' lack of drying implementation, evolution and feedback skills and tool through formal/informal training on agro-technology adoption.

(v) Reduce drying losses such as burns, cracking, roosting due to high temperature, acidity and bitter flavor due to fast drying, lose of flavor due to smoke taints in slow drying etc. [34,37]. (vi) Farmers sell quality produce at prices that reap maximum returns, i.e. farmers improved quality beans optimize value capture and increase profitability. This provides additional resources for farm exploration, exploitation and potentials to increase production, productivity which in turn improves local employment [5].

Downstream value chain, the value chain stakeholder access the produce with optimal desired quality and quantity, which support post drying packaging, optimal storage conditions, and shipping management such as reducing potential rotting, mold attacks etc. Moisture content dictates the storage duration and outcomes of the cocoa beans i.e. too dry cocoa beans lead to breakage and disintegration during transportation, poor downstream grinding and confectionery due to burns and bristle nature of the cocoa beans. These are overcomed with the new convection dryer to limit product rejection, boost increased demand competitiveness in the local and world market [17].

Policy implications**,** the results demonstrate the degree of quality, standards and research deficiencies in firms and industry. In this perspective the deployment of good practices, research/quality tools, skills, and innovation boost farmers and government revenues [22]. Policy development with possibilities for farmers to adopt the convection dryer, master/deploy DOE tool kit etc. help (i) improve the quality and quantity of export produce, boost competitiveness, and optimize foreign earnings, which further enhance employment, farms expansion and productivity. (ii) These efforts boost the country's revenue through taxes, duties and give the government incentives to invest in the development of quality management policies. (iii) Investing in the development of research base, innovation and technology through enhanced firm research, inter-firm research partnership, firms-universities alliances etc. provide advanced quality tools, skills and knowledge, to drive good practices in the drying process [18]. Therefore, the government gains competitive quality and quantity of the produce in the world market.

Conclusion

The cocoa value chain for Fako farmers is improved both locally and in international market when these parameters i.e. Temperature 35 °C, Time 96 hrs, Aeration rate 15m^3/s and Spaces to quantity ratio 12m^3/50kg are adhered to with optimal moisture content of 7.0%. Other improved experiments moisture results close to the optimal quality is in the range of 7.4% (high)6.3% (low). These results suggest that farmer's value loss per kilogram of cocoa will be reduced from $0.8/kg (highest) and $0.0/kg (lowest). Some of the limitations of the study are; farmers willingness to participate, financial constraints, and complex parameters combination. Further research can touch on the impact of fungi, molds and other bacterial on the dried cocoa beans produced by the new convection dryer and whether other parameters such as rotation rate can further optimize the cocoa value chain.

Declaration of Competing Interest

None.

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