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Development and performance evaluation of Maize-on-Cobs-Crib-Venturi utility for smallholder farmers

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ABSTRACT

The development and performance evaluation of a maize-on-cobs-crib-venturi utility as source of enhanced drying wind flow was undertaken with a view to help smallholder farmers'safely dry maize-on-cobs. The crib-venturi utility consists of a rectangular cob holding container / crib and a venturi structure of converging metal sheets with a widened inlet and constricted outlet openings. The crib-venturi utility was evaluated in terms of final moisture content, time taken to dry the maize-on-cobs, wind flow and drying efficeiency. Results showed that the moisture content of 18.3% (wb) was reduced to 14% (wb), drying time which was supposed to be 42 days was reduced to 25 days due to enhanced wind flow which improved by about 35% from 0.89±0.6 m/s at exit of the venturi structure, and crib-venturi utility improved drying efficiency from 17% to 23% on-research station at Agricultural Engineering and Appropriate Research Centre. The moisture content of 22.8% (wb) was reduced to 14. 2% (wb) and drying time which was supposed to be 60 days (farmer practice) was reduced to 25 days due to enhanced wind flow which improved by about 53% from 3.6±1.11 m/s at exit of the venturi structure, and crib-venturi utility improved drying efficiency from 21% to 39% on-farm in Kapchorwa, Uganda. The evaluation of the crib-venturi utility shows that it can be used for smallholder drying of maize-on-cobs in an oversized traditional crib.

Key words: Crib-venturi utility, Maize-on-cob, prototype, performance evaluation, Uganda

RÉSUMÉ

Le développement et l'évaluation des performances d'un utilitaire de maïs en épis-crib-venturi en tant que source de flux de vent de séchage amélioré ont été entrepris en vue d'aider les petits exploitants agricoles à sécher en toute sécurité le maïs en épis. L'utilitaire crèche-venturi se compose d'un conteneur / crèche rectangulaire contenant des épis et d'une structure venturi de tôles métalliques convergentes avec une entrée élargie et des ouvertures de sortie rétrécies. L'utilité du crib-venturi a été évaluée en termes de teneur en humidité finale, de temps nécessaire pour sécher les épis de maïs, de flux de vent et d'efficacité de séchage. Les résultats ont montré que la teneur en humidité de 18,3 % (wb) a été réduite à 14 % (wb), le temps de séchage qui était censé être de 42 jours a été réduit à 25 jours en raison de l'amélioration du flux de vent qui s'est amélioré d'environ 35 % à partir d'environ 0,89. ±0,6 m/s à la sortie de la structure du venturi, et l'utilité du crib-venturi a amélioré l'efficacité du séchage de 17 % à 23 % sur la station de recherche du centre de recherche en génie agricole et approprié. La teneur en humidité de 22,8 % (wb) a été réduite à 14,2 % (wb) et le temps de séchage qui était censé être de 60 jours (pratique des agriculteurs) a été réduit à 25 jours en raison de l'amélioration du flux de vent qui s'est amélioré d'environ 53 %. de 3,6 ± 1,11 m/s à

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la sortie de la structure du venturi, et l'utilité du crib-venturi a amélioré l'efficacité du séchage de 21 % à 39 % à la ferme à Kapchorwa, en Ouganda. L'évaluation de l'utilité du crib-venturi montre qu'il peut être utilisé pour le séchage de maïs en épis par les petits exploitants dans un crib traditionnel surdimensionné.

Mots-clés : utilité Crib-venturi, maïs en épi, prototype, évaluation des performances, Ouganda

INTRODUCTION

Maize (*Zea mays*), also known as corn is one of the world's leading cereal grains along with rice and wheat. About 175 million tons of maize is destined to food Worldwide.Its popularity as a crop is largely due to its diverse functionality as a food source for both humans and animals. Grains can be consumed off the cob, parched, boiled, fried, roasted, ground, and fermented for use in breads, porridges, cakes, and alcoholic beverages. Further processing leads to its use as food thickeners, sweeteners, oils, and non-consumables. Maize originally a New World crop, was introduced to Uganda in 1861 and by 1900 was already an established crop (Balirwa, 1992)

Today, maize is the most important cereal crop in Uganda providing over 40% of the calories consumed in both rural and urban areas (Lawrence *et al*., 2020). The crop has increasingly become a staple food in many parts of the country due to changes in people's eating habits. Small scale farmers, who constitute the bulk (80%) of the rural poor, also account for the largest share of maize production (Agona *et al*., 2001). Increasingly, maize has become a major non-traditional export cash crop particularly benefitting smallholder farmers. It is also an industrial crop for the animal feeds industry and it has high potential for value addition to support the agro-processing industry (Larsen *et al*., 2009; Plan, 2010).

In order to ensure crop, crop products and by-products of high quality, it is important that maize is propoerly dried to moisture levels of 12-13 %. This moisture level increases storage shelf-life, maintains seed viability and minimises mould growth. Unfortunately, over 90% of the maize produced in Uganda is sun dried by spreading it in thin-layers (Shepherd, 1999). Besides not drying the maize to the recommended moisture levels, the practice is very tedious involving lots of maize cob handling, time wasting, re-wetting from sudden rain and unhygienic. In addition, it predeposes the grain to contamination from dusts, soil, stones, and animal droppings. As a coppying mechanism, many farmers resort to selling maize at cheap prices to fresh cob roasters (Nuss and Tanumihardjo, 2010) and using over-sized crib width (more than 1.5m wide).

Farmers using the over-sized cribs are grappling with both qualitative and quantitative post-harvest losses of grain. Because the width of the tradional crib is wider than 1.5m reccomended by FAO, maize on cob loaded in the crib creates strong resistance to ambient air flow hence damping significant moisture as the saturated air fails to pass through the crib. The condition is exacerbated in wet seasons where humidity and rainfall remain high at harvesting. In the quest to address drying constraints under subsistence farming conditions and ensuring availabilty of the crop all year round, Agricultural Engineering and Appropriate Research Centre in Uganda adapted a venturi system onto wider maize cribs. The main purpose was to improve air speed passing through farmers' over-sided maize drying structure applying the venturi-effect through a converging passage between two walls built with ordinary roofing metal sheets, nails and wooden poles.

MATERIALS AND METHODS

Description of the crib-venturi utility and working principles. The structure consists of two main components that is a rectangular cob holding container /crib and a venturi system. The rectangular crib is where maize on cob is placed for drying and storage. It is made of wood and mettalic wire mesh on the walls and is roofed with iron sheets and 3 inch mashroomed nails. Its design, construction, orientation and site location incoporated all the factors required for an effective drying process as recommended by FAO (Bengtsson, 1986). The venturi component consist of a long tapered metal sheet-walled and wooden poled inlet-section, which ends in a throttle and then a second conical section designed with a smaller angle of exit all painted in black colour (Figure 1). The structure dimensions mentioned are full-scale values where:

L0=2,500mm (Venturi throttle outlet lenght)
W0=1,500mm (Venturi throttle outlet width)
L=1,620mm (Venturi inlet point lenght)
W=2,980mm (Venturi inlet point width)
H=3,860mm (Venturi structure cofiguration height)
α =27^0 (Structure orientation)
c =630 (Converging flow passage)
M= Walls built with ordinary roofing metal sheets, nails and wooden poles, all painted in black colour.

The attachement of this component is to benefit from the venturi effect. The principle is that the the atmospheric air enters the winder end and is impinged upon the throttle in the direction of the crib to increase speed. This drives the saturatued air all through the maize without causing damping. Using Bernoulli principle, there is a pressure drop in the throttle section causing constant sucking in of air (Bernoulli, 1738). Given that the air exit is narrower the air speed increases according to principle of continuity (Venturi, 1799; Blocken *et al*., 2008).

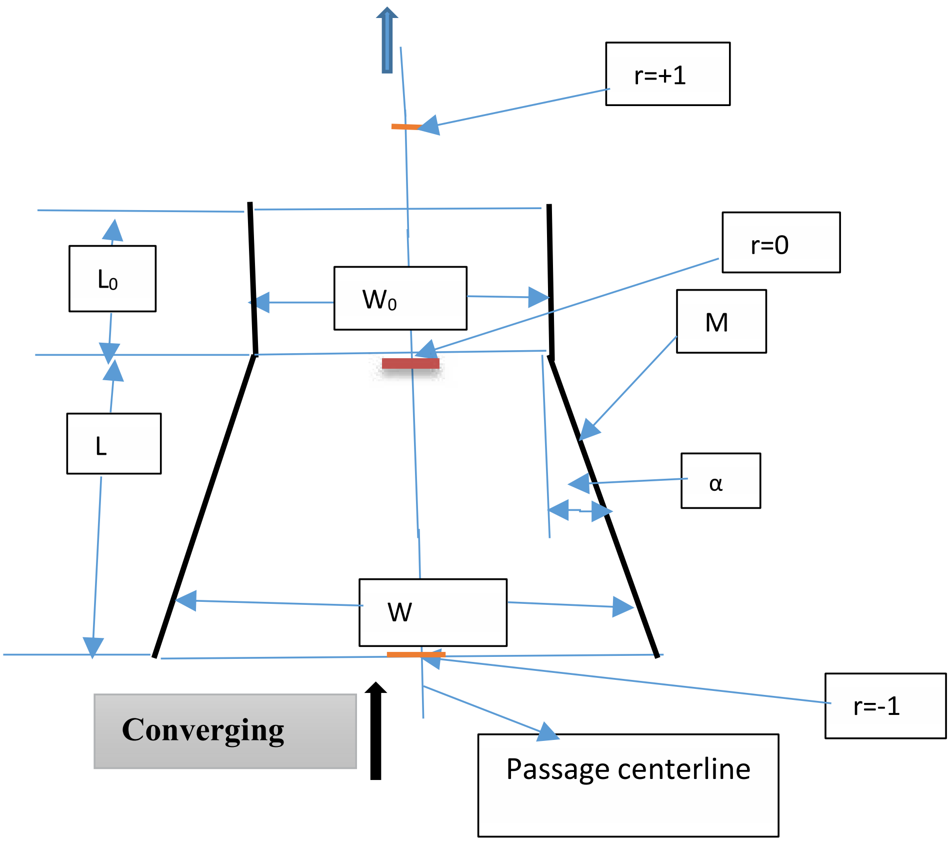

Figure 1. Top view of converging passage between two walls built with ordinary roofing metal sheets, nails and wooden poles

DESIGN PROCEDURES

Assumptions. The assumptions made in the design of the crib-venturi utility prototype are presented in terms of the efficiency of the crib-venturi utility prototype assuming a function of size entrance and exist, wall length (200cm throttle, 300cm inlet) and height (290cm), and pressure /resistance being a liner function of the wind entrance. The venturi structure adopted inlet width 25^0- $30^0 \pm 2$ and outlet angle 0^0-15^0 (Figure 2) charged to minimise the net pressure drop that define the characteristic curves.

Assumptions made on measurements in the design of the crib-venturi configulation were piloted at a scale of about 1:12 based on Blocken *et al.* (2008). The passage flow between building structures is mainly influenced by the structure orientation, structure arrangements, structure dimensions and passage width (Blocken *et al.*, 2008). The basic crib-venturi utility configuration and dimensions are illustrated in Figure 1, where r is a dimensionless coordinate along the passage centerline with r = 0 at the location of the narrowest passage opening. The direction of the r-axis is according to the flow direction (positive in downstream direction). Using the Venturi- effect guidelines, crib-venturi utility configuration, dimensions and experimental conditions were pilot down scaled at 1:12 (Gandemer, 1975) . H = 3.86m (>15m), 2L = 3.24m (>100 m), W = 2.98m(>30-45m) and open free-field exposure. This piloting work has only examined a 63 converging direction flow passage. The converging structure orientation (α =27^0C) is defined as the angle between the structure walls lengthwise edge and the approaching wind direction (Perry *et al.*, 1973). This is the angle between the structure walls lengthwise edge and the approaching wind direction (Figure 2).

Prototype description. The wind inlet width angle orientation was directly opposite the prevailing winds for optimal wind catch to allow the enhanced wind velocity go through the maize cobs in the crib width and expel the humidified air out to facilitate the drying process. The venturi outlet width angle orientation was fitted to touch directly opposite the 300cm width crib body container to facilitate investigation on drying front forms. The venturi effect utilises both the principle of continuity as well as the principle of conservation of mechanical energy. A plenum was constructed by enclosing beneath the crib stands (Figure 3) with metal sheets to force trapped air flow up through the drying maize cobs in the crib.

Performance evaluation and experimental Analysis. A 300cm crib width-venturi utility was constructed and tested at both the Agricultural Engineering and Appropriate Research Centre (AEATREC) of the National Agricultural Research Organisation (NARO), and on-farm in Kapchorwa district. The two sites greatly differ in terrain and weather posing worst drying conditions. Agricultural Engineering and Appropriate Research Centre is located in the Lake Victoria topographic zone in Wakiso district in the Central Region of Uganda. The district coordinates are: 00 24N, 32 29E at

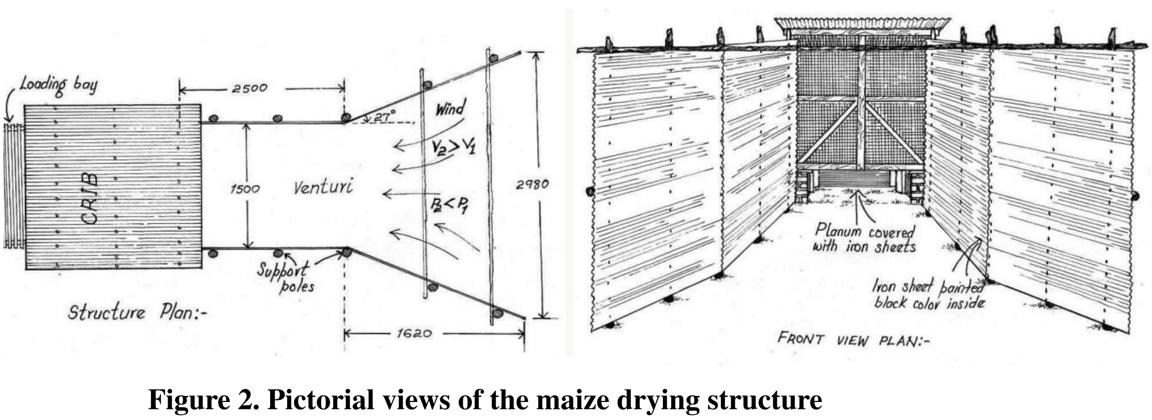

Figure 2. Pictorial views of the maize drying structure

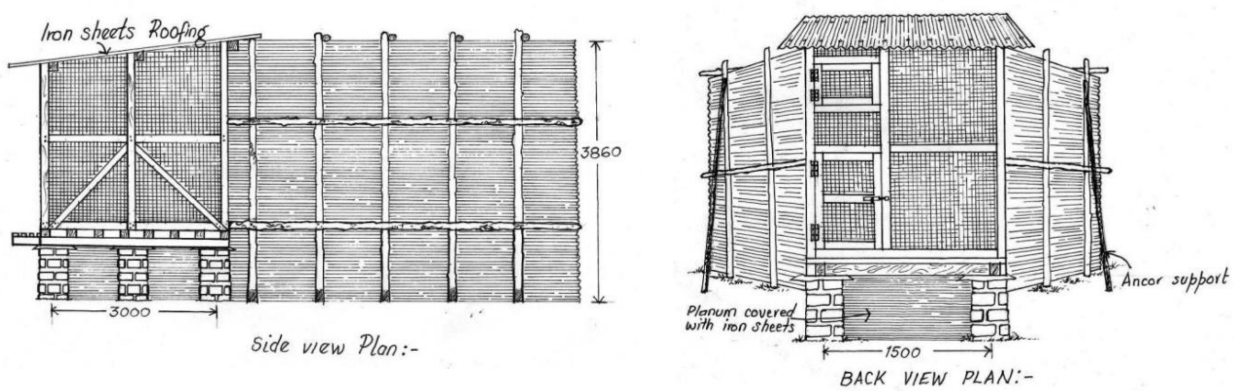

Figure 3. Details of the crib container for the drying structure

mean elevation 1,200m above sea level. The climate is warm and wet with relatively high humidity. The wetter season lasts 8.6 months, from March to November, with a greater than 59% chance of a given day being a wet day. The drier season lasts 3.4 months, from November to March coinsiding with second harvest maize season.

The temperature at the local agromet stations in Kawanda and Namulonge varies between 14.1 and 33.3 degrees centigrade throughout the year, with significant seasonal variations in humidity. The high humid (70-91%) period of the year lasts for 10 months, from August to June, during which time main harvesting and drying season of fresh maize on cob starts from May to July. The weather is muggy and oppressive at least 57% of the time.

The average hourly minimum and maximum wind speeds are 2.41 metres per second (May to August) and 2.95 metres per second (July), respectively, with predominant hourly wind direction varing throughout the year. The wind is most often from the south for 9.5 months (January to November), with a peak percentage of 80% in July http://www.wakiso.go.ug/wakiso/location-geography.

Kapchorwa District is in the Eastern Region of Uganda, on the slopes of Mount Elgon. Thirty-seven percent of the district is within Mount Elgon National Park, a forested mountain ecosystem on the border with Kenya. The district coordinates are: 01 24N, 34 27E, with altitudes ranging from 1,000m in the lowlands to between 1,400m and 2,000m in the highlands, which host mountainous forests. The average annual minimum and maximum temperatures at the local weather station in Buginyanya (at approximately 1,800m) are 13.2 and 23.2 degrees centigrade, respectively. The low humid (dew point) period of the year lasts for 2.8 months, from June to September (with an average daily high temperature below 25°C), during which time their only harvesting and drying season of fresh maize on cob starts from August to October. The weather is muggy, oppressive and does not vary significantly over the course of the year making drying difficult.

The average hourly minimum and maximum wind speeds are 2.82 metres per second (November to April) and 4.11 metres per second (December), respectively, with predominant average hourly wind direction varing throughout the year. Between May and September, the wind is most often from the west for 3.4 months with a peak percentage of 43% in July, while most often from the north for 1.1 weeks during September, with a peak percentage of 30%. It is also most often from the east for 8.3 months (September to May), with a peak percentage of 89% in January.

At AEATREC, crib width of 150cm which is recommended for maize drying by FAO was used to compare the performance of the developed utility. On-farm, crib width of 300cm which is the popular practice by farmers in Kapchorwa was used to compare the performance of the developed utility. Both the trapped air from the venturi stucture and the plenum is forced through the maize cobs and obsorbs some of its moisture, and in turn the drying proceed until the desired level of moisture content is attain.

De-husked maize-on-cobs were compensated for from farmers, brought to crib-venturi utility treatments for simultaneous loose loading to eliminate the impact of ambient conditions under natural convection in order to preserve and maintain their initial moisture content. The treatments were replicated three times. Trials were run for two harvesting seasons. The initial moisture content of maize on cob and dried grain were determined using a moisture analyzer and laboratory oven method. Temperature, relative humidity and pressure inside the treatments were recorded using data loggers. Three cages from metal dickson sheets were used to securely pack each a working sample size of 36 cobs to track performance of the prototype crib-venturi utility. The cages were purposely placed at A=75cm; B=150cm and 225cm along the 300cm crib-width moving from where the venturi outlet touches the crib. In the 150cm crib-width, the cages were placed as follow: A=37.5cm; B=75cm; C=112.5cm. Performance of the prototype crib-venturi utility on wind flow at the venturi inlet and outlet points was recorded using anemometers. Further, quality integrity of maize grain dried in the crib-venturi utility was determined based on EAS, 2011 and ISTA, 2016 standards. Drying in a well-designed and built crib, the moisture content should go down to around 14 percent within about 42 days.

Performance Indicators

Drying time and drying rate. The relative drying time (t14) was calculated from the drying curve and defined as the time taken to dry down to 14% grain moisture content, which means the duration from the initial moisture content to dry-down to 14% (wet basis) (Figure 4). In this study, an average drying rate was determined from the average moisture removal from 20% to 14% moisture content (wet basis) in order to present the relative drying rate of maize harvested at 22% and 18%.

The relative drying rate was determined using equation 1 (Gunasekaran and Paulsen, 1985)

$$\text{Relative Drying rate} = \frac{(MC20 - MC14)}{(t14 - t20)}, \text{(kg/day/kg)} \qquad \text{Equation 1}$$

where, MC_{14} and MC_{20} are actual grain moisture contents at 14% and 20% on the curve and t14 and t20 mean drying time (day) taken to get grain to 14 and 20% moisture content, respectively. The relative drying rate was then expressed as the average moisture removal in kg of water per day per kg of grain (kg/day/kg). Figure 4 illustrates the drying time and drying rate from the drying curve, where MC14, and MC20 indicate the grain moisture content 14% and 20%, and t14 and t23 indicate the time taken to reach these moisture contents.

Drying Efficiency. The crib-venturi utility prototype was tested to determine the drying efficiency using the following formula

$$\text{Drying Efficiency, } \eta = \frac{\text{Moisture removed}}{\text{Initial Moisture}} x100 \text{ (Percentage)} \qquad \text{Equation 2}$$

RESULTS

The results of this study was subjected to analysis of variance (ANOVA) while significant means were separated with the Duncan's Multiple Range Tests using SAS (2005) on the mean values obtained from the experiment in order to compare the mean moisture content, drying time of maize on cob samples and drying fronts in the maize crib container at the crib-venturi drying ambient conditions used.

The analysis showed that application of the venturi effect have significant impact on the drying time at about 43%. It took 25 days to dry the maize on cob from moisture content of 18.3% (wet basis) to 14% (wet basis) at AEATREC. The average moisture removal was 0.17kg of water per day per kg of grain (kg/day/kg). While it took 24 days to dry maize on cob from moisture content of 22.8% (wet basis) to 14. 2% (wet basis) in Kapchorwa. The average moisture removal was 0.36kg of water per day per kg of grain (kg/day/kg). Wind flow through the utility improved by 52.8% and 85.7% at AEATREC and on-farm respectively. Drying efficiency improved from 17% to 23%at AEATREC, while improved from 21% to 39% on-farm. Wind flow improved by about 35% from about 0.89±0.6 m/s at exit point of the venturi structure at BAERP, while improved by about 53% from 3.6±1.11 m/s on-farm.

Figure 5 shows the relationship between moisture content and time. It was observed that the final moisture content (wet basis) reduced as the time of drying increased. This showed that as the moisture content (wet basis) in the maize-on- cob decreased, it attained only a falling rate during the drying period. Drying continued till the rate of evaporation of water from the maize-on-cob reached critical moisture content (wet basis). The moisture removed with increase in drying time increased initially because of the high moisture content (wet basis) of the maize, which after sometime, the rate of moisture removed decreased due to reduction in the maize-on–cob moisture content (wet basis). It was observed from the drying curve shown below, that from the 3rd day of drying on wards, the mousture content trends between treatment and control were significantly different.

It was observed that the crib centre (150cm), along crib body width, had the highest moisture content due to the fact that it had air circulation lesser than the rest parts of the crib. Also, the mousture content trends between treatment and control were significantly different.

Figure 6 gives the relationship between moisture content and drying fronts in the maize crib container. Where: A-point (75cm) quarter way from venturi exit end wind direction. B-crib centre (150cm) along crib body width; C-point (225cm) three quarter way from end of crib body width.

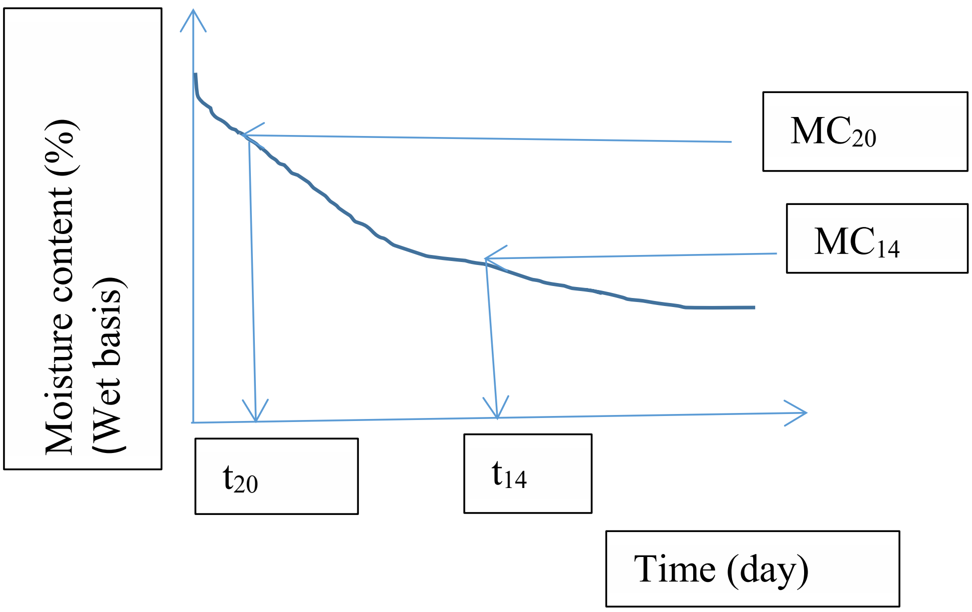

Figure 4. The drying curve of new maize drying structure

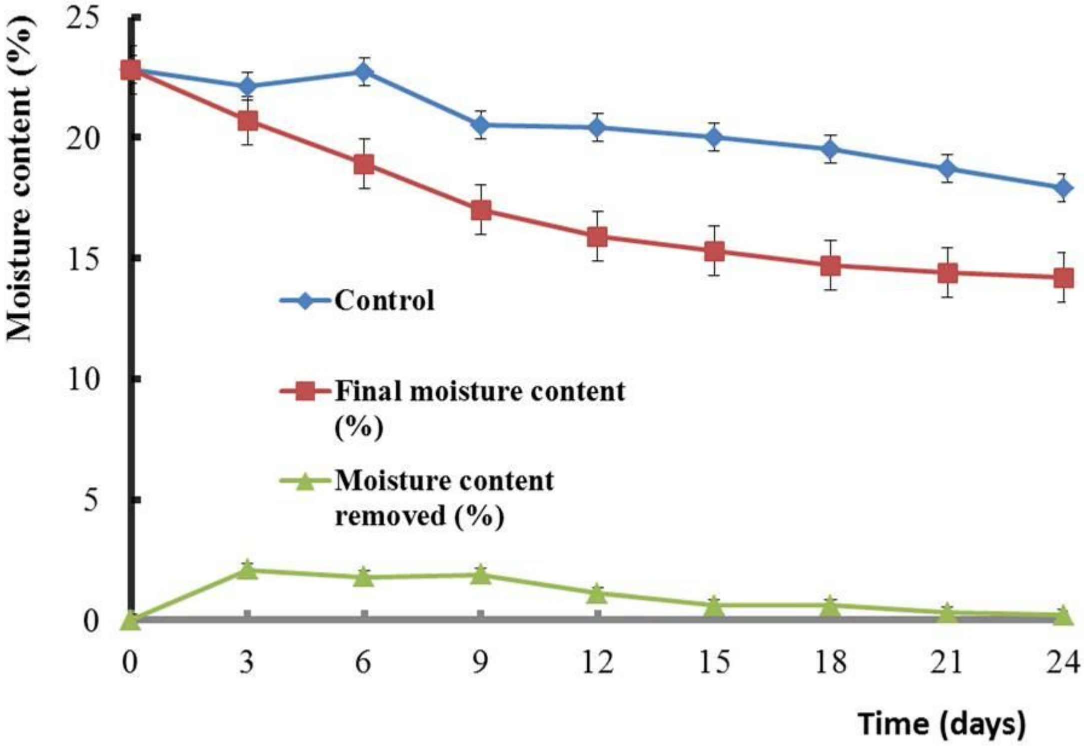

Figure 5. relationship between moisture content and time

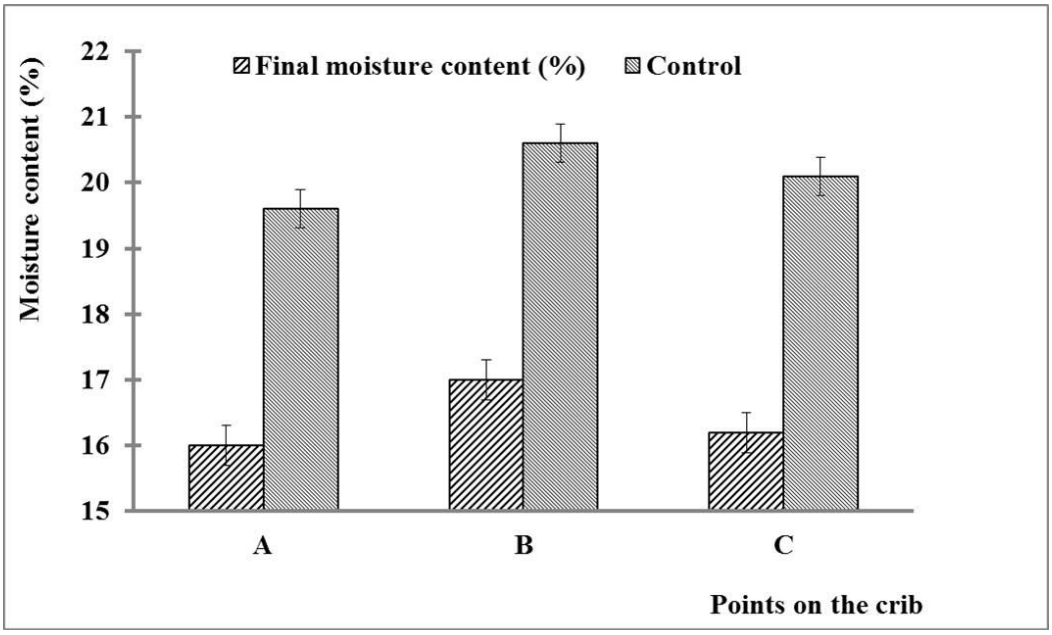

Figure 6. Relationship between moisture content and drying fronts in the maize crib container

CONCLUSIONS

A prototype crib-venturi utility was designed and fabricated to dry fresh maize-on-cob in a 300cm crib-width (oversized). The utility was fabricated mainly using locally available materials (Annex) and was primarily intended to match the smallholder farmers' needs of increasd holding capacity to dry and store their freshly harvested maize. Emphasis was also put on elimination of significant drying fronts by increasing velocity of air flow through such oversized crib option. The moisture content of the maize on cob was reduced from 22.8% to 14.2% (wet basis)within 24 days as opposed to 42 days. The average moisture removal was 0.36kg of water per day per kg of grain (kg/day/kg). Wind flow through the utility was enhanced by 85.7%. Drying efficiency was enhanced by 39%. Wind flow was enhanced by 53% at exit point of the venturi structure. Overall, the venturi effect significantly impacted on the drying time at about 43%.

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STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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