An Engineered solar crop and meat dryer for rural Africa: A techno-economic outlook

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Abstract. This paper introduces a new solar crop dryer design for small scale entrepreneurs going into crop storage and marketing. It is an indirect drying system requiring 2 m$^2$ ground space for installation of both the 2 m$^2$ collector and the 1 m$^3$ dryer chamber. Both collector and dryer are designed de-novo, and manufactured to give one assembly. The assembly is then analysed for heat and mass transfer using both TRNSYS and MATLAB software. For places with an equatorial climate, the system is predicted to be adequate for a start, with daily moisture removal limits of between 12 and 15 kg. This translates to a drying rate of about 20 kg/day wet produce from 75% to 12% moisture content. An economic analysis is done for two cases of direct manufacture and importation. In either case, it is found that breakeven is possible within the first one to two years of acquisition for high value products - in part because of the heavy crop and price losses currently experienced with sun drying. It is therefore concluded that the new product may not only be helpful in reducing food waste, but that it might also have economic viability to commercial entrepreneurs.

1. Introduction

Harvest-ready food crops face five loss stages between the farm and the dinner table [1]. The first two are at farm level, namely mechanical losses during harvesting and postharvest losses (PHL) due to high moisture content, handling, insect pest and rodent attack during storage. The next two: processing and distribution losses are in part influenced by moisture contents and packaging achievable at the farm level [2, 3]. The last stage, better classified as food waste, is at time of consumption. From this classification, it is seen that moisture control after harvest is a critical farm level activity because it controls 3 of the stages. In fact, together with packaging, their effective implementation could eliminate most of the food losses encountered.

In sub-Saharan Africa, PHL estimates vary depending on the weather, the type of crop [3], ease of access to markets and even gender of farm head [4]. Actual losses are difficult to estimate both in quantity and quality [5] but in a study in Uganda, Malawi and Tanzania, Kaminski and Christiaensen gave estimates of 1.4 to 5.9% on national maize crops, and up to 8% on cereals by mass [1]. Yet these average figures can be misleading when it comes to individual farmers. In Ethiopia, a 2017 report shows that 10% of households sampled lost an average of 24% of cereals [6]. When it comes to root crops like potatoes, cassava, yams, etc. losses can be higher because of the entrapped water in the bigger tubers. Ethiopia is reported to lose 20 to 25% of its potato production as a result [7]. The heaviest losses are in fruits and vegetables because of their relatively more perishable nature. Up to a third of these are reported to be lost at PHL level [8].
The above losses lead to malnutrition and malnourishment, with the result that up to 230 Million sub-Saharan Africans, or a third of the total world’s starved population were reported to be thus-affected [9]. In tackling this problem, governments have tended to focus attention on agricultural production increase. However, the populations have increased faster than outputs. A report by NEPAD for example gives a doubling of population over a 30 year period for the entire SSA region while production of cereals went up only 80% with even smaller increases in meat and fruits and vegetables [10]. This work therefore attempts to contribute in tackling the drying problem closer to the farm level just after harvest. It adds to previous work by the author and others, this time, introducing a variant dryer that occupies less space, loses less energy, and is more suitable for small scale commercial application at the rural village level. Accordingly, in section 2, we first do a quick review of dryer theory and practice and finally use those principles to introduce the new design. In 3, we do a performance prediction analysis of the designed and constructed collector-dryer assembly for a typical rural place at the equator. Finally in section 4, we check commercial viability through either the direct local manufacture route or through imports from South Africa for an agricultural country far away from South Africa. We conclude with a summary of the work, and a pointer to next steps.

2. Crop dryer theory and designs
Most farmers in Africa use direct sun drying to dry the harvested crops. As pointed out by Runganga and Kanyarusoke [11], this is fraught with problems of poor moisture control, contamination, and even product thefts/damages. It is slow and inconvenient – as the product must be covered or removed if the weather shows signs of changing to rainy form.

There are many types of crop dryers although they have not been commercialized to any significant extent in Africa. They may be classified into direct and indirect systems depending on whether the crop is heated directly by the sun or indirectly by hot air. A mixed flow system also exists. Also depending on the source of air circulation, they may be forced (active - fan driven) or naturally (passive - natural convection) ventilated. Figure 1 illustrates a few examples of dryers. In a left to right order, we have a direct system with forced ventilation, then one with natural ventilation followed by a mixed system. These three were developed at CPUT by Runganga and Kanyarusoke [12]. The fourth and last one is an indirect system with reflectors as reported by Sharma, Chen, and Lan [13].

2.1. The Physics of covered crop drying
Covered crop drying could be direct – in which case, the crop receives direct sunlight through a glazing cover, converts it to thermal energy, and then loses moisture by diffusion from within to the air between it and the glazing. Two forms of this mode are described in an earlier publication [11] and are illustrated as the first two in figure 1. In one, natural convection helps evacuate the moisture laden hot air, while in the other, forced convection does so, with help of an evacuation fan. For these direct systems, a schematic of the layout is shown in figure 2.
Alternatively, drying and can be indirect – whereby, it is effected using a current of heated air. It then does not matter how this air has been heated – as long as it is at a ‘good’ temperature and a ‘good’ relative humidity when it arrives in the dryer. In this paper, we look at a situation where the air is heated in a solar collector before entry into the drying chamber. Then, there are two subsystems to consider: the solar collector, and the dryer. Hereunder, we briefly describe the physics of these subsystems.

2.1.1. Solar collector Thermodynamics and design. Figure 3 shows the essentials of a simple solar collector. Ambient air enters the unit, is heated to raise its temperature while lowering its relative humidity as well. The exit temperature and relative humidity are given by equations (1) and (2).

\[ T_{\text{air-out}} = T_{\text{air-in}} + \frac{F_R A_p}{m_{\text{air}} c_{p,\text{air}}} [1 - U_L (T_{\text{air-in}} - T_a)] \]  
\[ \Phi_{\text{air-out}} = \Phi_{\text{air-in}} \left( \frac{P_{\text{sat-in}}}{P_{\text{sat-out}}} \right) \]  

The most important parameter in equation (1) is the overall heat loss transfer coefficient \( U_L \), which is dependent on different convection coefficients, radiation heat transfers and conductivity of the insulation materials. As the collector plate warms up and as weather conditions change, so does \( U_L \). Together with air properties and flow rate, it determines the heat removal factor \( F_R \) and an associated collector efficiency factor, as described in standard solar energy engineering books (e.g. [14]). The issues in design are to select glazing, plate and insulation materials, determine their dimensions and the spacing between glazing and plate so that \( U_L \) is as small as will most economically deliver a desired temperature.
for a given air flow rate. In crop drying, the flow rate and temperature are dictated by requirements of the dryer.

2.1.2. Indirect crop dryer Thermodynamics and design. In indirect drying, the hot air from the collector of figure 3 (or from some other thermal reservoir) is directed to a crop dryer. There, crop drying consists of two steps. First, water molecules migrate from the interior of the crop to the surface, and then, the water evaporates from the surface into the surrounding air. The first step is considered to be controlled by laws of diffusion, commonly expressed in Fick’s law given by equation (3) and where the diffusivity $D$ is temperature-dependent in line with the Arrhenius chemical kinetics equation (4).

$$\frac{\partial m_w}{\partial t} = \nabla (D \nabla m_w)$$

$$D = D_0 \exp\left(-\frac{E_a}{RT}\right)$$

If moisture diffusion in a drying crop bed is considered to be in the singular crop-air direction, $'y'$, then equation (3) simply becomes:

$$\frac{dm_w}{dt} = D \frac{d^2m_w}{dy^2}$$

At the end of drying, when steady state is achieved, it is easily seen by solving equation (5), that the moisture distribution in the bed will be linear, meaning that it is not possible to dry a thick bed to zero moisture content. The issue in drying therefore, is to ensure that the maximum moisture content in the crop bed gives a water activity index $\alpha_w$ below that at which microorganisms stop growth, and at which crop enzymatic activities cease. Suitable values are reported as: 0.55 for bacteria, 0.61 for molds and yeasts, and 0.70 for fungi [15]. The activity index is the relative humidity inside the crop body – which is the ratio of partial crop water vapor pressure to the saturation water pressure at the crop temperature as in equation (6).

$$\alpha_w = \frac{P_{c-w}}{P_{sat-w}}$$

The second step in drying - the transfer of moisture from the crop surface to the air – is a dynamic evaporative process which is controlled by the relative water partial pressure differentials between the crop surface and the air. Beginning with a high surface partial pressure from diffusion of the earlier step, steam flows into the relatively dry air, raising its humidity, but also lowering that in the crop until both partial pressures (in the air and at the crop surface) equalize. This process is both air-temperature and velocity dependent. These two in the first case determine the heat transfer rate to the crop – in line with equation (7) and hence, control the rate of water diffusion to the crop surface. Secondly, velocity helps convey the newly arriving vapor from the area surrounding the surface, adding a suction effect onto the internal diffusion process. Besides, moderately higher velocity (not high enough to blow the product) means higher dry air flow rate, and therefore a higher ability to absorb the vapor.

$$\frac{q}{A_c} = (h_{ev} + h_{conv})(T_{air} - T_c)$$

There are 5 stages of heat and mass transfer to consider in crop drying, depending on the crop and the conditions in the drying chamber. Figure 4 illustrates the stages. A brief description of the stages is as follows:

I. Initial heating up to drying temperature - here, the heat transfer is largely of sensible form with generally rising moisture losses from zero as crop temperature rises.
II. Steady state drying at drying temperature - A steady state is achieved in which the crop surface is constantly saturated with moisture. The heat transfer in this case is largely evaporative, dictated by the drying chamber temperature and airflow rate. The rate of moisture diffusion in the crop matches that of evaporation at the surface.
III. Slow drying after critical point C at end of saturated evaporation – now the moisture in the crop has reduced to below a critical value and the internal diffusion rate can no longer cope with the rate of the previous stage. Hence, internal diffusion takes over the control of drying rate. The crop still has some unbound water between its molecules.

IV. Slower drying after exhausting unbound water in crop;

V. Difficult region of near zero drying, and which could start moisture reabsorption from the air.

The issue in crop dryer design is to consider the nature of crop initial conditions and then provide conditions for it to be dried to some level in region IV. Ekechukwu states that grains typically enter dryers when already in region III while fruits, vegetables and tubers enter while in region II because of their higher moisture contents [16]. In the latter case, convective heat and mass transfer in the dryer significantly affect drying time while water diffusion within the crop in the former is the main controlling phenomenon.

2.2. A simple indirect heated crop dryer for rural farmers

The principles in section 2.1 were used to design a low cost 2 m X 1 m solar collector coupled to a 1.0 m X 1.0 m X 1.0 m drying chamber. Figure 5 shows the assembly while Table 1 gives the key specifications and materials costs.

![Figure 5. A brand new optimised forced ventilation indirectly heated crop dryer assembly](image-url)
Table 1. Key specifications and costs of the collector-dryer assembly

| Item               | SOLAR COLLECTOR | Cost (US$ Equiv.) | DRYING CHAMBER | Specification                  | Cost (US$ Equiv.) |
|--------------------|-----------------|-------------------|----------------|--------------------------------|-------------------|
| Dimensions         | 2 m X 1 m X 0.1 m | 31.13             | Outer – Galv. Steel sheets 0.5 mm | 39.00             |
| Casing             | Aluminium sheet 0.9 mm | 31.13             | Inner – Al sheets 0.9 mm | 62.26             |
| Glazing            | Double Polycarbonate 1.5 mm | 62.21             | Double PC 1.5 mm for door | 31.11             |
| Insulation         | EPS 25 mm with 3 mm plywood on top | 12.00             | Extruded polystyrene 25 mm | 20.00             |
| Collector Plate    | Aluminium sheet 0.9 mm | 31.13             | Aluminium angles 25 mm X 25 mm X 3 mm | 30.00             |
| Fan                | 10.8 W; 12 V DC | 53.33             | Weight          | 25 kg | 39 kg | |
| Mfg. cost          | 50.00           | 50.00             | Tot. Prd. cost  | 239.80 | 232.37 | 472.17, say 500.00 |

3. Performance expectation of the dryer
Performance of the dryer in rural areas is expected to vary with the weather and crop/product being dried. Here, we use TRNSYS simulation to obtain temperatures and humidity ratios exiting the collector to enter the dryer. In the dryer, we use these, and published transport properties of various crops/products to obtain drying rates and times for the products. We illustrate this approach for a place at the equator, where typical seasonal crop harvesting is done twice a year in the dry seasons.

3.1 Solar collector TRNSYS simulation for Gulu, Uganda
Figure 6 shows the TRNSYS setup and its outputs for determining collector temperature and humidity ratio outputs for one rural place in Uganda, East Africa.

3.2. Formulation of energy and mass balances for MATLAB® programming
As mentioned in 2.1, some products enter the dryer in stage II and others in stage III of drying. Taking those entering in stage II, the crop surface is at the dryer’s wet bulb temperature, \( T_{wb} \) (°C) because of saturation with water, while the chamber is at \( T_{ch} \) > \( T_{wb} \) to facilitate heat transfer to the crop, and subsequent mass transfer into the chamber. The program further calculates the time of reaching the critical point for the crop/product, and then switches to stage III drying. In this computation, differences between stages III and IV are ignored, so that it is supposed target moisture content is attained in stage III.
In phase II of drying (Figure 4), the crop surface temperature is steady at the drying chamber’s wet bulb temperature, and moisture is steadily migrating to the chamber at a rate \((\omega_{ch} - \omega_a)\dot{m}_a\). Referring to figure 7, the energy equation for the dryer can then be written as:

\[
\dot{m}_a (h_{a-c} + \omega_a h_{s-c}) = \dot{m}_a (h_{a-ch} + \omega_{ch} h_{s-ch}) + \dot{Q}_l
\]  

For a well-insulated chamber, with \(\dot{Q}_l << \dot{m}_a (h_{a-c} + \omega_{ch} h_{s-ch})\), adiabatic drying conditions may be assumed so that:

\[
h_{a-c} + \omega_a h_{s-c} \approx h_{a-ch} + \omega_{ch} h_{s-ch}\]  

The heat and mass transfer equations at the crop surface – after applying the Chilton—Colburn analogy, give:

\[
T_{ch} - T_{wb} = \frac{0.622 h_{fg-wb} \rho_{a-ch}^{0.23}}{c_p \rho_{air} d_{air} P_{atm}} \left[ P_{sat-wb} - \frac{P_{atm} P_{sat-ch}}{0.622} \right]
\]  

The wet bulb temperature, \(T_{wb}\) can be found from the adiabatic heat transfer between the dryer chamber air and the crop surface at \(T_{wb}\) as:

\[
T_{wb} = T_{ch} - \frac{1}{c_p \rho_{air} d_{air} P_{atm}} \left[ \frac{0.622 P_{sat-wb}}{P_{sat-ch}} h_{fg-wb} - \omega_{ch} (h_{s-ch} - h_{f-wb}) \right]
\]  

Equations (9) to (11) can be solved simultaneously for \(T_{ch}\), \(\omega_{ch}\) and \(T_{wb}\). To do so, all key thermodynamic properties in the chamber are first related to the chamber temperature \(T_{ch}\) as given below:

- Latent heat of evaporation \(h_{fg}\) (kJ/kg) at temperature, \(\theta^{°C}\):
  \[h_{fg} \approx 2500.304 - 2.2521025\theta - 0.021465847\theta^{1.5} + 3.1750136\times10^{-4}\theta^{2.5} - 2.8607959\times10^{-5}\theta^{3}\]  

- Saturation enthalpy of liquid water, \(h_f\) (kJ/kg):
  \[h_f \approx -0.02844699 + 4.211925\theta - 0.001017034\theta^2 + 1.311054\times10^{-3}\theta^3 - 6.756469\times10^{-8}\theta^4 + 1.724481\times10^{-10}\theta^5\]  

- Specific enthalpy of superheated water vapor in chamber air, \(h_{s-ch}\) (kJ/kg):
  \[h_{s-ch} = h_f - h_{fg} + 1.82(T_{ch} - T_{wb})\]  

- Diffusivity of water vapor in excess air at temperature, \(\theta^{°C}\) (\(0 < \theta < 100\)) \(D\) (m\(^2\)/s):
  \[D = 0.219\times10^{-4} + 9.875\times10^{-8}\theta + 8.125\times10^{-10}\theta^2\]  

**Figure 7.** The dryer subsystem and its energy and mass transfers
3.3 MATLAB® programming for estimating drying times of different crops

For TRNSYS results in 3.1, equations (9) – (11) are solved iteratively in MATLAB®, upon use of relations (12) – (16). The procedure is to guess an initial value for $T_{ch}$, starting with a value of $T_a$, the ambient temperature from TRNSYS. Then, compute the appropriate $\omega_{ch}$ and check whether the resulting $T_{wb}$ satisfies equations (10) and (11). If not, increment the guess value of $T_{ch}$ by a standard value (e.g. 0.5°C) and repeat the computations until the equations are satisfied to within acceptable limits. This procedure is done for each result from TRNSYS simulation, and the outputs are assembled in a two column matrix of the form:

$$Mat = [Time \quad \dot{m}_d(\omega_{ch} - \omega_a)] \quad (17)$$

The integral of $\dot{m}_d(\omega_{ch} - \omega_a)$ with respect to $Time$ gives the cumulative moisture loss from the crop. For different crops, the time to exit drying phase II can be therefore be determined.

4. Results from fully loaded dryers

In this section, we illustrate results of the TRNSYS simulations for places in neighborhood of Gulu a rural weather station in Uganda, just north of the equator. This is summarized in figure 8. The slope of the collector is fixed at 5° in line with earlier work on maximizing radiation incidence on solar collecting surfaces [17]. In figure 9, we show results of the formulated MATLAB® program for a few days in the dry (post-harvest) season at the beginning of the year. The first two show typical hourly drying rates while the third shows total daily moisture removals for the first 10 days of the year.

![Figure 8. Gulu, Uganda 2X1m² (1.82 m² effective glazing area) TRNSYS performance prediction](image)

(a) Performance on a good sunny day  
(b) Performance on a cloudy day
5. Economics of the crop dryer
For a given farmer, economy of the designed dryer is dependent on the initial purchase cost, the general weather parameters during the harvest period, the crops dried, the running and maintenance costs and its expected life span. In this section, we analyze these costs for three crops – one in each category: fruits and vegetables; grains/cereals; and roots/tubers. We theorize on two supply chain scenarios – i.e. where the product is locally manufactured in an economy, and where it is imported from a country like South Africa, where the costs of raw materials are as given in Table 1 above. We make the assumption that retail price in a country of manufacture is 200% of the manufacturing cost with trade margins of up to 25% of retail - so that the manufacturer price is 150% of manufacturing costs. For imports, we also assume trade margins of 25% on retail revenues but that the importer prices the product at 125% of the landed cost consisting of cost, insurance, freight, clearance and import tax - if any.

5.1 Costs of crop dryers
Initial consumer costs consist of the purchase price, the delivery and installation costs. Mathematically this is expressed as in equation (18).

\[ C_{\text{cap}} = C_{\text{pur}} + C_{\text{div}} + C_{\text{ins}} \]  \hspace{1cm} (18)

Subsequent to installation, running costs consist of operating (labor and electricity mainly) and maintenance (regular cleaning, inspections, corrections, and painting of outer surfaces as may be necessary). For a labor cost rate \( c_l \) US$/day, energy rate \( c_e \) (US$ per kWh), an annual maintenance cost \( C_{\text{main}} \), and an expected system life \( L \) years of 365 days each averaging \( t_h \) equivalent hours of 1 kW/m\(^2\) collector incident power, the daily cost of using the dryer is given by equation (19). The first bracketed terms form a fixed daily cost while the last two terms give daily variable costs, depending on usage of the dryer.

\[ C_{\text{use}} = \left[ \frac{C_{\text{main}}}{365} + \frac{C_{\text{cap}}}{365L} \right] + (c_l + c_a t_h) \left( \begin{array}{c} 1 \text{ if used} \\ 0 \text{ if not used} \end{array} \right) \]  \hspace{1cm} (19)

The above two equations, for capital expenditure and recurrent costs with linearly amortized capital are valid for any consumer, drying any crop. However, for a given country, the detailed values depend on whether the dryer is locally manufactured in the economy in question, or is imported. A separate detailed analysis for Gulu Uganda, gives a summary costing for the dryer of this paper in both local manufacture and imported modes.

5.2 Revenue gains from usage of crop dryers
The farm level revenue gains from use of a crop dryer depend on the crop/product being dried, its price when well dried and when poorly dried as in sun drying, and on physical product losses due to poor drying. For a daily drying rate (post-harvest wet mass basis), \( \dot{m} \), farm gate wet mass basis prices \( P_{\text{dry}} \)
and $p_{\text{sun}}$ for well dried to moisture fraction $w_{\text{dry}}$ and sun dried crops/products to moisture $w_{\text{sun}}$, and mass loss fraction (e.g. due to damages, thefts, etc.) $l_{\text{sun}}$ due to sun drying, equation (20) gives the expression for this gain per day of using the dryer:

$$R_{\text{gain}} = \left(1 - w_{\text{harvest}}\right)m \left[\frac{p_{\text{dry}}}{1-w_{\text{dry}}} - \frac{p_{\text{sun}}}{1-w_{\text{sun}}} (1-l_{\text{sun}})\right]$$

(20)

Equations (19) and (20) can now be used together for each crop/product to determine the breakeven point for the investment per crop. Examples of data of one example from each key food category is given in table 2. Figure 10 gives graphs to estimate breakeven points for the products in a country far from South Africa for both imported and locally manufactured dryers. It is seen that oily crops (e.g. Ground nuts), fruits and vegetables give a breakeven within one year (2 seasons) under local manufacture conditions and within 2 years when the units are imported. Lower value starchy foods like maize, bananas, and even beans, require longer 3 to 4 years, and up to 9 years for bananas in imported units, to give a break even.

Table 2. Daily revenue gain data parameters for different products drying in a 1X1X1 m³ dryer heated by a 2X1 m² solar collector.

| Crop/Product | Wet Harvest Density (kg/m³) | Moist % wet basis | Temperatures °C | Sun-drying losses [% harvest] | Dryer energy Harvest season Dryer daily Water Inflow capacity Dryer crop masses (kg) | Daily revenue gain (US$) |
|--------------|-----------------------------|-------------------|-----------------|------------------------------|---------------------------------------------------------------------------------------------|---------------------------|
| Maize (grains) | 720                         | 35                | 20              | 12                           | 30 6 5.44                                                                                | 2.48                      |
| Cassava (Roots) | 106.0                       | 75                | 10              | 15                           | 30 6 5.44                                                                                | 0.30                      |
| Pineapple (fruits) | 104.5                      | 80                | 80              | 10                           | 30 6 5.44                                                                                | 1.39                      |
| Bananas | 955                         | 75                | 15              | 10                           | 30 6 5.44                                                                                | 1.39                      |
| Ground nuts (oily) | 740                         | 37.5              | 35              | 9                            | 30 6 5.44                                                                                | 15.96                     |
| Fish (Meats) | 900                         | 75                | 25              | 7                            | 30 6 5.44                                                                                | 17.11                     |
| Beef | 128                         | 75                | 25              | 12                           | 30 6 5.44                                                                                | 5.92                      |
| Beans | 760                         | 40                | 30              | 5                            | 30 6 5.44                                                                                | 1.99                      |
| Cabbage (vegetables) | 600                         | 80                | 80              | 4                            | 30 6 5.44                                                                                | 6.35                      |

Figure 10. Breakeven analysis for different products in Uganda, East Africa
6. Conclusion
In this paper, we have introduced a rather new design of a solar crop dryer when compared to those we and others, have previously worked on. It belongs to the forced ventilation, indirectly heated category, but this time with a downdraft rather than the more common updraft units. This arrangement saves space, reduces energy loss through ducting (now inexistent) and through the back plate of the collector. About half of the collector now rests directly on top of the drying chamber, virtually eliminating convection losses through that area. If that is not good enough from a collector point of view, the entire top surface of the dryer is now shielded from convection and radiation losses, meaning a further reduction of energy losses from the dryer itself. Moreover, support by the dryer means less bulk, less system weight and parts, and ultimately, lower costs.

A thermodynamic analysis of the mass and heat transfer was done and standard TRNSYS software was used to estimate year round performance of the collector in a rural place such as Gulu in Uganda. Dryer temperatures were predicted to be easily in the 40 to 50°C range, which is good enough for drying most agricultural products. MATLAB® programming was able to show that limits of daily moisture extraction for the new designed unit could be in the range of 12 to 15 kg. Noting that this was estimated for the fastest drying phase of crops, when moisture diffusion in the interior of the crop did not matter, it gives a fair indication of what quantities to load into the dryer to achieve an optimal transit through the particular drying phase. More work is required with each crop/product to investigate full performance of the dryer during phase 3 drying mode. That, among others, forms the next phase of the work.

The new crop dryer cost about US$ 500 to manufacture, using locally available materials in South Africa. This gives a recommendation of about US$ 1000 to consumers in South Africa. This price is out of range for small subsistence farmers but those are not the intended beneficiaries of this product – as there are less costly alternatives for them from our previous work. The product is intended as a starting point for the small scale business person going into agricultural produce storage and marketing. A conservative economic analysis of the system assuming usage in only half the year (harvest seasons for Uganda and other equatorial countries) and even then, operating an effective 6 hours a day, yields quick returns relative to sun drying. High protein and oil crops, which also happen to be high value crops as well, facilitate breakeven within 2 to 3 seasons (effectively under two years). It is thus clear the systems are not only technically feasible, but are commercially viable as well.

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