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Solar Food/Crop Drying Practices in Uganda: The State of the Art & Prospective Development

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ABSTRACT

Drying has been widely used as a food processing unit operation since ancient times. Though drying practices have evolved and each time improving, the prevalence of agricultural losses especially in developing countries has gone unnoticed. Challenges for well-engineered solar drying systems still exist. This is attributed to drying technology developers focusing on industrial technology design. The objective of this paper was to shed light on solar drying challenges and opportunities in Uganda and how they can be harnessed for development of appropriate solar drying systems. Systematic review of literature was done. In a nutshell, there has been unceasing efforts towards reducing food losses through advancement of drying techniques but this is not based on a complete analysis of all key players. Major focus is on large scale processors with less attention to small and medium enterprises yet they dominate food/crop processing in the developing world. There is therefore need for re-alignment of plans to cater for drying needs of the small and medium processors. This may be through providing affordable, improved and efficient drying systems that use readily available renewable energy and materials.

Keywords: solar crop dryers; food-losses; drying practices; novel drying

INTRODUCTION TO FOOD DRYING

Given the exponential growth rate of the world population, there is increasing need for renewable and sustainable energy sources since the available fossil fuels are limited and getting depleted (Khanlari *et al.,* (2020), Prakash *et al*., (2016), Srinivasan & Muthukumar, (2021), Gorjian *et al*., (2021), Tiwari *et al*., (2018). Solar energy as one of the renewable energy sources is more advantageous than conventional fossil fuels and hydroelectric power because it is clean, sustainable and is widely accessible all over the globe. This makes solar energy suitable for food/crop drying on farm and in communities that are not connected to the National grid. Uganda faces a challenge of Agricultural food losses due to poor preservation techniques. Solar drying although dates back several centuries Gorjian *et al*., (2021), Chauhan *et al*., (2018), Guiné, (2018), is still one of the most relevant but challenging food preservation unit operation. Drying preserves food through lowering water activity so as no microbial activity can take place with diminished chemical and biochemical reaction rates. This reduces the use of refrigeration and space needs for storage and transportation (Guiné *et al*., 2009, Guiné, 2010, Usman & Idakkwo, 2011). Existing drying practices in Uganda include open sun drying on various drying surfaces such as bare ground, rooftops, roadsides, and tarpaulins, drying on meshed raised platforms, greenhouse solar dryers, tunnel solar dryers and passive/active solar dryers.

Despite the existence of various drying practices in Uganda, food losses can go up to 80%. This calls for need into research and development of modern, safe and reliable food drying systems from locally available materials. This review paper sheds light on the existing drying practices, the different stake holders in the drying operations, existing drying research and institutional frameworks, the challenges and opportunities that can be harnessed for better drying.

METHODS AND MATERIALS

Systematic review of literature was done by formulating the research question, identifying relevant articles, appraise quality of included studies and summarize the evidence (Figure 1). Results were then interpreted in order to develop a detailed framework for novel drying research and development. Preliminary research was done to identify relevant articles, avoid duplication of previously addressed questions, and assure that we have enough articles for conducting its analysis. Inclusion criteria was based on study design, and articles which contain information answering the research question. Exclusion criteria was based on unrelated, duplicated, unavailable full texts, or abstract-only papers. Search databases used include Google scholar, Web of Science, Research Gate, Science Direct and Scopus.

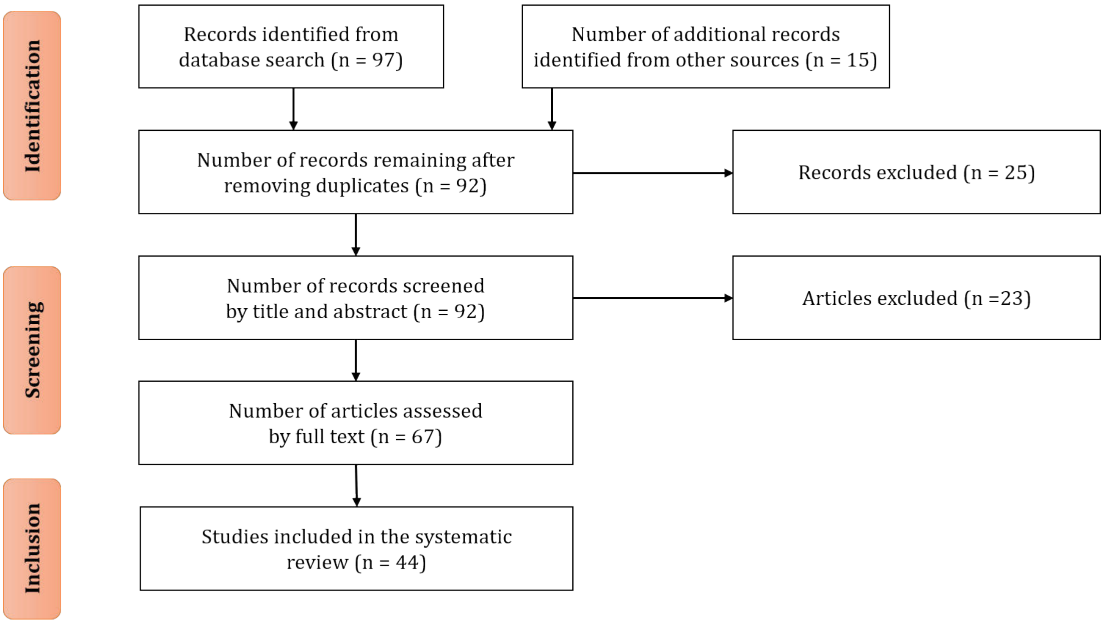


FIGURE 1: Systematic review Prisma.

THE DRYING PROCESS

Water removal from food materials requires a lot of energy. According to Guiné, (2018), it involves an energy consumption of about 20-25% of the total energy used by the food industry. Drying mainly involves heat and mass transfer. These are vital because they provide the necessary energy to convert the liquid water present in the food into vapour (Chappell & Lebel, 2009). During heat transfer by convection, heat exchange occurs between a solid and fluid in contact if there is a temperature difference between them (Singh & Heldaman, 2014, Toledo, 2007, Earle, 2003). During drying, heat is conveyed by convection from the contiguous air and by absorption of radiation on the product surface (FIGURE 1). Heat transfer by convection is assessed as the rate of heat interchange at the solid-fluid interface. The rate of heat transfer by convection is proportional to the difference in temperature as expressed in Equation 1 (Singh & Heldaman, 2014, Berk, 2009, Toledo, 2007, Earle, 2003).

$$q = hA\,(T_{m-}T_s) = hA\,\Delta T \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

Where h is the surface heat transfer coefficient, T_m the temperature of the fluid and T_s the temperature at the surface of the food, A is the surface area of the food. During drying, there is unsteady state conductive heat transfer shown as a rate of temperature change with time as described by Fourier's Second Law of Heat Transfer in Equation 2 (Singh & Heldaman, 2014, Berk, 2009,Toledo, 2007, Earle, 2003).

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_P}\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right] \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

Where $\frac{k}{\rho C_P} = \alpha$ the thermal diffusivity of food, T is temperature, t is time.

The residual energy is used for surface water evaporation and the vaporized moisture is evaporated water is detached from the product surface by natural convection and wind forces (Weiss & Buchinger, 2012).

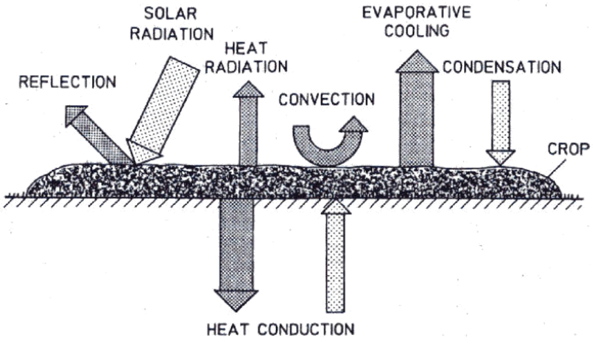


FIGURE 2 : Heat flow influencing sun drying. Source: Weiss & Buchinger 2012.

According to Ekechukwu (1999) and Kanyarusoke (2019), there are five stages of heat and mass transfer to consider in crop drying, depending on the crop or food being dried and the conditions in the drying chamber (FIGURE). The first stage is the heating period. The second stage is the constant rate drying period. The first falling rate is the third stage, at which the dried product moisture is below a critical value. Stage four is the second falling rate period which is characterised by slower drying after exhausting unbound water in the product being dried. This is followed by the fifth and last stage known as the difficult region of near zero drying which could as well start moisture reabsorption from the air.

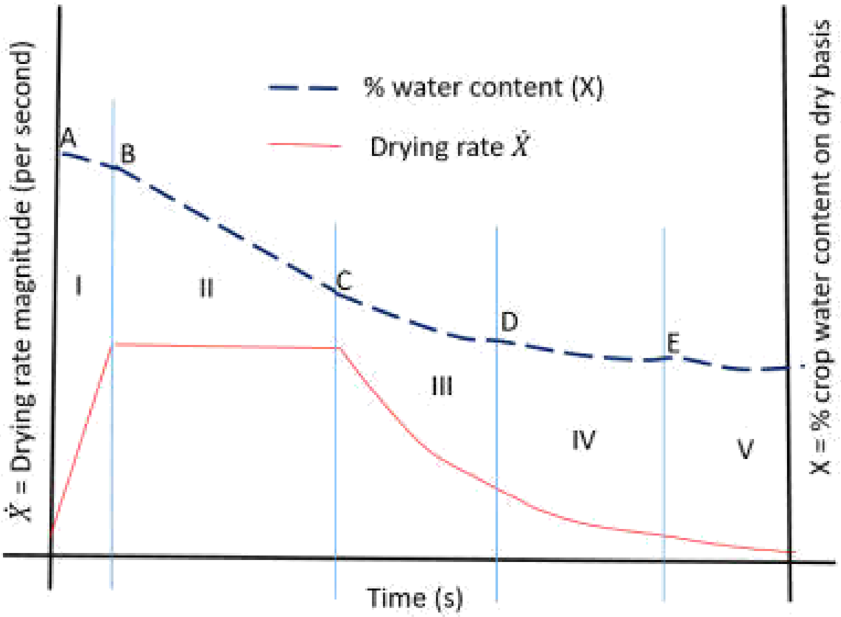


FIGURE 3 : Different stages in crop drying.
Source: (Kanyarusoke, 2019).

EXISTING DRYING PRACTICES

According to Lewicki (2006), drying is mostly achieved through air, vacuum or freeze drying. Consequently, there are a number of drying methods which include solar drying, hot air convective drying, freeze drying, vacuum drying, spray drying, Infrared drying, microwave drying, radiofrequency drying, osmotic dehydration and combined processes (Lewicki, 2006, Guiné, 2018). The main interest of this study lies in solar drying because it is the most widely used drying practice for agricultural food products in Uganda but prospects for modern drying practices at industrial scale are also discussed.

1. Solar drying

Solar drying uses the sun as the energy source thus being a very economical and sustainable drying method. However, it has many drawbacks such as nutritional degradation, labour intensive, needs a large surface area for drying, the food is exposed to contamination sources and is also intermittent because it strongly depends on weather conditions (Harmain, 2012, Guiné, 2018, Hnin *et al.*, (2018). Ziaforoughi & Esfahani, (2016) and Qiu *et al.*, (2016) state that solar greenhouses might reduce these challenges since they are highly efficient and achieve higher temperatures as a result of the greenhouse effect while protecting the foods. Solar drying has two forms; direct and indirect solar drying. Under direct solar drying, food material receives the solar radiation while under indirect solar drying, the energy from the sun is harvested by collectors that eventually heat the air used for food drying (Guiné, 2018).

2. Solar drying methods

As one plans the drying operation, they must choose the appropriate drying practice/technique based on the prevailing weather conditions and type of the food material to be dried.

2.1 Open Sun drying

Open Sun drying is the simplest way to dry food products (Figure 3), and works best for small-scale operations where the harvest volumes are low (50–100kg) (CAVA, 2010). Under sun drying, products are spread on various surfaces like bare ground, tarpaulins, concrete floor, raised platforms and roof tops. The drying process normally takes between 3 to 7 days. In their study of cassava drying technologies in Uganda, Menya *et al.*, (2020) revealed that it takes 4 days for open sun drying to dry the smallest achievable cassava chip by hand knife to dry to the desired storage moisture content. For sun drying to be effective, there must be enough sunlight, good air drift and very low humidity. The time of drying and quality are affected by the food shape, size and initial moistures levels of the fresh food product (Udoro *et al.*, 2013).

FIGURE 4 : Open sun drying on bare ground (Primary data, 2019).

Open sun drying in Uganda is used in all parts of the country for drying grains, cereals, roots & tubers and herbs.

Raised drying platforms with solid drying surfaces reduce contamination but do not significantly improve airflow. Therefore, improved raised platforms with meshed drying surfaces are used since they reduce exposure to dust, contamination by domestic animals, provide sufficient air flow and products do not need frequent turning over. These are mostly used for fruits and vegetables but also sliced cassava chips.

2.2 Solar dryers

As technology advancement takes shape, solar drying has become a very promising, cost-effective and environmentally friendly use of the energy from the sun (Sudhakar, 2021). Solar dryers have been categorized into many ways (Hii *et al.*, 2019; Sudhakar, 2021; Sultan *et al.*, 2021; Weiss & Buchinger, 2012) (FIGURE).

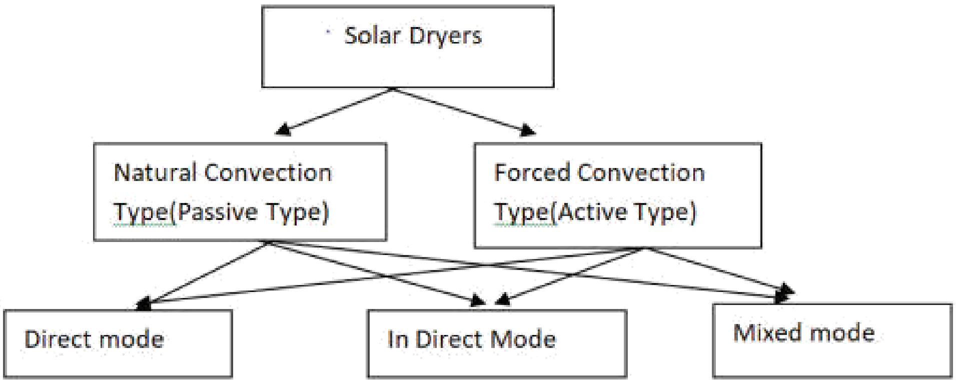
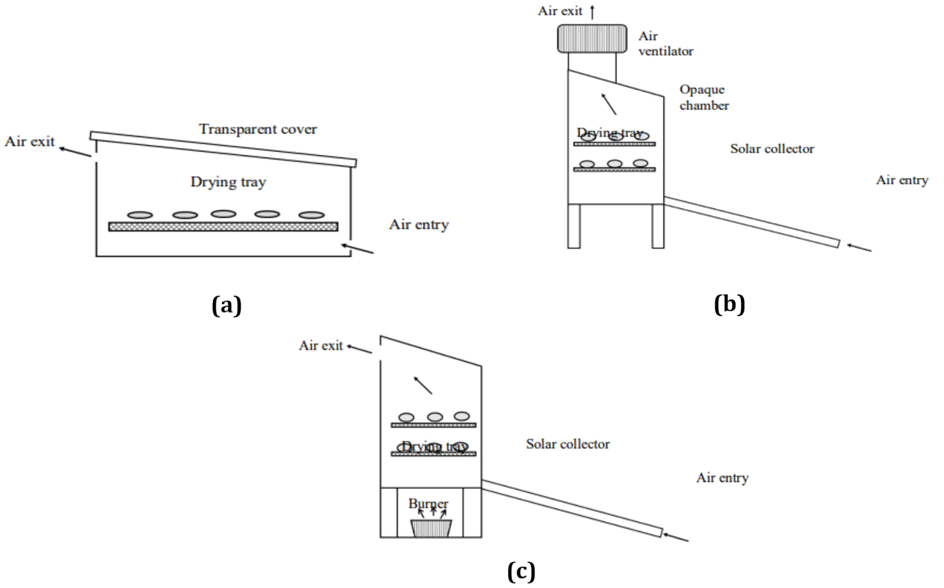


FIGURE 5 : Classification of solar dryers (Sudhakar, 2021).

In passive solar dryers, air is heated and distributed by buoyancy force or by wind pressure or both (Visavale, 2012). This type of dryers is cheap, easy to install and use thus best suited for small batch drying in developing countries. In Uganda, they are mostly used in areas of Kayunga for drying pineapple slices (FIGURE a). On the other hand, active solar dryers have fans and pumps to move the heated air from the collector to the drying chamber. Active solar dryers only use solar-energy for heating and use motorized fans and ventilators for air circulation (Visavale, 2012). Down draft solar dryers (FIGURE 6b) are some of the active drying systems used for drying fruits and vegetables, beef, herbs etc. Because of their designs, active dryers tend to be more efficient than passive dryers. Active dryers are widely used for commercial operations together with conventional fossil-fuel.

Direct solar dryers use direct sunlight, materials being dried are put under a transparent cover such as glass or plastic and they absorb solar radiation directly (Weiss & Buchinger, 2012). According to Sudhakar (2021), some of the radiation is reflected by the transparent cover whereas the balance is conveyed inside the chamber into the food product thus increasing its temperature and reducing the moisture levels. For indirect solar dryer, the food product is put in an impervious chamber and solar energy is absorbed by collector detached from the drying chamber. Indirect dryers are mostly applied for very sensitive products to solar radiation and temperatures. The hybrid dryers combine features of both direct and indirect types as well as solar dryers with other heat sources apart from the solar energy. These various classifications of solar dryers are illustrated in FIGURE 5.



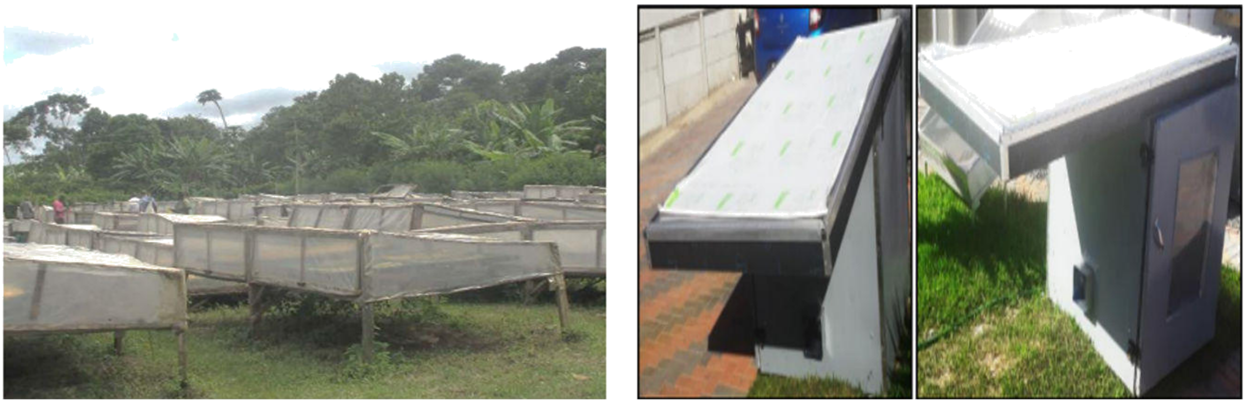
(a) (b)

(c)

FIGURE 6: Classification of solar dryers (a) direct solar dryer (b) indirect solar dryer and (c) hybrid
Source: (Hii et al., 2019).

All dryers described above are updraft systems where heat is supplied from bottom upwards into the drying chamber. The up-draft design has disadvantages of occupying more space and waste more heat since there are heat losses both at the top surface and bottom of the solar collector. There are downdraft dryers introduced by Kanyarusoke (2019).

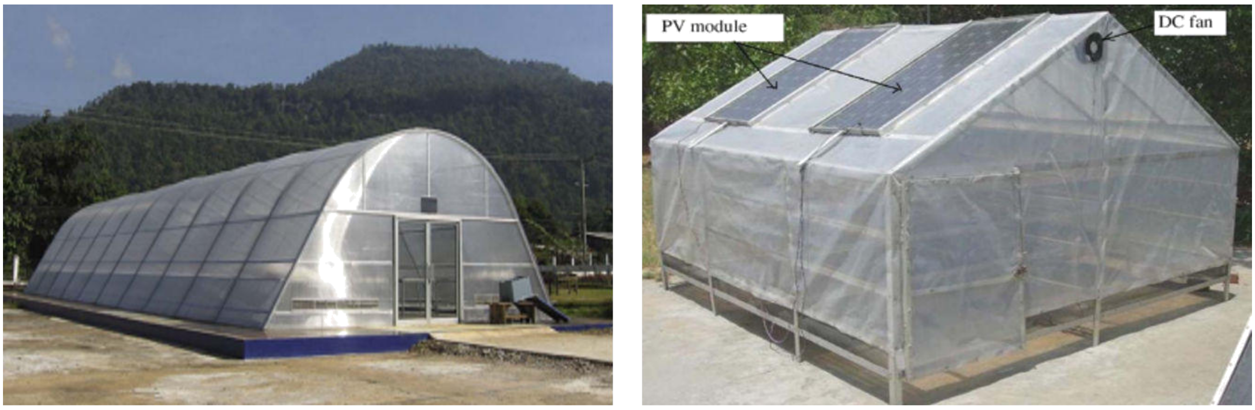
The downdraft design saves space, and minimizes heat losses because heat lost to the bottom is lost to the drying chambers that contain the products being dried unlike up draft designs. Additionally, there are no heat losses to the top because the top of the dryer is the solar collector. A basic downdraft dryer is shown in FIGURE 6b.



(a) **(b)**

FIGURE 7 : (a) passive solar dryers used for drying pineapple slices in Kayunga. ***Source:*** (Ahumuza *et al*.,2016); (b) Down draft solar dryer. ***Source:*** (Kanyarusoke, 2019).

Greenhouse dryers use direct radiation from the sun through a canopy of polycarbonate material which is largely transparent for incoming short wavelength solar radiation to heat and dry the food products. Products dried in greenhouse dryers are free from external hazards hence having a superior quality. However, the drying efficiency of greenhouse dryers depends on climatic conditions hence calling for additional heat sources and also requires a large space. Some applications of the greenhouse system include poultry, crop cultivation, aquaculture and crop drying (Singh *et al.*, 2016). Greenhouse dryers can be designed to adopt natural and forced convection modes of operation as described by Singh *et al.*, (2016), Khanlari *et al.*, (2020), Chauhan *et al.*, (2018), Mishra *et al.*, (2020) and illustrated in FIGURE 7.



(a) **(b)**

FIGURE 8: (a)Natural convection greenhouse dryer (b) Forced convection greenhouse dryer. ***Source:*** (Singh et al., 2016).

3. Advanced sophisticated large scale/industrial methods

Convective dryers that either use hot air or combustion gases as heat transfer media contribute up to over 85 % of industrial dryer applications (Zarein *et al.*, 2015). Since drying involves simultaneous mass and heat transfer, it is very energy intensive and roughly consumes 12–20% of the total energy in manufacturing industry (Raghavan *et al.*, 2005).

Product quality in the aspects of nutritional contents, functional traits and sensorial attributes is also a major concern today. Some of the industrial drying technologies in Uganda include vacuum drying, microwave drying, freeze drying and Refractance window dryers. These have advantages of having short drying time, little or no contamination, and preserve nutrients for heat sensitive products.

These nevertheless have high acquisition and operation costs, are energy intensive and inappropriate for processors who are not connected to the National grid. Consequently, major technological advancement in terms of drying technique, drying pre-treatments and quality has been realized hence addressing the need for better techniques with improved utilization of energy (Dev & Raghavan, 2012, Mujumdar & Huang, 2007).

Research into improved drying technologies should however consider many factors to suit various categories of end users like on-farm processors, small and medium scale enterprises and industrial processors. According to Moses *et al.,* (2014), the major factors for research and development in novel drying include those listed in FIGURE 8.

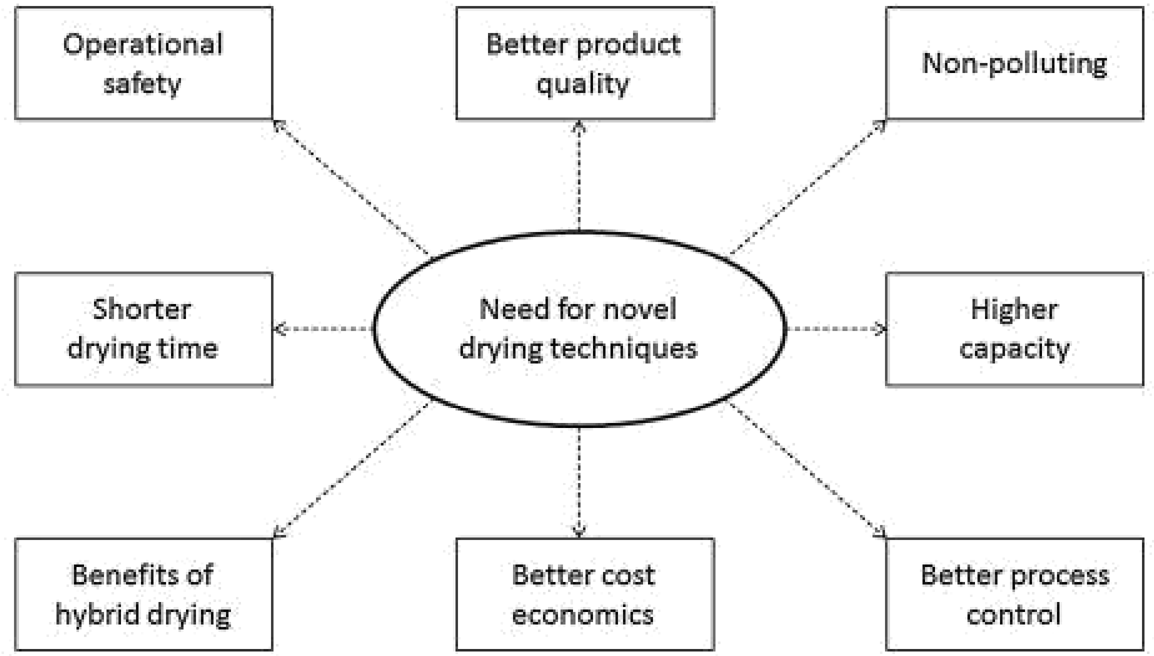


FIGURE 9: Key drivers for novel drying research and development.
Source: (Moses et al., 2014).

ANALYSIS OF LITERATURE

Since drying reduces the water activity in foods, it makes it possible to transport food to distant places, enables safe storage and enhanced shelf life hence reducing agricultural food losses. Despite drying having been widely used since ancient times, food losses still exist. This is attributed to weather changes, poor drying practices, poor access to efficient drying technologies and moisture testing facilities. Additionally, inconsideration of social set up of target users by technology developers leads to production of inappropriate technologies. We suggest that novel drying research and development must consider a number of factors at each stage of technology advancement like identification, formulation and use as illustrated in FIGURE 1.

With concern of the various factors that affect drying technology research, the model in FIGURE 1 is recommended if appropriate drying technology access, acceptance and use are to be exhibited with reduced agricultural food losses. Though drying practices have evolved and each time improving, the prevalence of agricultural losses especially in developing countries has gone unnoticed. Technology development bodies selectively focus on mainly industrial technology design. They have moreover failed to see involvement of on-farm, small and medium enterprises in drying and use of many drying technologies. This has seen many large-scale processors having efficient drying methods unaffordable by majority of the processors. There is clear demand therefore, for a framework that puts into consideration social and economic atmospheres of all stakeholders and area of technology adoption.

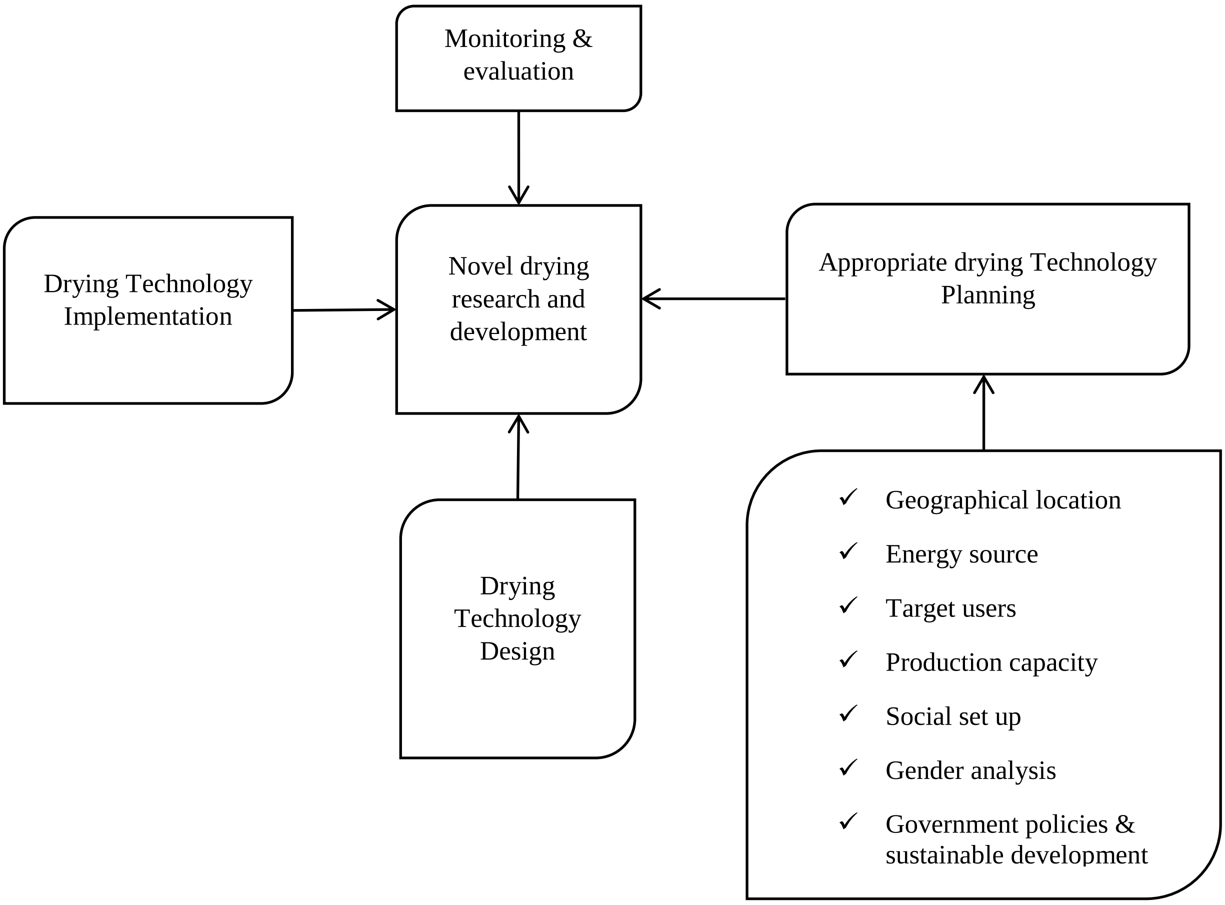


FIGURE 10: Schematic diagram of impact novel drying research and development.

PROSPECTIVE DEVELOPMENTS

Farmers have no access to moisture testing facilities thus guessing attainment of desired storage moisture content and dispatching partially dried products to the market. Prospective research in Novel solar drying for small and medium enterprises is also in establishment of the relationship between drying conditions and the final product moisture content. This relationship once established consequently allows for automation of the drying system for easy usage and better results. With this fully automated and solely solar powered drying system, a quest into minimum final product moisture content that ensures that moisture regain during a rainy season does not go beyond the desired values can be done. Additionally, design for high capacity/bulky processors is long overdue.

CONCLUSIONS

In conclusion, there has been unceasing efforts towards reducing food losses through advancement of drying technologies but is not based on a complete study of all key players. Major focus is on large scale processors with less attention to small and medium enterprises yet they dominate food/crop processing in the developing world. Additionally, the efficient practices developed are affordable by high value food product processors. There is therefore need for integrated solutions for food/crop drying that will provide improved but affordable drying systems from readily available materials.

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