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Review

Review of solar dryers for agricultural products in Asia and Africa: An innovation landscape approach

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ABSTRACT

Solar drying is one of the most efficient and cost-effective, renewable, and sustainable technologies to conserve agricultural products in Asian and sub-Saharan African (SSA) countries. This review paper presents the different types of solar dryers that are widely used in Africa and Asia. In addition, the pre-eminent effects of their use on product quality, as well as their economic, environmental, and social impacts, are highlighted. Since financial, external, and structural factors play a key role in the adoption and scaling of solar dryers, this paper also discusses the impact of these factors on the effectiveness of solar drying technologies in selected Asian and SSA countries.

1. Introduction

Increasing global population, which is projected to be more than 9 billion by 2050, entails increasing food production by about 70% (Food and Agriculture Organization (FAO), 2009). Although the expected population growth rate from 2007 to 2050 is projected to be more than 50% lower relative to the growth rate from 1963 to 2007, high rates are still projected in sub-Saharan Africa (SSA), and East and Southeast Asia (ESA) where the incidence of food insecurity and malnutrition is already high (Divo et al., 2014). While improving productivity is key, reducing the existing high rates of global food loss and waste, including post-harvest loss, along the various production and supply chains, will play a key role in tackling the problem of food insecurity in SSA and ESA. Globally, close to 1.3 billion tonnes of food produced for human consumption are lost annually (Food and Agriculture Organization (FAO), 2011). Hodges et al. (2010) reported that the critical factors influencing food loss in developed countries occur at the consumption stage, whereas in less developed countries, most losses mainly occur early in the value chain, especially in post-harvest handling and processing (Chegere, 2018). High rates of food loss contribute to food shortages and have left millions in low-income countries suffering from malnutrition (Food and Agriculture Organization (FAO), 2010; Premanandh, 2011; Munesue et al., 2014). In particular, inappropriate and sub-optimal drying practices along the food value chain have led to significant income losses among farmers, food distributors, processors, and exporters in SSA and ESA regions. Beyond income losses, poor drying has also contributed to aflatoxin contamination, a major food safety and public health concern in SSA. In this regard, the use of appropriate drying technologies can potentially enable small-scale producers to significantly reduce post-harvest losses, improve the quality of food, and generate income and employment opportunities.

Drying is often considered to be an energy-intensive and cost-effective method to improve the storability of various types of agricultural products. During a simultaneous transfer of heat and mass, moisture is evaporated near the surface by several mechanisms such as liquid and vapor diffusion, capillary and gravity flows, and flow caused by shrinkage and pressure gradients (Sharma et al., 1986). A reduction of the moisture content prevents the risk of microorganism growth,

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minimizes many of the moisture-intermediated, deteriorative reactions such as enzymatic reactions, non-enzymatic browning, and oxidation of lipids and pigments, and substantially reduces weight and volume (Kumar and Tiwari, 2007; Barnwal and Tiwari, 2008). Among numerous available methods, open-air sun drying is the most preferred method in tropical countries, due to its affordability, especially for smallholder farmers in rural areas. However, the drying process greatly relies on ambient conditions and is very prone to contamination by dust, rain, wind, pests, and rodents (El Hage et al., 2018; Singh et al., 2018), leading to low-quality products and a loss of farmers' income.

To overcome these problems, several systems such as the greenhouse dryer (Janjai et al., 2007; Azaizia et al., 2017; Hamdi et al., 2018; Iskandar et al., 2017) and the hybrid solar dryer (Amer et al., 2018; Eltawil et al., 2018) have been introduced. These systems are faster, more efficient, and more hygienic, resulting in lower crop losses relative to the traditional open-air sun drying method (Muehlbauer, 1986; Chua and Chou, 2003; Karim and Hawlader, 2004; Tomar et al., 2017). During the solar drying process, the moisture in raw agricultural materials is removed by conduction, convection, and radiation modes of heat transfers. The solar radiation passes through a transparent sheet and is retained as heat in a drying chamber or solar collector at a temperature of 30–60 °C. Thermal energy is then transferred to the drying chamber by natural convection in a passive system; hot air is led into the chamber by fans or blowers in an active system. To obtain the desired quality and assure a good return for the producers, however, the systems must be properly designed and scaled to meet the requirements of specific crops and environments.

This study presents a review on the adoption and scaling of solar drying technology for agricultural products in SSA and Asia with an environmental lens. The remainder of the paper is organized as follows. Section 2 presents classifications of solar dryers and section 3 considers their importance. Section 4 and 5 discuss successful case studies in Asia and Africa, respectively. Section 6 reflects on the way forward and section 7 presents the conclusions.

2. Classifications

During the last decades, various types of solar dryers have been developed to reduce post-harvest losses and to improve product quality. However, only few types are used on scales beyond demonstration projects or have been commercialized (Müller et al., 2012). Solar dryers for agricultural products can be classified based on their size, design of the system, and mode of solar energy utilization. Herein, the passive, active, and hybrid solar dryers focusing on the method of air movement (natural or forced convection) and mode of heat transfer (direct or indirect) are presented (Fig. 1).

2.1. Passive solar dryers

The direct passive solar dryers (natural convection) such as cabinet and greenhouse dryers have a simple and cheap construction. A drying chamber usually consists of an insulated box with inlet and outlet holes and a transparent glass/polyethylene/polycarbonate sheet (Seveda and Jhajharia, 2012; Kumar et al., 2016; Sivakumar and Rajesh, 2016). The solar-heated air is circulated through the agricultural materials either by buoyancy forces or as a result of air pressure, or a combination of both (Tomar et al., 2017; Müller et al., 2012; Tiwari et al., 2016). The humid air escapes through an outlet on top or is ventilated through the chimney of the dryer (Ghaffari and Mehdipour, 2015; Chauhan and Rathod, 2018). During drying, the solar radiation is partially reflected to the atmosphere while the rest is transmitted into the cabinet and absorbed by the materials. Tomar et al. (2017) suggested that an adequate moisture removal is required to prevent degradation of the materials by condensation in the drying chamber. The cabinet dryer is suitable for small-scale drying of fruits and vegetables (Jayaraman et al., 2000), while the greenhouse dryer is used for large-scale drying of multiple agricultural products (Hossain and Bala, 2005; Sallam et al., 2015; Patil and Gawande, 2016). The average drying efficiency of the passive dryer ranges from 20 to 40%, depending on the type of materials, airflow rate, and location (Kumar et al., 2016). Although a passive dryer can protect agricultural products from rain and foreign materials, it has some drawbacks. For example, Hii et al. (2006) reports that passive drying causes overheating and low product quality. Similarly, Milczarek et al. (2016) has shown that the cabinet dryer causes discoloration in apricots.

The indirect passive dryer (forced convection) contains a drying unit with a separate solar collector and three main components: solar collector, drying unit, and air duct for circulation. The air is heated while flowing through a low-pressure drop solar collector and then passes through air ducts into the drying chamber and over the drying trays. The moist air is discharged through air vents or a chimney at the top of the chamber (Tiwari, 2016). The average drying efficiency is 13–25%, which is lower than the direct solar dryer (Kumar et al., 2016). However, Tomar et al. (2017) and Tiwari et al. (2016) reported that unlike the direct passive dryer, this method overcomes the problem of cracking and helps to preserve vitamins and color as agricultural products are not directly exposed to solar radiation.

2.2. Active solar dryers

Active dryers have a ventilation system to circulate heated air inside the drying chamber or from the solar collector to the drying chamber. Fans or blowers are run by electricity, which can be harnessed from a photovoltaic (PV) module or grid (Tiwari et al., 2016). In particular, in the passive mode of the greenhouse dryer, a ventilator or chimney is built for the natural circulation of heated air, and in the active dryer, an

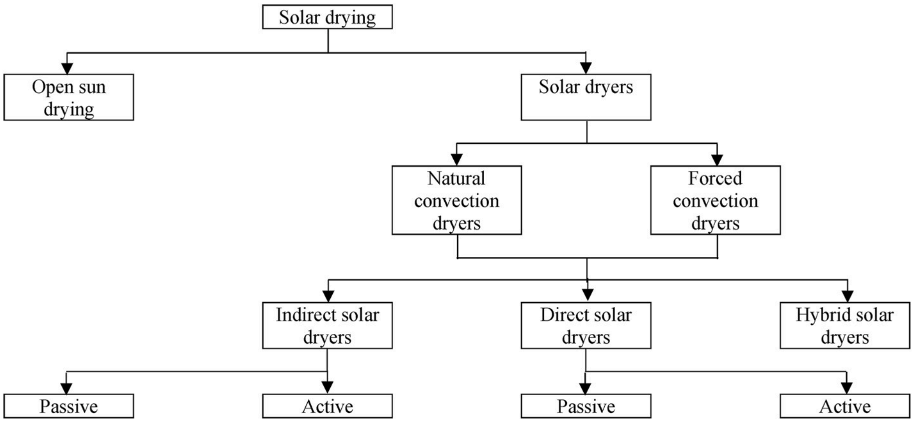

Fig. 1. Classification of solar dryers.

exhaust fan is provided for air movement. An active dryer has been reported to be more suitable for crops with a higher moisture content such as papaya, kiwi, cabbage, and cauliflower than the passive dryer (Chua and Chou, 2003; Taylor and Weir, 1985). The active dryer requires more investment than a passive dryer and is more difficult to operate and maintain (Soponronnarit, 1995). To achieve high drying efficiency and product quality, the optimal temperature and air mass flow rate must be controlled (Ghatrehsamani et al., 2012).

2.3. Hybrid solar dryers

In a hybrid dryer, agricultural materials are dried under direct solar radiation and/or back-up energy or stored heat in the absence of sunlight. The air is pre-heated by another auxiliary source of energy such as a solar PV module, electricity, liquefied petroleum gas (LPG), diesel, or biomass. This dryer can be used in both single and mixed modes (direct and indirect types of drying). Bala and Woods (1994) report that hybrid drying could reduce microbial infestation in products. Queiroz et al. (2004) show that the heat pump dryer can be 40% more energy efficient relative to the electric resistant dryer. Ferreira et al. (2007) present a study for banana and determine that the drying time obtained in hybrid drying is lower compared to open-air or artificial drying. In addition, better color, aroma, and texture were observed in hybrid dried banana compared to open-air sun drying (Amer et al., 2010). Eltawil et al. (2018) developed a hybrid, portable tunnel dryer to dry peppermint by enhancing its performance using a solar PV system and flat plate solar collector. They determined that the quality of the hybrid-dried peppermint was higher than that of open sun-dried peppermint. The dryer efficiency was 31% with a net carbon dioxide (CO_2) mitigation of 32 tons over its life span. In addition, the hybrid dryer has been applied for various crops such as mushrooms (Reyes et al., 2013), pineapples (Gudiño-Ayala and Calderón-Topete, 2014), and cashew nuts (Dhanushkodi et al., 2017). It is suitable for the fast drying of crops that require high product quality.

3. Importance

In this section, four prominent features of the solar dryer are discussed – quality as well as economic, environmental, and social aspects.

3.1. Quality aspects

During food drying, numerous physical, chemical, and nutritional characteristics undergo modification due to mass and heat transfers (Krokida et al., 2001; Aguilera, 2003; Lewicki and Jakubczyk, 2004; Prachayawarakorn et al., 2008). Mokhtarian et al. (2016) report that solar drying with air recycling minimized color changes and volume shrinkage of dried pistachio nuts when compared to sun drying. Chen et al. (2005) show that a brighter color was observed in dried lemon samples under complementary solar drying when compared to samples dried by hot air at 60 °C.

The loss of bioactive compounds depends on the properties of the drying air, particularly on the temperature, which can lead to the solubilization of compounds bound to insoluble fiber portions in the product (Toor and Savage, 2006) or freed by cell wall breakage (Omoni and Aluko, 2005). Negi and Roy (2000) report that the retention of provitamin A obtained from solar drying of some leafy vegetables, such as savoy beet, amaranth, and fenugreek, was equivalent to results from cabinet drying at 65 °C. Bechoff et al. (2009) also found that solar and sun drying were not significantly different in terms of the provitamin A content in orange-fleshed sweet potato. When compared to a hot air dryer at the same temperature (42 °C), hot air cross-flow drying retained more provitamin A. Similarly, Bengtsson et al. (2008), reported that open-air sun drying caused a higher loss of all trans-β-carotene than solar drying. Mehta et al. (2017) documented that more of the functional compounds, such as flavonoids, polyphenols, and vitamins A and C, were retained in solar-dried bitter gourd and capsicum, in comparison to hot air and open-air sun-dried samples. Prajapati et al. (2011) evaluated vitamin C degradation during hot air and solar drying of Indian gooseberry (*amla*) shreds and found the highest loss of vitamin C in hot air drying. Similarly, Pragati et al. (2003) reported that *amla* fruits dried under indirect solar drying had a better vitamin C retention than those obtained by direct drying. Vangdal et al. (2017) showed that the high temperature and oxygen concentration involved in both oven and solar drying led to a rapid degradation of vitamin C in organic plums. However, the anthocyanin, phenolic, and hydroxycinnamate (neo--chlorogenic acid) contents were higher in oven-dried than in solar-dried samples. This result might be related to the formation and accumulation of melanoidins and/or Maillard reaction products in oven-dried samples, which also function as antioxidant substances through a chain-breaking mechanism (Miranda et al., 2009; Vega-Gálvez et al., 2009). In addition, the generation of phenolic compounds at high drying temperatures might be caused by the availability of phenolic precursors from the non-enzymatic inter-conversion between phenolic molecules (Que et al., 2008). As phenolic acids are mainly bonded to carbohydrate and proteinaceous moieties, Hartley et al. (1990) suggest that the release of polyphenolic constituents becomes more amenable for extraction due to the breakdown of cellular constituents and covalent bonds during high thermal processing.

3.2. Economic aspects

Assessing the economic viability of investments on solar dryer technologies requires detailed financial and economic appraisals as such investments are often made based on perceived economic and technical viability. Compared with other commercial dryers, the solar dryer is known to be a capital-intensive method (Tiwari, 2016). In addition, compared to traditional sun drying methods, solar dryers offer several economic advantages such as lower costs for fossil fuel and combustion equipment. They also achieve high-quality results and thus increase the market value, secure stable and high income even under various climatic conditions. Specifically, the use of solar dryers enables small-scale producers to significantly reduce post-harvest losses in a cost-effective and energy-efficient manner, improve the quality of food, and generate additional income and employment opportunities.

In the literature, annualized costs, life cycle savings, and payback period (PBP) have been used to examine the economic feasibility of solar dryer (Aravindh et al., 2014). However, it should be noted that these calculations critically depend on many factors such as the physical characteristics of drying materials, climate conditions, and system factors of the dryer (design, type, size, and efficiency) (Kumar et al., 2016; Purohit et al., 2006). For example, in India Purohit et al. (2006) reported that solar drying is financially attractive for cash crops such as tea and coffee but not for vegetables such as cabbage and tomato. In Thailand, the estimated PBP for a 1000-kg capacity greenhouse type dryer for fresh products, such as chili, is about 2 years (Kaewkiew et al., 2012). Hollick (1998) also reports that the PBP for a solar dryer with a total fixed cost of US$71,111 and annual fuel consumption costs of US$33,600 is approximately 2 years. In general, estimates for economic returns of solar dryer technologies valued at market prices and without considering possible positive environmental effects, are much higher relative to traditional drying technologies. However, to obtain a more accurate cost-benefit analysis, other advantages such as improved quality, higher yields, and less land use, should be considered.

3.3. Environmental aspects

Fossil fuels and electricity are widely used as energy sources in most drying systems which results in high operational costs and environmental problems by increasing greenhouse gas (GHG) emissions. As a result, food producers have shifted towards clean energy-based technologies such as solar and thermal energy in both direct and indirect forms (Eswara and Ramakrishnarao, 2013). Eltawil et al. (2018) suggested that the energy usage of the solar dryer could be computed using indicators such as embodied energy, time to energy payback, CO_2 emission, and carbon mitigation. Arata et al. (1993) found that at an efficiency level of 40%, a solar dryer system can decrease conventional energy consumption by 27–80%. Liu et al. (2015) indicate that the power consumption of the fan in the forced ventilation greenhouse dryer accounts for 5% of the total energy. The combination of solar and conventional energy could save 20–40% of energy. Piacentini and Mujumdar (2009) report that hot-air drying system emits about 15 tons/year of CO_2 when operated with electrical energy at 100 kWh/day and 25 days/month for 11 months/year. Ekechukwu and Norton (1999) suggest that the use of solar dryers could reduce CO_2 emissions relative to other drying systems.

3.4. *Social aspects*

Global warming, particularly due to high levels of GHG emission, poses a significant threat to the world. Governments and industries worldwide have attempted to reduce emissions by switching from fossil-fuel-based energy to solar energy (Abdelaziz et al., 2011). Most governments address the issue by establishing energy policies, which focus on legislation, international treaties, and market incentives to investors (Pirasteh et al., 2014). Although tax credits have been suggested to mitigate emissions (Carley, 2009), Solangi et al. (2011) noted that energy policies are often country-specific and hence “one size-fits” type incentives are unlikely to be effective. Some countries (e.g., Canada, Germany, France, Spain, China, and Malaysia) promote the use of renewable and clean sources such as solar energy. In 2015, about 19.3% of the global energy consumption is generated from renewable energy sources, wind/solar/biomass/geothermal power accounting about 1.6% (Renewable Energy Policy N, 2017).

Depending on the type of technology, solar energy and biofuels provided the most jobs. For example, in 2016 the renewable energy sector created employment opportunities for about 9.8 million people. Most of these employment opportunities are from Asia, particularly in China, which accounts for 62% of all the renewable energy jobs (Renewable Energy Policy N, 2017). In addition, the use of solar energy would significantly improve public health as various epidemiological studies have found that GHG emissions can elevate risks of non-allergic respiratory and cardiovascular morbidity, cancer, allergic illnesses, and adverse outcomes in pregnancy and birth (World Health Organization (WHO), 2005).

4. A successful case study in Asia

The application of solar drying technology has proven to be practical and economical in many countries. This section presents case studies of commercially scaled-up solar dryers and the keys to success in Thailand, India, China, the Philippines, and Indonesia.

4.1. *Thailand*

In Thailand, drying is one of the main post-harvest approaches to preserve the quality of agricultural products. Small-scale farmers mostly use open-air sun drying. Mechanized dryers such as the cabinet tray dryer heated by gas (LPG) or electricity are often used by industries. In some enterprises, the drying process might start with open-air sun drying and continues in a cabinet tray dryer (Janjai, 2012). However, sun drying is time-consuming and less hygienic, hence the use of LPG/electricity have substantially increased in the last few years.

The use of solar drying has been developed to respond to the high demand from both domestic and international markets for dried agricultural products. For example, more than ten years ago, the open-air sun drying on a bamboo mat was widely used for drying fresh bananas in Bangkrathum district, Pitsanuloke province, the major dried banana production area of Thailand (Fig. 2A). This method resulted in poor quality dried products since the bananas were not protected against contaminants. As a result, most dried bananas were contaminated with microorganisms and worms. A lengthy drying time was also required for any given commodity (5–7 days), resulting in high yield losses. Estimates suggest that about 40% of dried products were lost during the dry season and 90% in the rainy season. To reduce losses, a greenhouse solar dryer, “Parabolic Solar Dome”, has been introduced to small-scale enterprises as well as cooperatives in Bangkrathum district by the Solar Energy Research Laboratory (SERL) and the Department of Physics, Silpakorn University, in collaboration with the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy (MoE), and the Department of Food Technology (FT), Silpakorn University, Thailand. The dryer consisted of a parabolic roof structure with a size of $8.0 \times 20.0 \times 3.5$ m^3 covered with 6-mm thick polycarbonate sheets (Fig. 2B). As indicated by Janjai (2012), the parabolic shape contributes to reducing wind load and increases the effect of solar radiation while the polycarbonate sheets develop a greenhouse effect inside the dryer, reducing convection and radiation of heat losses from the dryer into the surrounding environment.

Using this solar drying system, the product quality (Fig. 2C), drying time, and specific energy consumption have been significantly improved. The volume of dried products increased from 1 ton to 2 tons/drying cycle and the production loss was less than 10%. The drying time was reduced from 5-7 days to 3–4 days and the price significantly tripled compared to the open-air sun-dried products. In addition, the estimated PBP of this greenhouse dryer was about 2.3 years. The use of the dryer successfully encouraged other small-scale producers in the same district to use solar dryers with the support of the MoE. To increase the sense of ownership, the Ministry established a contract with producers to partly invest (40% of the total investment cost) in their own dryers through a program call “Solar Dryer Subsidy”. In this program, the cost of the parabolic greenhouse solar dryer, including landfilling, concrete floor, construction, materials, and labor, depends on the size of the dryer. For example, the 49.2 and 166.4 m^2 sizes cost about US$237 and 170 per m^2, respectively. Zero-cost training is provided by the FT, Silpakorn University under the support of the MoE. Krungkaew et al. (2020) who studied the costs and benefits of parabolic greenhouse solar dryers for dried herb products in Thailand showed that replacing fuel with solar energy in the traditional drying method results a positive net present value (NPV).

Adopting this technology has enabled farmers and producers in the area to significantly reduce their post-harvest losses of perishable agricultural products, resulting in better product quality and higher incomes. Interestingly, this parabolic greenhouse dryer has been fully accepted for various agricultural products. At present, about 500 units have been installed by the collaboration between the DEDE, SERL, and FT and are being used in different parts of the country. For example, they are commercially used for drying fish in Songkla Province, meat and tomato in Nakhon Pathom Province, coffee in Chiangmai Province, mango in Samutsakhon Province, medicinal plants in Prachupkirikhun Province, macadamia nuts in Loei Province, and rice crackers in Lumpang Province. Commercial production of some parabolic solar dried products available in the market are presented in Fig. 3.

The Thai MoE has launched many projects for promoting the use of a parabolic solar dryer since 2013 with the successful example of the solar-dried banana to support the development of renewable energy (CRE) projects in communities. Some of them were selected for the joint projects based on the availability of renewable energy sources, selection of mature technology, the share of local materials and technology used, project management structure, and market security (Chaichana et al., 2017). In this project, 243 households have been supported in seven communities that use solar dryers to dry mango, banana, *stevia* leaves, and rubber. The annual income generated from the use of parabolic solar dryer is estimated at US$70,075, which is approximately 290 US $/household/year. To achieve sustainability, community members were

Fig. 2. Comparison of open-air sun drying and greenhouse solar drying in Thailand: (A) traditional open-air sun drying of banana in Pitsanuloke Province; (B) greenhouse dryer with parabolic shape; and (C) an example of solar-dried banana products available on the domestic and international markets.

Fig. 3. Commercial production of some agricultural products in Thailand using “Parabolic Solar Dome”: (A) Dragon fruit; (B) Lotus flowers; (C) Coffee beans; (D) Kaempferia parviflora (Thai black ginger); (E) Lingzhi mushroom; (F) Chili; (G) Pork meat; (H) Fish; and (I) Rice crackers.

encouraged to partly invest in the project and the MoE also encouraged communities to become legal entities.

Production of glutinous rice crackers provides another example of solar drying. Pawakote and Koonsrisuk (2018) installed fins and baffles in the air-flow channels of the drying chamber to improve the mass flow rate and the outlet temperature of the dryer. Srittipokakun and Kirdsiri (2013) developed a mixed-mode dryer for small-scale commercial producers with limited or no access to electricity. The use of this system resulted in lower drying time and operational costs relative to artificial drying. In addition, Janjai et al. (2007) designed a PV-ventilated parabolic-shaped greenhouse dryer for drying chili, banana, longan, and green tea. In this system, the air temperature was found to be in the range of 60–65 °C at noon during the dry season. The drying time for 100–150 kg of chilies was significantly reduced compared to open-air sun drying. Moreover, the PBP for drying chili was approximated at 3.4 years. Phusampao et al. (2014) used the same model greenhouse solar dryer with six DC fans powered by PV modules to dry macadamia nuts in Loei Province. Their findings showed that the drying time for 730 kg of in-shell nuts was reduced from 5 to 3 days and an estimated PBP for this dryer was about 1 year.

4.2. India

India is primarily an agriculture-dependent country and 60% of the population still depends on agriculture for their livelihood (Aravindh et al., 2014). It is estimated that about 10–40% of the raw agricultural productions, especially fruits and vegetables, are lost at various stages of harvesting, storage, and processing. This problem results in unstable prices and food insecurity (Ali, 2004; Maheshwar and Chanakwa, 2006). Many methods of food preservation have been applied to tackle this problem, but almost all the technologies still use fossil fuels. Therefore, solar drying is one of sustainable methods for food preservation, as solar energy has great potential with the annual radiation ranging from 1200 to 2300 kW/m^2 (Yadav et al., 2015).

Ayyappan and Mayilsamy (2010) constructed a community model greenhouse dryer for copra drying in Pollachi. The dryer was 4 × 10 × 3 m^3 and the chamber was covered by 200 μ thick UV-stabilized polyethylene sheets. Two exhaust fans with a diameter of 30 cm and three air vents with butterfly valves were used for air circulation. The loading capacity was 5000 coconuts/batch. With this dryer, the moisture content of the samples was reduced from 52 to 8% in 2.5 days and a high-quality product was achieved.

Shahi et al. (2011) developed a poly-house type dryer with a capacity of 100–150 kg to dry fruit and vegetables such as apple, tomato, capsicum, cabbage, leafy vegetables, and carrot in the Kashmir valley. This work was conducted under the All India Coordinated Research Project on the Application of Plastics in Agriculture at the Division of Agricultural Engineering SKUAST (K), Srinagar. The dryer consists of a drying chamber, drying trays, and an exhaust fan. The poly-house dryer can decrease the drying time by about 40–50% compared to open-air sun drying. The local producers could recover the cost of this dryer within a period of 1.5 years.

Debbarma et al. (2013) developed a low-cost bamboo solar dryer to dry green chilies at Maulana Azad National Institute of Technology (MANIT), Bhopal. The drying efficiency was improved by 17% when compared to traditional sun drying and the costs were about US$9, which poor farmers in semi-urban and rural areas of India can easily afford. In the same year, the Society of Energy, Environment, and Development (SEED) at Hyderabad developed a solar-powered air dryer for processing fruit and vegetables (Eswara and Ramakrishnarao, 2013). The stationary chamber was built from stainless steel with a glass cover at a 20° slant for proper radiation. The solar-heated air passed through the trays and the moisture was removed with solar-powered exhaust fans. In addition, electrical heating was provided during sunless hours. The temperature inside the drying chamber was in the range of 40–65 °C (Aravindh et al., 2014). Average efficiency was around 90% and the loss of approximately 10% was due to the heat loss through the inner and outer surface of the glass cover (Eswara and Ramakrishnarao, 2013). As reported by Tiwari (2016), SEED has installed about 180 solar dryers to process fruit, vegetables, medicinal plants, fish, and marine products at demonstration and commercial scales in 18 States of India, from Kashmir to Trivandrum and from Gujarat to West Bengal. In addition, SEED has trained about 1,000 Indian women, NGOs, and young adults in the solar drying of various agricultural products.

One key factor for the success of the solar dryer in India has been the presence of a favorable enabling policy enviroment. In 2010, the Jawaharlal Nehru National Solar Mission (JNSSM), also known as the National Solar Mission, was launched by the Government of India and State governments to promote solar power. This mission aimed to establish a favorable environment for the technology to penetrate both central and regional levels (Jawaharlal Nehru National, 2012). The first phase (2010–2013) focused on capturing the most accessible options in solar thermal energy applications and to promote off-grid systems to serve populations without access to commercial energy and modest development technology. During the second phase (2014–2022), the scaling of solar energy in the country has been promoted. Under this policy, a 30% subsidy is provided for the installation of solar-energy-driven equipment. In some States, such as Tamilnadu, the subsidy for setting up solar dryers was up to 50%.

4.3. China

China is the leading producer of agricultural products worldwide but is increasingly facing serious energy supply and the environmental challenges (Honghang et al., 2014). Since 2007, China emits the largest amount of CO_2 worldwide with an emission load of 300 million tons (Bruckner et al., 2014). Apart from the use of crude oil and raw coal, China also ranks first in the world in electricity consumption. Due to the pressing issues of post-harvest losses, energy supply, and the environment, China has examined its energy structure and developed a roadmap for solar energy (Ruicheng et al., 2014; Urban et al., 2016).

Solar drying of agricultural products is environmentally-friendly and has rapidly been applied (Yanlai et al., 2011). Various types are being commercially used in the country, such as the greenhouse dryer, collector dryer, collector-greenhouse hybrid dryer, integrated dryer, and focusing dryer (Piacentini and Mujumdar, 2009). Ruicheng et al. (2014) reported that since 2000, more than 200 solar drying systems have been installed in China with a total area of 20,000 m^2 of solar collectors that are used to dry various materials such as corn, vegetables, fruits, and Chinese herbal medicines. The aim is that by 2020 more than 50% of grain drying will take place with solar drying systems and that the solar share will be more than 40%. Recently, Hao et al. (2018) applied a flat plate solar collector with dual-function (FSDF) in a hybrid dryer. The system was composed of the FSDF, a water tank and auxiliary system, and a drying chamber. The ambient air was heated by the FSDF and then sent to the drying chamber by the fan. Meanwhile, the absorbed solar energy of the FSDF was also collected in the water tank when the temperature of the heated air was higher than the maximum drying temperature. When the heat from solar radiation was insufficient, the collected energy of the water tank was released to heat the air. With this system, they claimed that solar energy can be efficiently used, and the product quality can be improved. Moreover, the annual cost of the FSDF hybrid dryer proved to be 1.1% lower than electricity, 142.9% lower than the heat pump, and 13.7% lower than coal.

To support the use of solar thermal energy in the country, Ruicheng et al. (2014) and Shuiying et al. (2011) report that China will (1) establish development goals and formulate a "Renewable Energy Law"; (2) carry out research on near (2020), mid-term (2030), and long-term (2050) energy strategies for the systematic and integrated development of solar energy, which will focus on market, technologies, industry, and policies; and (3) put forward various economic incentives such as providing financial assistance through investment subsidies as well as product and consumer subsidies for the solar industry.

4.4. The Philippines

Among various agricultural products, rice is one of the major crops in the Phillipines (United Nations Development Programme (UNDP), 2018). Post-production losses of rice in the country occur mainly in handling and drying (Food and Agriculture Organization (FAO), 2017). Delayed, incomplete, or inefficient drying can result in losses of quantity and quality. Highway dryers are mostly used to dry paddy rice. Rice is spread out in thick layers to sun-dry alongside roads and highways. This method of drying requires little investment but is not possible during the rainy season and at night. Open-air sun-drying leads to the development of cracks in the kernels, overheating, or rewetting of grains, resulting in a low milling quality. Therefore, the solar dryer is highly recommended for the production of premium quality rice.

A tunnel dryer for drying paddy rice was tested at the International Rice Research Institute (IRRI) in the Philippines in 1989 by the University of Hohenheim (UHOH) (Djokoto et al., 1989). Thereafter, the Inflatable Solar Dryer (ISD) or Solar Bubble Dryer (SBD), which is an innovative, low-cost technology, was developed at the UHOH, IRRI, and GrainPro Inc (www.grainpro.com). This dryer is a tunnel type (Fig. 4A and B) in which the performance depends on solar radiation, the relative humidity of the ambient air, and moisture content of the agricultural materials. The ISD is mobile and completely independent of fuel or the power grid. A report of IRRI (International Rice Research Institute (IRRI), 2016) showed that the ISD takes less time than conventional sun drying and protects the commodities, especially seeds and grains, during drying. It can also be set up on concrete pavements, ground surfaces, and grassy areas to dry materials with a capacity of 0.5–1 ton, depending on the type of materials. Apart from operating all systems by solar energy, the ISD can be connected to power from the grid to run the ventilators and solar energy to dry the materials. As reported by Salvatierra-Rojas et al. (2017), when the ISD was applied to dry paddy rice, the targeted moisture content of 14% wet basis can be achieved within 26–52 h during the rainy season and between 4 and 26 h during the dry season which is a shorter time frame than for open-air sun drying.

In addition, the Philippines Center for Post-harvest Development and Mechanization (PHilMech) (http://www.philmech.gov.ph/) modified the tunnel dryer, which originated from the UHOH, Germany, to the Multi-Commodity Solar Tunnel Dryer (MCSTD). This version comprises a heat collector, drying chamber, and fan/blower with a capacity of 250 kg. The heat collector and drying chamber are covered with a UV-stabilized polyethylene plastic sheet and mounted in metal frames with an inverted V shape. An axial fan with an electric motor is used to force air into the heat collector, increasing the drying air temperature to 45–60 °C. The MCSTD is suitable for drying various perishable products, particularly fruits, vegetables, fish, and seaweed. The investment cost has been reported to be US$3,462 to 4,423. The PHilMech claimed that the producer will be profitable when the MCSTD is acquired through a facility loan payable within 5 years at an annual interest rate of 14%. The investment can be recovered within 3 years and 2 months and the return on the investment is 34.8%.

Like other developing countries, the Philippines have recognized the impact of high dependence on fossil fuels and exposure to price fluctuations, also the importance of renewable energy in matters concerning public health, natural ecosystems, and the environment. Therefore, the Republic Act (RA) 9513 or the Renewable Energy Act of 2008 was established to accelerate exploration and the development of the country's renewable energy resources, such as biomass, solar, wind, hydro, and geothermal power, and the ocean (Philippine Institute for Development Studies (PIDS), 2017). Different policies have been implemented by governments such as the Feed-in-Tariff (FiT), the bidding and quota systems, green certificate trading, and fiscal incentives (e.g., rebates or tax exemptions) to promote and support the development of renewable energy.

4.5. Indonesia

Indonesia has a huge potential for renewable energy (Abdullah, 2006; Hasan et al., 2012). However, renewable energies (solar, wind, hydro, and biomass) contribute only 3% to the national energy resources, which come mainly from fossil fuel, natural gas, and coal (Hasan et al., 2012). The potential use of renewable energy is rapidly increasing since Indonesia has the highest energy consumption among all countries in Southeast Asia (Kumar, 2016). Among all the renewable energy sources, the country has a high amount of solar energy with average radiation of 14.4 MJ/m^2/day. The most common applications of solar energy are related to thermal energy used by industries, such as solar drying, heat pumping, cooling systems, water heating, and desalination (Handayani and Ariyanti, 2012).

Sun drying of agricultural products has been considered as a viable technology in this tropical country (Halawa et al., 1997). Traditional open-air sun drying is still the most common method used by smallholder farmers (Amin, 2008; Yahya, 2016; Laksono et al., 2017). However, the traditional method has many disadvantages, as already mentioned. Up to now, solar dryers suitable for small processing units are gaining attention from the government, the domestic private sector, and NGOs (Abdullah, 2007). Many domestic and international researchers have worked on the development of various types of dryers.

From 1992 to 1996, an ASEAN-Canada project introduced state-of-the-art solar drying technologies in five ASEAN countries, including Indonesia (Halawa et al., 1997). The project successfully implemented the transfer of knowledge on innovative technologies. Among various dryers developed in Indonesia, tunnel dryers have been widely used, especially in cocoa and coffee processing. Amin (2008) designed and constructed a tunnel dryer with a capacity of 500 kg cocoa/batch. The results showed a thermal efficiency of 31% with an average drying temperature of 38.6 °C, while investment and operational costs were relatively low. A simple locally made dryer was used to dry turmeric (*Curcuma longa*), and the drying time to achieve the desired moisture content of 10% was 30 min faster than in the traditional method (Soebiantoro et al., 2018). The performance of a mixed passive solar dryer integrated with a biomass stove to dry ginger was reported by Laksono et al. (2017). With a drying temperature range of 40–60 °C, the performance was adequate, and the product quality met the Indonesian standard requirements. To dry natural rubber on small-scale farms, Breymayer et al. (1993) reported a state-of-the-art dryer (also known as a smokehouse) equipped with a solar air heater and a biomass furnace. The addition of external heating sources for the drying chamber achieved a desirable air temperature between 45 and 60 °C. During the rainy season, the dryer was able to uniformly dry 320 kg of rubber sheets to the desired moisture content of 0.5% in 5 days. To dry one kg of rubber, the system also provided a reduction of 1.5 to 0.3 kg in firewood commonly used in conventional smokehouses.

With regard to product quality improvement, greenhouse dryers

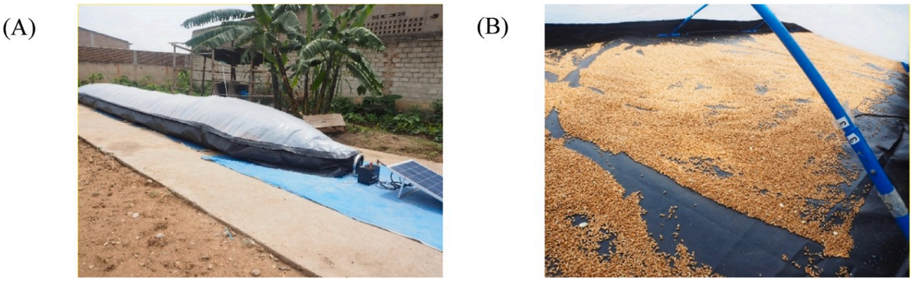

Fig. 4. Inflatable Solar Dryer (ISD): (A) Outside and (B) Inside the dryer.

were introduced in 1999 in many parts of Indonesia (Abdullah et al., 2001). This type of dryer is commonly used to dry various agricultural products, such as cloves, coffee cherries, cocoa beans, sliced fruit, spices, fish, and other marine products (Abdullah, 2007). A greenhouse dryer was used to dry 64 kg of vanilla pods, and the time required to reduce the moisture content from 82.6 to 37.8% was 51.3 h (Abdullah and Mursalim, 1997). A dryer of this type was also tested to dry *Arabica* coffee beans in North Sumatra (Siagian et al., 2017). After fermentation, the beans with a moisture content of 80% were first dried using traditional open-air sun drying and then in the greenhouse dryer. By using the dryer, it took 3 days to dry the beans to the desired moisture content of 12%.

The agricultural sector in Indonesia is dominated by smallholder farming activities (Abdullah, 2007). Therefore, the tunnel and greenhouse dryers seem to be the most promising options for rural areas (Patil and Gawande, 2016). However, the technology still faces some challenges, such as high investment costs and a long PBP, especially for small-scale cooperatives and smallholder farmers (Patil and Gawande, 2016; Prakash and Kumar, 2014). A low-cost and efficient dryer, which can be locally constructed, is preferable (El Hage et al., 2018). Furthermore, integration of a PV-driven system to power the fans of active dryers can be an attractive option, especially in rural areas outside Java Island, where 48% of the population still has difficulty accessing commercial energy sources (Abdullah, 2006).

The utilization of renewable energy still needs comprehensive support from government and non-government institutions in terms of policy, regulations, subsidies, tax incentives, and promotion (Hasan et al., 2012; Mujiyanto and Tiess, 2013). In terms of policy, the Indonesian government provides subsidies to meet the needs of the community that are aimed at lowering energy production costs, increasing energy producer revenues, or reducing costs paid by energy consumers. Policymakers often justify subsidizing energy on the grounds of supporting economic growth, reducing poverty, and ensuring the security of energy supply (Mujiyanto, 2016). In addition, the FiT policy has been established (Suprayogi, 2016) to increase the growth of private investment to develop solar energy in the country.

5. What is the situation in Africa?

Drying by direct exposure to the sun is widely used in SSA countries, and solar drying research has been obscured by technological and economic constraints. Due to the availability and accessibility of data, this section presents the situation for an application of solar dryers in Burkina Faso, Kenya, Uganda, and Democratic Republic of the Congo (DR Congo).

5.1. Burkina Faso

About 70% of the energy in Burkina Faso comes from fossil fuel, and 20% of electricity is imported from Ghana and Côte d'Ivoire (Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 2009; Moner-Girona et al., 2016). However, the country has a huge potential for solar energy production. The average annual radiation is 19.8 MJ/m^2/day with an annual sunlight duration of around 3,000 h. As exhibited (Fig. 5), utilization of solar energy through a PV-driven system is mostly used for refrigeration, water pumping, communication, lighting, and electronics (Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, 2009), but applications of the PV system to heat water and for the solar drying of agricultural products are still inadequate (Ramde et al., 2009).

For agricultural products, traditional open-air sun drying is still the most commonly employed method for sesame stalks, paddy rice, cassava grits, shea paste, and many more (Fig. 6). However, this traditional method leads to severe post-harvest losses, especially for highly perishable agricultural products, such as vegetables and fruits (Sheahan and Barrett, 2017). Losses of around 30% for all crops and of 50% for fruits and vegetables have been identified (Nonclercq et al., 2009).

Fig. 5. A PV-driven system run by a women's cooperative for different business activities in Saria, Burkina Faso.

Based on a survey conducted in Burkina Faso, it was concluded that a proper design of a solar dryer strongly depends on the characteristics and added value of the agricultural products, energy access, costs, the availability of skilled labour, and material for construction, as well as the financial ability of the users (Boroze et al., 2014). Under Burkina Faso's climate conditions, the operational costs of solar dryers with low energy inputs vary between 10.7 and 279.2 US\$/m^2 drying area. In comparison, the cost of traditional open-air sun drying is around US\$0.0 to 8.9 (CBI Market Information Database, 2014). However, the majority of solar dryers available on the local markets are not designed for co-operatives or small-scale industrial or individual use and are not even locally manufactured (Nonclercq et al., 2009).

Some case studies have been conducted in relation to the development of suitable solar dryers for different agricultural products. Drying of different mango varieties was done using traditional open-air sun drying, but since 1996 the use of gas dryers has been integrated with the traditional method (CBI Market Information Database, 2014). To promote the use of biomass to dry mango in rural areas, a dryer integrated with a biomass burner was also developed by Beritault et al. (2010). Two different greenhouse dryers, one manufactured in France (M5-003) and the other locally in Burkina Faso (Banco), were used to dry cucumber, mango, and onion (Coulibaly et al., 1988). A prototype of a solar cabinet dryer to dry tomato in West African countries was designed and constructed by the Université Libre de Bruxelles (Nonclercq et al., 2009). Due to the lack of a conservation method, high losses of tomatoes were reported by Venus et al. (2013) during the transport from Burkina Faso to a market in Ghana.

As part of a collaborative research project by the UHOH, Stuttgart, Germany and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) Green Innovation Centre, an ISD application was introduced in 2017–2018 (Fig. 7). For drying paddy rice in Bama, the capacity of an ISD (SBD 50, GrainPro Inc, Zambales, the Philippines) is up to 2 tons. The price of the one-unit of ISD, including one PV-panel (100 Wp) and two DC fans, without training costs, was estimated at around US\$2,040.5, obviously too expensive for the farmers and their cooperatives. The training cost for 1–2 days was about US\$500–800, depending on location.

The utilization of a PV-driven system to run the fans for active solar dryers in Burkina Faso can provide affordable electricity and support a sustainable energy generation system. However, the system application still faces many challenges, such as theft, poor access to standards and certifications, as well as incompetent technicians for installation and maintenance (Ramde et al., 2009). On the other hand, the current costs of solar components, such as a PV-panel, solar charge controller, and a battery, are still beyond the investment capability of rural customers

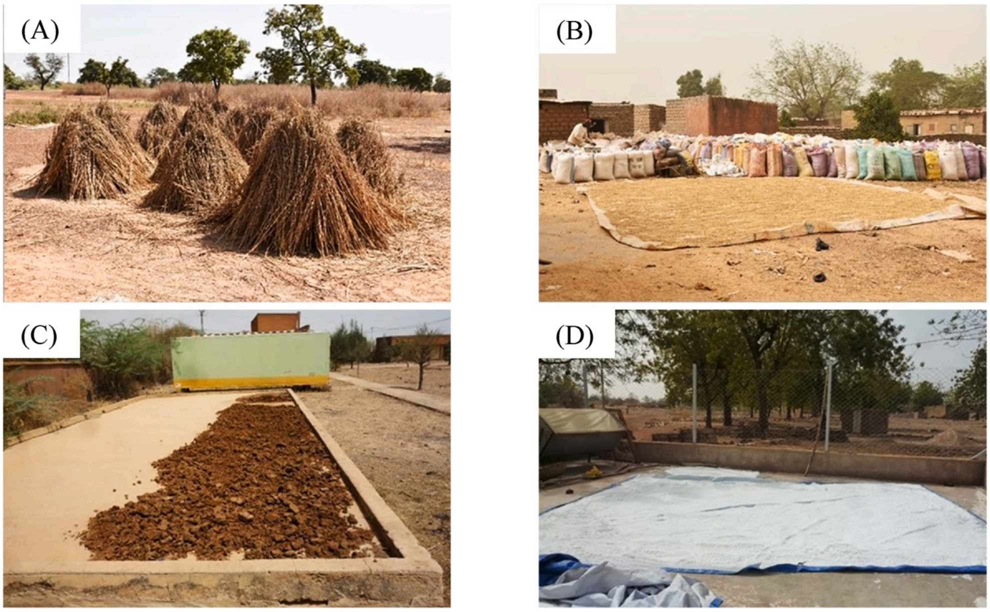

Fig. 6. Traditional open-air sun drying of sesame (A); paddy rice (B); shea paste (C); and cassava grits (D) in Burkina Faso.

Fig. 7. Application of inflatable solar dryers to dry paddy rice in Burkina Faso.

(Ramde et al., 2009; Bensch et al., 2018) Nevertheless, this financial issue could be resolved through a solar microcredit program that could cover 40–50% of the investment costs (Holt, 2016). From another case study conducted in a village in Burkina Faso, Ouedraogo et al. (2015) reported that a hybrid configuration of a PV-panel and a diesel generator also appeared to be an affordable system to generate electricity.

In Burkina Faso, high demand for active dryers integrated with a PV-driven system has been identified to dry fruits and vegetables at both cooperative and individual levels (Nonclercq et al., 2009; Boroze et al., 2014). To ensure a successful implementation in the country, a comprehensive data mapping of the solar radiation, testing facilities, standard protocols, production of local solar components, development of an efficient drying operation, as well as a promotion of tax incentives, should be established (Ramde et al., 2009).

5.2. Kenya

Kenya covers diverse climatic zones, from tropical to semi-arid and arid. Despite being the largest economy and one of the most diverse in Eastern Africa, a large proportion of the population is still employed in the agricultural sector (Eberwein et al., 2016; United Nations Economic Commision for Africa (UNECA), 2017). In general, the solar potential is high, with an annual average of 18 MJ/m^2/day and diverse uses of solar energy have been established (Kiplagat et al., 2011). Kenya is a mong the few African countries which have successfully adopted small-scale solar PV energy and started to build up a growing industry in this field (Amankwah-Amoah, 2014). PV installations became more affordable in recent years and developed into an interesting and important off-grid energy source in rural areas (Kiplagat et al., 2011). PV-based off-grid solutions have also been applied for post-harvest purposes in rural areas, such as in a milk-cooling system (Salvatierra-Rojas et al., 2017).

Traditional open-air sun drying is still a widely applied technique in the agricultural sector, but a several types of solar dryers are adopted in practice. As can be seen (Fig. 8A and B), the application of a tent and greenhouse dryer for fruit dehydration is used at the Small and Mid-size Enterprise (SME) level. For many years, projects on solar drying have been conducted under Kenyan conditions researching the application of various dryer types for different commodities such as maize or fish, e.g., Othieno (1987), Thoruwa et al. (1996), Kituu et al. (2010), and Ronoh et al. (2010). Also, combined drying techniques with an additional desiccant have been developed (Thoruwa et al., 2000).

Kenya was also part of a collaborative research project between the UHOH and the International Center for Tropical Agriculture (CIAT). In this project, the application of the ISD technology for different value chains and commodities was investigated, including processed products such as cooked beans and blanched amaranth leaves, among others (Fig. 8C and D). Constraints that limit their further application, identified by previous projects on the topic of solar dryers, such as by Othieno (1987), are partly still valid and often attributed to initial investment costs, missing technical or process knowledge, or poor construction materials.

5.3. Uganda

Uganda has a very high potential for renewable energy, especailly hydropower, solar, and biomass (Food and Agriculture Organization (FAO), 2015). It is estimated that only 9–12% of the total population has access to electricity, and in rural areas, this figure is much lower. This country has a high solar potential, even during the rainy season, with average horizontal radiation of 18.4 MJ/m^2/day.

Over 30,000 off-grid, PV-systems are installed and a FiT system is implemented (Twaha et al., 2016). Traditional open-air sun drying is still used as a dominant technique for conservation. Solar drying is also used to conserve fruits during periods with low market prices or to enable access to the export market (Chongtham et al., 2010). The types of dryers found in the field include a cabinet type, tunnel dryers, and different hybrid models with a separated drying and collecting area

Fig. 8. Greenhouse-type (A)- and cabinet dryer used for fruit processing (B); drying amaranth leaves using an ISD (C–D).

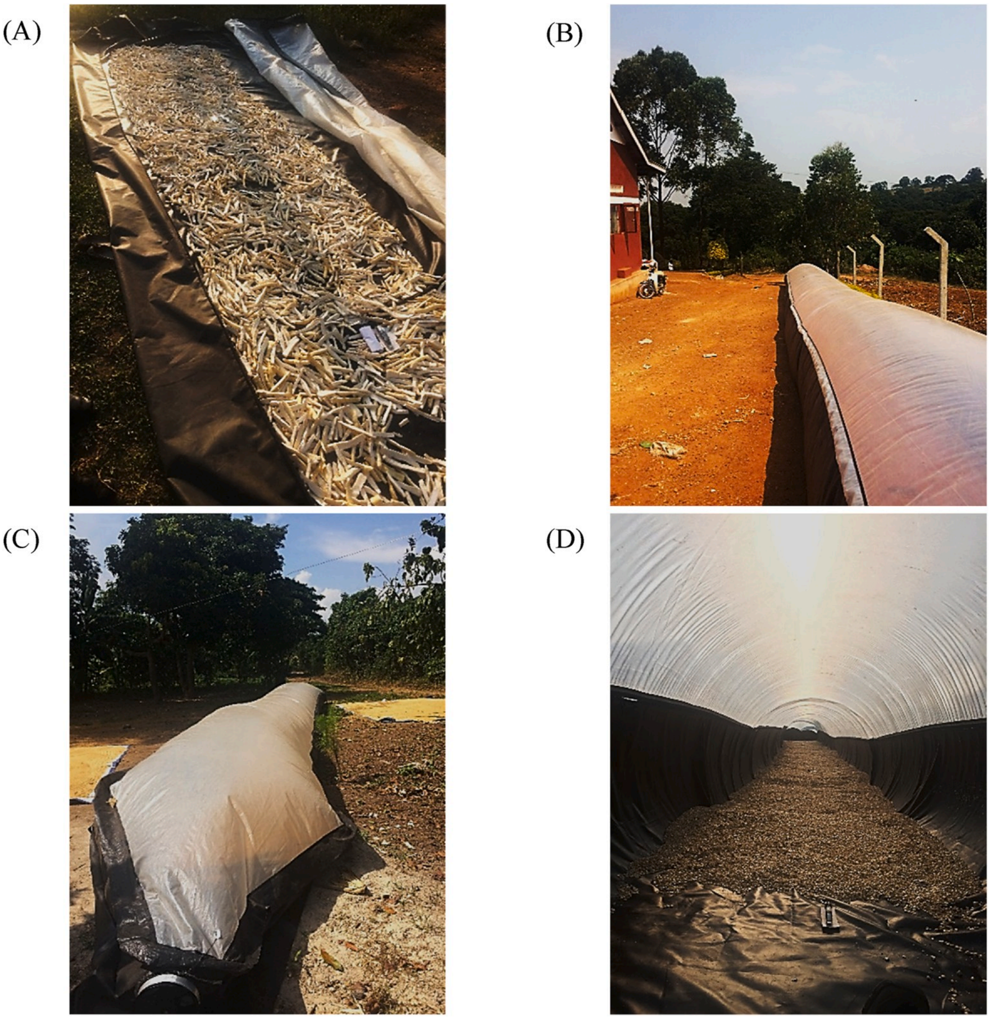

Fig. 9. Application of ISD in Uganda – Drying of cassava chips (A); bean seeds production at cooperative level (B); drying of amaranth seeds at farmers' level (C); inside the dryer whilst maize is drying (D).

(Kiggundu et al., 2016). Amongst the restraints and problems identified for the application of solar drying were the use of poor construction materials, poor design, and inadequate capacity (Kiggundu et al., 2016) as well as insufficient capital resources (Chongtham et al., 2010).

Several solar drying techniques have been tested over the last decades for different applications in Uganda, e.g., Kiggundu et al. (2016), Plumptre (1967), and Musinguzi et al. (2006). Recently, experiments have been conducted with an ISD type dryer (SBD 25 and SBD 50) to research the applicability of the ISD technology for different crops such as maize grain, amaranth, and beans. The experiments have been conducted at both farmer and cooperative levels (Fig. 9A–D). Drying systems of these types can improve the post-harvest process, but challenges persist, including high investments in the PV components, lack of technical know-how, and theft (Kiggundu et al., 2016).

5.4. DR Congo

In DR Congo, Kusakana (2016) reported that about 93.6% of the country is highly dependent on fuelwood, while the major share of electricity production, mainly from hydro- and thermal power stations, is used by the industrial sector. This country has very high levels of solar radiation, ranging between 11.9 and 21.6 MJ/m^2/day (Kusakana and Vermaak, 2013), yet there are only 836 solar power systems with a total power of 83 kW operating in Equateur, Katanga, North-Kivu, and Kasai Provinces, and Bas-Congo.

In the agricultural sector, sun drying is still the most important post-harvest operations in the country, especially for maize and cassava (Fig. 10A and B). At small-scale cooperative or smallholder farmer levels, the unhygienic and low performance of drying practices is the major factor driving post-harvest losses and aflatoxin contaminations (Kamika et al., 2016). Although oven drying is more efficient than the conventional sun drying, it is found not economically viable. Therefore, a low cost and locally made greenhouse dryer has been introduced by IITA as an alternative method to improve the quantity and quality of dried products. With the application of a solar dryer (Fig. 10C and D), for example, the cassava community processing center, which is managed by the youth and a women's group in Katana, Eastern DR Congo, recorded a significant increase in production of high-quality cassava flour and other derived products as well as improved income.

Though the interest in the renewable energy sector in DR Congo is growing through many projects, it is mostly focused on hydropower technology (Kusakana, 2016). There are many challenges regarding the general energy situation. As in many SSA countries, most of these are actually linked to the lack of proper policies and technological advancements, political and economic instability, and the low level of educational background and awareness.

6. Future recommendations

Solar drying technology presents great potential as an eco-friendly method to reduce post-harvest losses in low and middle-income countries. However, the adoption of the solar dryer technologies, particularly in SSA countries, is facing several challenges, such as high costs, lack of information, technology and financing, poor institutional and legal framework, and inadequate regulations and legislation on renewable energy (Karekezi and Kithyoma, 2002; Tchanche et al., 2009). Therefore, to scale up solar drying, (1) governments should support renewable energy policies and encourage the use of solar technologies at both individual and industrial scales; (2) a financial system for the large agricultural sector should be enhanced by liberalizing both, distribution and tariff settings, while an energy subsidy through loans might be required for the small to medium scale; (3) cooperatives should be created at multilateral levels, such as farmers, government bodies, private organizations, and NGOs; (4) solar dryers should be designed based on practical experience, local climate, and economic conditions. For example, low-cost and simple dryers should be disseminated to rural areas targeting small- and micro-enterprises and households. (5) Training of users on solar drying for each crop should be provided; and (6) national media networks should be generated in raising awareness of dryer applications to speed up the adoption of the technology.

7. Conclusions

This review offers justifications for the use of solar drying as an affordable and cost-effective alternative method to overcome the restrictions of traditional sun drying, especially in low-income countries. Numerous types or designs of solar dryers can be constructed according to the budget, location, and requirement of the materials to be dried. Optimization of the process, especially with respect to different classifications of dryers, must be considered to preserve the final quality of the dried products. As costs are the main determining factor for scaling up this technology, the short- and long-term costs and benefits should be

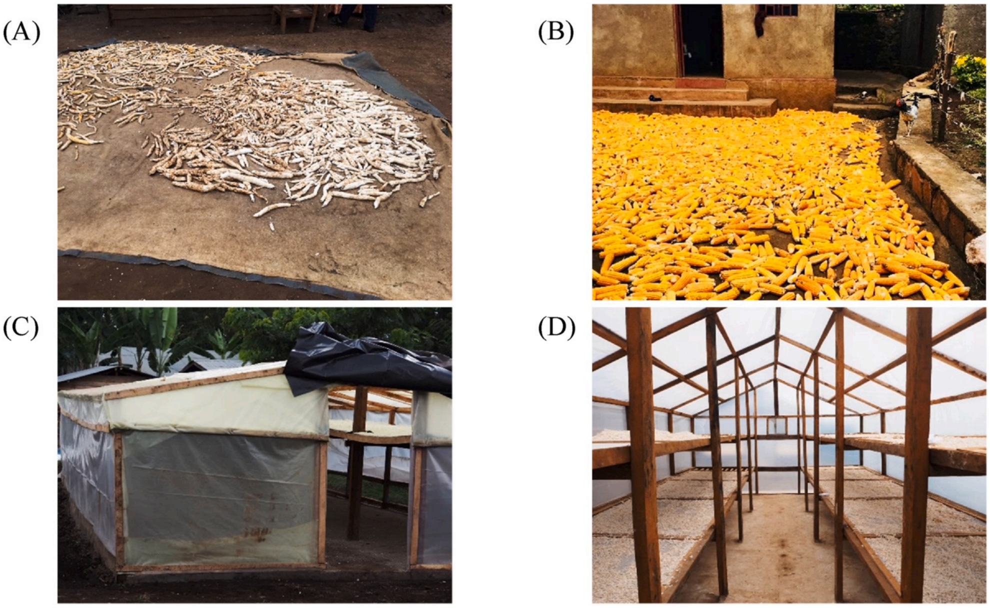

Fig. 10. Traditional open-air sun drying of cassava (A) and maize (B) and application of locally made solar dryer for drying cassava (C-D) in Eastern DRC.

analyzed and supported. Finally, increasing the adoption of the technology both in Asian and SSA countries still requires effective cooperation and communication between key actors in the agricultural research–extension–producer linkage.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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