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A review of quality characteristics of solar dried food crop producst

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Abstract. Sun drying is perhaps one of the oldest methods of food preservation that has been practiced for centuries. The direct usage of solar radiation which is renewable and abundant favours farmers that harvest and process at small quantity. As technology advances, an alternative to sun drying evolves to maximize the potential of solar radiation and this technology is known as solar drying. Solar drying has several inherent advantages over sun drying namely faster drying rate, better protection of products, reduce risk of prolonged drying, lesser risk of product spoilage and improvement in product quality. Various studies have reported the application of solar drying for fruits, vegetables, grains, seeds, beans, herbs, spices and medicinal plants. Product quality improvement is definitely associated with solar dried products as compared to sun dried and to some extent oven/hot air dried products. However, uptake of this technology especially among farmers in developing countries are still low despite the many years of research and technology advancement. Nonetheless, some successful application of solar drying have been reported in countries such as Indonesia, Laos, Zimbabwe, Tanzania, Brazil, Uganda, Kenya and Senegal.

Keywords: quality characteristics, solar dried, food crop

1. Introduction

Conventionally, most food crop products are dried using mechanical dryers that utilize convective hot air to dry the products to final content safe for storage. Food crop products are dried mainly for purposes such as storage and preservation, reduction in weight and volume, ease in transportation and reduction in spoilage and wastage. Solar drying is one of the alternatives to drying with aims to reduce dependency on fossil fuels and electricity in drying operation. Solar drying also helps to eliminate the disadvantages associated with natural sun drying such as prolonged drying duration, low drying throughput, contamination by foreign matters/debris, rewetting by rain droplets and low drying temperature (ambient condition). In recent years, solar drying have received much attention in agricultural sector owing to the following reasons:

- To substitute the scarce and expensive fossil fuels
- To improve quality of sun dried products

- To increase revenue of farmers with small farm size
- Government's efforts towards the use of sustainable and renewable energy

Upon processing, product quality is the only criteria that decides the marketable opportunities of the dried products in the market. Product quality is equally important in fresh, semi-dried and fully dried products in both edible and non-edible food categories. Traditionally, most food products are dried under direct sunlight to achieve the required degree of dryness. This has been done ever since mankind realizes the importance of drying. However, thanks to technological advancements many food products are now dried by mechanical dryers. Nevertheless, in many parts of the world sun drying is still a usual practice especially in many developing countries [1, 2, 3, 4].

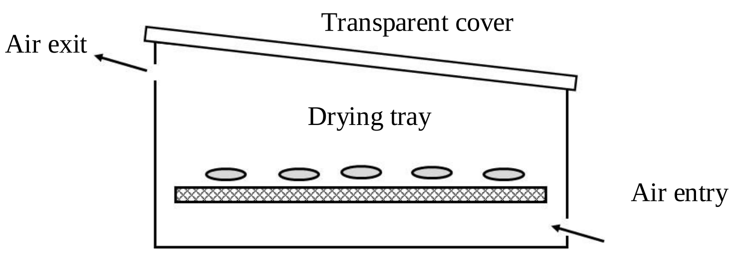
Comparisons of product quality between sun and hot air drying have been discussed in many published literatures. However, when comparing these techniques against solar drying, it depends on several factors such as types and designs of solar dryers/collectors, the nature of the products when expose to sunlight, drying rate and inclusion of auxiliary heating device. Hot air drying has been associated with several quality damaging issues such as case hardening, colour deterioration, high degree of shrinkage, degradation of nutrients, flavour loss and etc. [5,6,7,8,9,10].

On the other hand, sun drying has its inherent disadvantages owing to the unpredictable weather conditions, which often lead to quality deterioration [1, 3, 11]. Therefore, solar drying in some extent helps to solve these problems. However, this is only possible when care is taken during the design, construction and testing of the solar dryer for the target agriculture product. In this paper, reported studies on the product quality aspects are compiled for food crop products dried using solar dryers. This mini review serves as a useful guide to industrial practitioners, scientist and academic researchers with the aim to provide latest development on the implication on product quality as affected by solar dryer design and operation.

2. Classification of Solar Dryers

Various published literatures have reviewed and classified solar dryers into several categories depending on the mode of operations [1, 3, 12, 13, 14, 15]. Generally, solar dryers developed for agricultural food products can be classified into direct, indirect and hybrid type solar dryers (Figure 1). It can also be further classified into active or passive mode [16]. The definition of direct solar dryer is straightforward where the product inside a transparent enclosure is dried under direct exposure to solar radiation (Figure 1a). In the case of indirect solar dryer, drying is achieved either by natural or forced convection and the product is placed in an opaque drying chamber and solar energy is absorbed by collector separated from the drying chamber (Figure 1b). The hybrid solar dryer combines the characteristics of the direct and indirect types and it also denotes solar dryer that uses another heat source in conjunction with solar energy (Figure 1c) [17].

(a)



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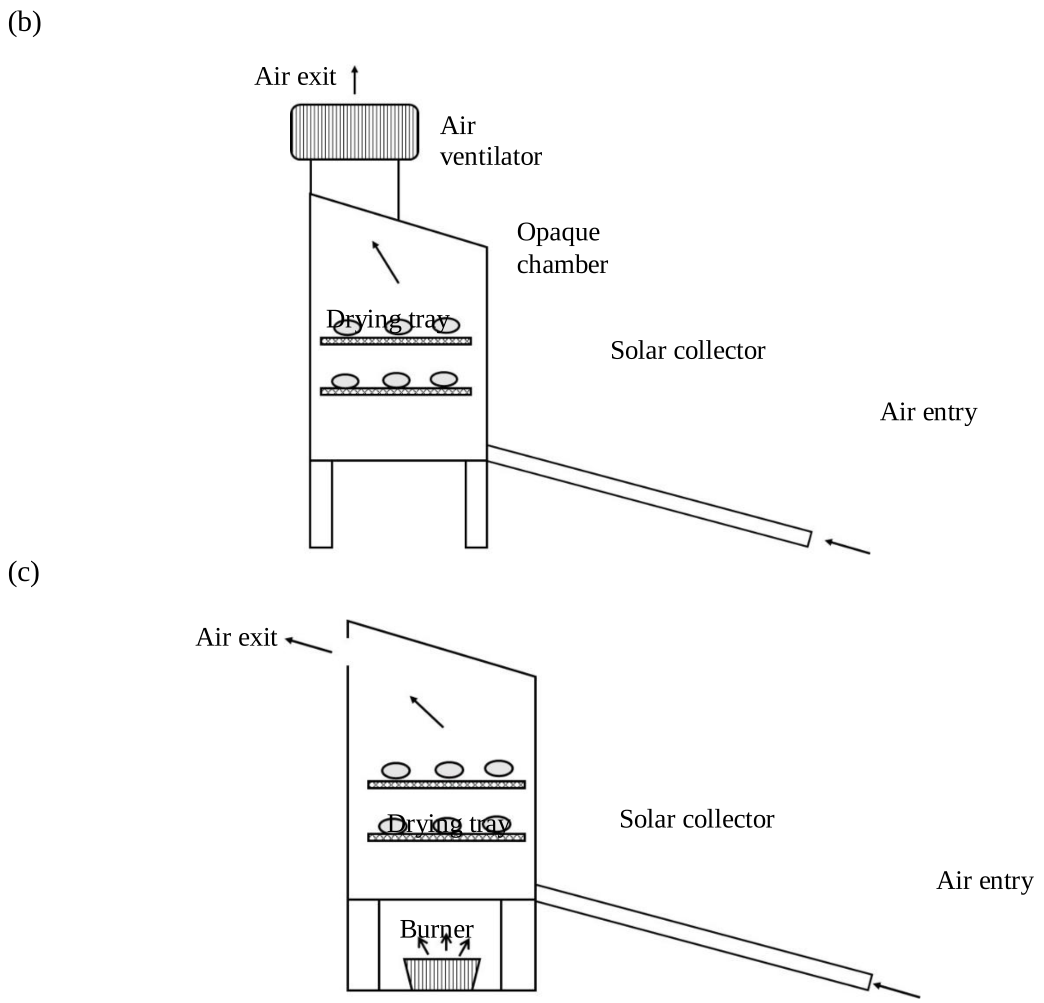

Figure 1. Classification of solar dryers (a) direct solar dryer (b) indirect solar dryer and (c) hybrid solar dryer

3. Product Quality

3.1 Quality attributes

Leitzmann,1993 [18] mentioned that food quality represents the sum of all properties and assessable attributes of a food item. In general, product quality of dried products can be classified into physical, chemical, biological and nutritional depending on the type as listed in Table 1. Further elaboration of some of these quality attributes can be found from various published literatures [19, 20, 21, 2, 6, 22].

Table 1. Selected dried product quality attributes.

Attribute	**Parameters**
Physical	colour, texture, shrinkage, porosity, rehydration, breakage
Chemical	flavour, odour, water activity
Nutritional	calorie, vitamins, minerals, fibres, lipids, proteins, carbohydrates, antioxidants
Biological	mould, yeast, E. coli, Salmonella, mycotoxins, aflatoxins
Sensory	appearance, odour, flavour, after taste, mouthfeel, texture, colour

Some established grading systems are available for some dried products such as for grains, cocoa, coffee, spices and etc but it is recommended to search for quality standards from relevant authorities (e.g. Department of Health) before the dried product is produced and packed for shipment and sales.

According to the US Food and Drug Administration, the water activity (aw) of a food is defined as the ratio between the vapor pressure of the food itself, when in a completely undisturbed balance with the surrounding air media, and the vapor pressure of distilled water under identical conditions [18]. Typically for dried food products, the water activity should not exceed the critical value of 0.85 and 0.62 to prevent the activity of bacteria and yeasts/moulds, respectively. As a safe practice, it is desirable to have water activity below 0.6 for dried food products.

3.2 Quality of Solar Dried Products

The quality aspects of solar dried products are not widely reported as compared to the design and performance aspects of solar dryers (e.g. computer simulation, energy, exergy and economics). The following tables (Table 2 – 5) show the research findings summarized from various solar drying studies for food crop products such as vegetables, fruits, grains, seeds, beans, medicinal plants, herbs and spices. The summary covers as many as possible food crop products that are commonly dried using sun light but also subject to investigation using solar drying for quality improvement purposes. Further details of the studies can be obtained from the reference sources as indicated in the tables.

Table 2. Vegetable products**.**

Product type	Type of solar dryer	Location	Major findings	Ref.
Carrots	Solar cabinet dryer	India	- High β-carotene loss was found in solar cabinet dried carrots due to longer drying time and exposure to light leading to oxidation. - Low rehydration ratio was observed due to greater shrinkage in solar dried samples.	[24]
Sweet potato	Green house solar dryer	Uganda	- Solar dried sample showed no significant losses in total carotenoids as compared to sun and hot air dried samples. - Sun drying showed the lowest retention value.	[25]
Green leaves	Indirect solar dryer	India	- Higher losses of β-carotene and ascorbic acid were observed in solar drying as compared to hot air cabinet drying upon storage. - Chlorophyll loss was also higher in solar dried sample. - Retention of the quality parameters of leafy green vegetables was better at faster drying conditions.	[26]
Spinach,	Enclose	Africa	- Maximum retention of ascorbic acid and total	[27]

cowpeas, sweet potato and cassava leaves	d solar dryer		carotene was observed in enclosed solar dryer with shade as compared to sun drying. - Sun drying showed minimum retention of these nutrients. -	
Okra	Solar tent dryer	Ghana	- Degradation of vitamin C destruction during solar drying of okra was not influenced significantly by sample thickness. - Vitamin C remained fairly constant after 48 h of drying. - Slice thickness showed no significant effect on the changes in whiteness of the solar dried okra with drying time.	[28]
Tomatoes	Concent ratedSol ar Dryer	Tanzania	- Internal temperature and relative humidity of a solar dryer with concentrated solar reflector is higher than a normal dryer. - The concentrated solar reflector dryer led to increased drying rates of tomatoes. - Drying times of tomatoes were reduced in the concentrated solar dryer and quality such as pH, titratable acidity, colour, Brix, lycopene, and vitamin C was comparable for both types of dryers.	[29]
Sliced Potatoes	Solar hybrid drying	Algeria	- The optimum solar panels chosen are 1 panel or 2 panels based on air drying temperature and water content variation. - The hybrid solar drying of the potatoes slices with panel induces a considerable colour changes in all tested cases.	[30]
bitter-gourd and capsicum	Solar, hot air, and sun drying	India	- Solar dried bitter-gourd and capsicum has the highest moisture loss and maximum retained functional components. - Solar dried vegetables attained the highest score of sensory acceptability and proved to be a potent technique over hot air and open sun drying.	[31]
Mush rooms	Solar drying and natural sun drying	Germany	- Solar drying and natural sun drying produced astonishing vitamin D contents and excellent source of dietary. - Whole UVB-treated brown button mushrooms contained high vitamin D2 content and could also boost vitamin D2 formation. - Slicing of mushrooms prior to UVB induced a ten-fold increase in vitamin D2 content.	[32]

Table 3. Fruit products.

Product type	Type of solar dryer	Location	Major findings	Ref.
Lemon slices	Solar dryer associated with the PV module	Taiwan	- Dried lemon samples with bright colour were observed under complementary solar drying using gradual temperature increment (range 36 – 52°C). - Lesser browning was observed as compared to hot air drying at 60°C.	[33]
Grapes & figs	Indirect and direct solar dryers	Egypt	- Vitamin C content of dried fruits was low due oxidation during solar drying especially when the samples were either scalded or sulfurized. - The colour of grapes dried using indirect solar dryer showed high acceptance as compared to the natural dried sample (medium acceptance). - The texture and colour of figs dried using mixed solar dryers showed better acceptance than the natural dried samples.	[34]
Grapes, apricots, and beans	Solar Drying System	Iraq	- The most effective factor on the drying rate is the temperature of the air inside the cabinet. - The effect variation of speed of air inside the drying cabinet is small and no need for high velocity air inside the cabinet.	[35]
Plums	Greenhouse dryer	Turkey	- Both solar and open sun drying of plums pre-treated by combination of 1% potassium hydroxide and 60°C dipping temperature or by combination of 1% sodium hydroxide and 60°C dipping temperature resulted in relatively higher values of redness and yellowness as compared to artificial drying. - The combined effect of solar radiation and these pre-treatment combinations reduced the darkish colour of plums during solar drying and open sun drying.	[36]
Indian gooseberry	Forced convective	India	- Flaking treated sample retained maximum ascorbic acid (76.6%). - The greater retention of ascorbic acid in flaking	[37]

	solar dryer		treated sample might be due to reduced exposure of the sample in the drying air. - Loss of taste and flavour were found lower in flaking and pricking treatments.	
Papaya latex	Rock bed indirect solar dryer	India	- Solar dried latex had a slightly higher preteolytic activity than the fresh sample because of the effect of ultraviolet radiation on the histidine residue which is essential for proteolytic activity. - This was attributed to the use of the indirect dryer since the latex was not exposed to any direct radiation.	[38]
Sorbus Fruits	Convective Dryer and Microwave Oven	Turkey	- The results showed that convective drying air temperature and microwave oven power levels influenced the total drying time, total energy requirement, specific energy requirement and color difference for sorbus fruits. - 50° C drying air temperature and PL-1 was found to yield better quality product in terms of color retention of Hunter L, a, b and ΔE. - Convective drying is preferred for better drying energy consumption and colour retention.	[39]
Feijoa	Freeze Dryer	Iran	- In this study, 7 pre-treatments (ascorbic acid, microwave, blanching with hot water and steam, potassium carbonate, osmotic and ultrasound) were used at different levels to improve the quality of dried samples. - The pretreated samples were freeze-dried, and their qualitative parameters (pH, rehydration, vitamin C, failure force, and total color differences) were analyzed. - Mean comparison of different treatments showed that the ultrasonic pretreatment can relatively preserve product parameters better than other pretreatments.	[40]
Deglet-nour Dates	Solar dryer	Algeria	- Dates were dried under direct natural convective solar drier, under indirect convective solar drier and in indirect natural solar drier. - The drying with indirect natural convective dryer provides a good product quality (visual colour change) with acceptable duration, and it is satisfactory and competitive to a forced convective solar drying	[41]

			process.	
Persimmons	flat plate solar collector	Pakistan	- The correlation between vitamin C content of persimmon at different slice thicknesses and drying temperatures showed that there is a strong negative correlation between drying time and moisture lost and drying rate with values of -0.991 and -0.997. - Persimmons may be dried at a temperature lower than 50°C and slice thickness more than 1.0 cm to get dried persimmons rich in vitamin C.	[42]
Orange Peel	Solar Tunnel Dryer	India	- Orange peel need 14 hrs to dry in natural convection where as it took 8 hrs to dry in natural convection along with sensible heat storage material. - Solar tunnel dryer integrated with solar air heater and sensible heat storage material represents a more drying efficiency than mechanical dryers. - Sensible heat storage is a good method to improve the performance of the dryer.	[43]

Table 4. Grains, seeds and beans.

Product type	Type of solar dryer	Location	Major findings	Ref.
Cocoa	Indirect and direct type solar dryers	St Lucia	- Dried sample from indirect dryer showed the highest cut test score while the direct dryer showed the lowest. - The dried beans from the direct dryer were more brittle and higher in acidity than open air and indirect dryers. - Overall dried bean quality is the best from the indirect dryer.	[44]
Cocoa	Direct solar dryer	Malaysia	- Overall quality evaluation (flavour, acidity, fermentation index, appearance and odour) indicated that lower drying load of 20 kg beans is recommended. - At this quantity, drying period was shorter and eliminates the risk of putrefactive development in beans due to unfavourable weather condition.	[45]
Cocoa	Indirect solar dryer	Côte d'Ivoi	- Shrinkage decreased linearly with decrease in moisture content.	[46]

		re	- The real density decreased linearly from 825.10 kg/m^3 to 695.25 kg/m^3) with decrease in moisture content. - The porosity increased linearly from 15.82 to 24.67% with decrease in moisture content.	
Coffee	Solar tunnel dryer	Indonesia	- Visual and organoleptic tests showed no significant difference between the solar dried and sun dried beans. - This could be due to the rather similar drying rates between solar and sun drying.	[47]
Coffee	Solar dryer with black transpired air solar collector	Thailand	- Coffee beans dried faster in the solar dryer and produced acceptable cup with no serious defects. - No OTA forming fungi was found in solar dried samples.	[48]
Rice	Mixed mode passive solar dryer	Iran	- Solar dried rice resulted in higher degree of whiteness than sun dried rice. - Samples dried in solar dryer are similar in flavour than those dried under the sun.	[49]
Rough rice	indirect and mixed-mode active solar dryers	Iran	- Bending strength for solar dried samples showed no significant difference with continuous dried sample at 35°C and 45°C. - However, highest head rice yield was obtained when both cultivars were dried in a continuous dryer.	[50]
Corn	Drying bin installed will bin-wall solar collector	Canada	- The quality of solar dried corn was superior to that dried using one-pass high-temperature. - The improvement was in physical characteristics of the kernels i.e. stress cracking, bulk density and breakage susceptibility.	[51]
Cashew nuts	Solar cabinet	Indonesia	- Cashew kernels looked bright-white and clean without black spot or toxin sign	[52]
Pistachio nuts	Direct solar dryer	Iran	- Both solar and sun dried samples showed excellent taste as compared to hot air dried samples. - No aflatoxin was found in both sun and solar dried pistachio nuts.	[53]

Peanut	Solar water and solar air dryer	USA	- In terms of milling quality, there was no significant difference among dried products from solar water, solar air and conventional dryers (range 1.1 – 4.5 % split kernels)	[54]
Bulgur	Forced convectio n Solar dryer	Turke y	- No significant difference in terms of overall acceptability based on flavour and mouthfeel among tray, solar, sun and microwave samples. - However, solar dried sample showed the highest acceptance score (7.8) as compared to other samples (scores 7.6-7.7)	[55]
Melon seeds	Flat plate solar dryer	Nigeri a	- Proximate composition of solar dried seeds was not significantly different from other drying methods. - No significant differences were observed in the colour, texture and taste of all dried seeds.	[56]
Green peas	Solar cabinet	India	- Colour and overall acceptance from solar dried sample was observed higher than sun dried sample. - Solar dried sample showed lower shrinkage (38%) and hardness (548 g) and higher rehydration ratio (1.69) as compared to sun dried sample (Shrinkage 80%, hardness 590 g and rehydration ratio 1.35)	[57]

Table 5. Medicinal plants, herbs and spices.

Product type	**Type of solar dryer**	**Location**	**Major findings**	**Ref.**
Thyme	Solar dryer using wire basket	West Indies	- The essential oils extracted from the oven dried and solar dried samples were 0.5% and 0.6% (per 100 g dry wt), respectively. - The oleoresin and ash content were 27% for both drying methods and 1.6%, 2.03% and 2.25% for the fresh, oven dried and solar dried samples, respectively.	[58]
Turmeric	Solar biomass dryer	India	- Dried turmeric rhizomes obtained from solar drying by two different treatments namely water boiling and slicing were similar in terms of physical appearance. - Sample dried in open sun had lesser volatile oil.	[59]
Wild coriander	Direct cabinet	Peru	- Some leaves from upper trays of the direct solar dryer were completely brown in colour which	[60]

	solar dryer and indirect cabinet		could be due to the effect of direct solar radiation in combination with high temperatures. - The highest preservation of natural colour and absence of browning were observed from samples using indirect solar dryer. - Essential oil from samples dried in the indirect solar dryer was closer in its composition to those obtained from oven or the fresh one.	
Pegaga leaf	Solar assisted dehumidification dryer	Malaysia	- The colour of solar dried pegaga leaf did not become darker due to the lower air temperature used (T< 56°C) and the lower RH used (RH < 36%). - Pegaga leaf dried at 65°C using warm air became darker.	[61]
Olives leaf	Indirect forced convection solar dryer	Tunisia	- The values of *L** parameter of the solar dried olive leaves increase compared to the fresh one. - The luminance of the leaves was improved by solar drying but the greenness of the leaves reduced. - Dried olive leaves dried at 60°C (at 3.3 m^3/min) showed total phenols close to the fresh leaves. - The olive leaves dried at 40°C (1.62 m^3/min) exhibited the lowest DPPH radical scavenging activities.	[62]
Henna, rosemary, marjoram and moghat	Unglazed transpired solar dryer	Eygpt	- The amounts of oil obtained from medicinal plants dried in the solar dryer were higher compared to the traditional drying methods. - Higher test scores for sensation were obtained for the solar dried plants (rosemary, marjoram, and moghat) in terms of colour, odour, and taste.	[63]
Pepper	Solar tunnel dryer	India	- Overall quality is better in solar dried peppers over commercial samples - A total quality improvement in terms of colour, appearance, aroma and pungency was achieved - All the tunnel dried samples were qualified for ASTA and Agmark standards of pepper quality.	[64]
Saffron	Single tray solar	India	- Drying at 40°C at tray load of 1kg/m^2 is optimum condition for high quality saffron with intense flavour	[65]

	dryer		- Content of crocin pigments from solar drying (153 g/kg) was better than sun (127 g/kg) and shade drying (110 g/kg).	
Saffron	Heat pump assisted hybrid photovoltaic-thermal solar dryer	Iran	- Colouring characteristics (Crocin content) of saffron improved with drying air temperature and heat pump system. - Aromatic strength (Safranal content) of saffron increased with increasing air temperature. - No significant change in bitterness (Picrocrocin content) was observed at different air temperatures and heat pump system.	[66]
Safed musli	solar dryer assisted with reflector	India	- Solar dried sample with reflector showed the highest acceptance sensory score (8.5) as compared to sun dried sample (5.2) in terms of colour, texture and flavour.	[67]
Ginger	Solar tunnel dryer	India	- Sun and solar tunnel dried ginger showed the maximum retention of essential oil (13.9 mg/g of dry ginger) and oleo-resin content (45.2 mg/g of dry ginger) - Gingerol content is the highest in both sun and solar dried samples	[68]

Based on the compiled lists above, it clearly shows that solar drying has a positive impacts on quality of dried products such as better retention of nutrient, improved physical appearance, better antioxidant properties and higher sensory and product acceptance scores. However, the adaptation of solar drying is still relatively scarce as technology transfer activities involved laborious extension activities and services in order to disseminate the correct information and advice to the farmers. Government and non-governmental organization have to educate the right target groups and promote the use of solar drying technology. In this regard, the level of adaptation is still considered low due to several reasons as follow:

- High capital cost of installation (e.g. solar panel and building) and lack of durability in the dryer design
- Lack of government incentive to encourage the use of new technology.
- No premium price is given for better quality product dried using solar drying.
- Farmers are reluctant to learn new technique and replace the conventional one that has been used for decades.
- Difficulties in getting spare parts and lack of skilled personnel for periodic maintenance job.
- Limited funding to carry out continuous and follow up extension work to promote the use of solar dryers.
- Allocation of dryer to each household may make it prohibitive to involve too large target group
- Lack of power supply or fuel source to power auxiliary heater or fan

Nevertheless, there has been some successful examples of commercial installation of solar drying such as the large scale (1 tonne capacity) solar greenhouse dryer for fruits and vegetables built in Laos [69], the solar cocoa processing center with annual production of 85 tonnes built in Indonesia [70] and also from compilation of works carried out in various countries (Zimbabwe, Tanzania, Brazil, Uganda, Kenya and Senegal) as reported by Weiss and Buchinger, 2003. [71]

4. Conclusions

Solar drying are broadly applied in various agriculture food crops such as fruits, vegetables, grains, seeds, beans, herbs, spices and medicinal plants. Generally, the main processing variables that determine the final quality of the solar dried products are the drying time as well as the exposure period to sunlight. The drying rate of product is important as it influences the physical and chemical changes, and therefore affects both the quality attributes and level of acceptance of the product by consumers. Appropriate methods should be used to monitor and evaluate these quality attributes.

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