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Performance of UC Davis chimney dryer: time saving and retention of nutritional quality of carrot and brinjal

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ABSTRACT

UC Davis (University of California, Davis) chimney dryer is a low cost technology and has been developed by the expert of UC Davis, USA to dry food products targeting to ensure the nutritional security. Experiments were conducted following completely randomized design with three replications. Slice thickness of carrot (experiment 1) was 1.5 cm with and without skin while thickness of brinjal (experiment 2) was 1 and 2 cm. Overall, less time required to dry both carrot and brinjal under UC Davis chimney dryer compared to sun dryer condition. Carrot drying time was 82 hours under UC Davis chimney dryer whereas 122 hours required to dry under open sun drying condition; so UC Davis saved 34% time to dry carrot compared to open sun dry condition. Similarly, 21 to 25% time has been saved for brinjal drying under UC Davis chimney dryer compared to open sun dryer condition. No significant difference of protein, phosphorus and potassium contents of carrot and brinjal found from both systems of dryer indicating the no deterioration of mineral contents due to high temperature in UC Davis chimney dryer. Moisture and dry matter contents were also significantly different from each other. Overall, acceptance of physical appearance of both carrot (without skin) and brinjal (1 cm sliced thickness) was selected as the best under UC Davis chimney dried product compared open sun dried product, considering shape, size and colour of the dried products. UC Davis chimney dryer can efficiently reduce the duration of drying of vegetables and also avoid noise from birds and dusts compared to open sun dryer condition; and products can be stored for long time, thus ultimately provide nutritional security round the year for the rural people.

Keywords: Brinjal, carrot, nutritional security, UC Davis chimney dryer

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1 Introduction

Vegetables are a good source of vitamins, minerals, dietary fiber and phytochemicals which are important for human health and well-being. The numbers of malnourished people globally exceed 2–3 billion (FAO, 2009). The mortality rate for children under five is a leading indicator of child health and overall development in countries. Nutritional security is a major concern in Bangladesh, in line with SDG-3, good health and well-being (Sustainable Development Goals by United Nations). Nutritious vegetables can sustainably alleviate nutritional diseases, which are very common in Bangladesh (Ezzati et al., 2002). On the other hand, vegetable consumption has direct influence on millennium development goal; MDG 4 (reduce child mortality) and MDG 5 (improve maternal health). Nutrient dense vegetables in diet is a critical means by which good health can be maintained (Keatinge et al., 2011).

Both carrot (*Daucus carota*) and brinjal (*Solanum* *melongena*) are the most important vegetables in Bangladesh in terms of both, production area and yield. Carrot is crunchy, tasty, and highly nutritious and particularly good source of beta carotene which is precursor of vitamin A, fiber, vitamin K1, potassium and antioxidants, and also have a number of health benefits (Bjarnadottir, 2015). Brinjal is a nutrient-dense food, meaning they contain a good amount of vitamin K and C, mineral and fiber in few calories and also high in anthocyanin, a pigment with antioxidant properties that can protect against cellular damage (Link, 2017).

Overall, vegetables are highly valued in the human diet. The moisture content of fresh vegetables is more than 80% (Changrue et al., 2006). Unfortunately, vegetables are inherently perishable due to high moisture content (some up to 95%). That's why, a big proportion of the fruits and vegetables are lost and it is up to 20–40% in Bangladesh depending on crop, markets and region (Wills et al., 2007). A lot of pre and postharvest research are conducted on vegetables and fruits using modified temperature and packaging to extend the shelf life of the product (Hasan et al., 2014; Monira et al., 2015, 2016; Parveen et al., 2004). Although, major part of food (33%) is lost or waste throughout the supply chain from farm production to consumer consumption in the world, this amounts to about 1.3 billion tons per year (FAO, 2011). Losses or wastes of food in supply chain of developing countries are due to different reason like lack of proper storage technology and scant awareness of postharvest management, with loss typically involving surplus product that cannot be immediately consumed by the household or sold in the market (Gustavsson et al., 2011). Ultimately, it is causing the food insecurity, nutritional security and has impact on the livelihoods. On the other hand, many agricultural products especially, perishable crops like fruits and vegetables harvesting season peaks the production in a short period of time. Huge production during this peaks, product quality is often high, but prices are typically low because supply is greater than demand and the uncontrolled marketing system reduces the price. Farmers are used to feed these excess product to animals or even discarded. So, an alternative use for vegetables in sun drying traditionally practiced; but some disadvantages of open sun drying are: exposure of the foodstuff to rain and dust; uncontrolled drying; exposure to direct sunlight which is undesirable for some foodstuffs; infestation by insects; attack by animals etc (Madhlopa et al., 2002).

In order to improve traditional drying, solar dryers which have the potential of substantially reducing the above-mentioned disadvantages of open air drying, have received considerable attention. Hnin et al. (2019) reported that drying is one of the most vital preservation techniques used in the food industry, because it can enhance the food quality and reduce the energy consumption. So, UC Davis chimney dryer model has been developed by the UC Davis, USA is a simple and low cost technology. In the present study, UC Davis chimney dryer can be made from local materials of developing countries like Bangladesh, and dry the product fast with maintaining the quality of product through increasing temperature principles. This can help to extent to reduce the food loss and enhance the nutritional security through supplying dried food in the lean time of production. Also, can create marketing opportunity to develop good packaging and maintain quality of the product. As, chimney dryer technology can trap the sunlight and increase temperature in the area of product or tunnel of dryer which enable to save time to dry the horticultural fruits, vegetables or agricultural product. Ultimately, helping to reduce the manpower cost and improve quality of the dried product through reducing time and protect the unexpected events like rainfall, insects, birds etc. That's why, it's very important to do work on drying of vegetables through chimney dryer to reduce the required time of drying and to maintain the physical characteristics and nutritional quality of carrot and brinjal.

2 Materials and Methods

2.1 Experimental site

The experiments were conducted at the Bangladesh Agricultural University- Germplasm Center (BAU-GPC) and Central laboratory of BAU in 2018.

2.2 UC Davis chimney dryer

The chimney dryer was constructed by wooden frame. The dryer comprises a long 'table' covered with black plastic (4 mm polyethylene film 10 m × 3 m, and 7 m × 3 m sheet of black nonwoven fabric) and connected to a chimney at one end. Chimney made of 4 poles stabled with 60 cm x 0.25 m cross section covered with clear plastic. The height of this stack is 2.6 m above the table (0.6 m height of table) and flow rate in the stack is 270 m^{-3} h^{-1}. Mesh trays (60 cm) are placed along the length of table where product is placed on mesh trays. A clear plastic sheet is placed over the trays of the table and it creates a tunnel that traps solar energy, increase the air temperature and pass the excess heat and humidity through the chimney (Fig. 1). North-south direction placement enables to trap more solar energy. The constructed dryer was placed on the roof of farmer's hostel of BAU-GPC.

2.3 Materials and experimental design

Two experiments were conducted on carrot (Experiment 1) and brinjal (Experiment 2). Vegetables both

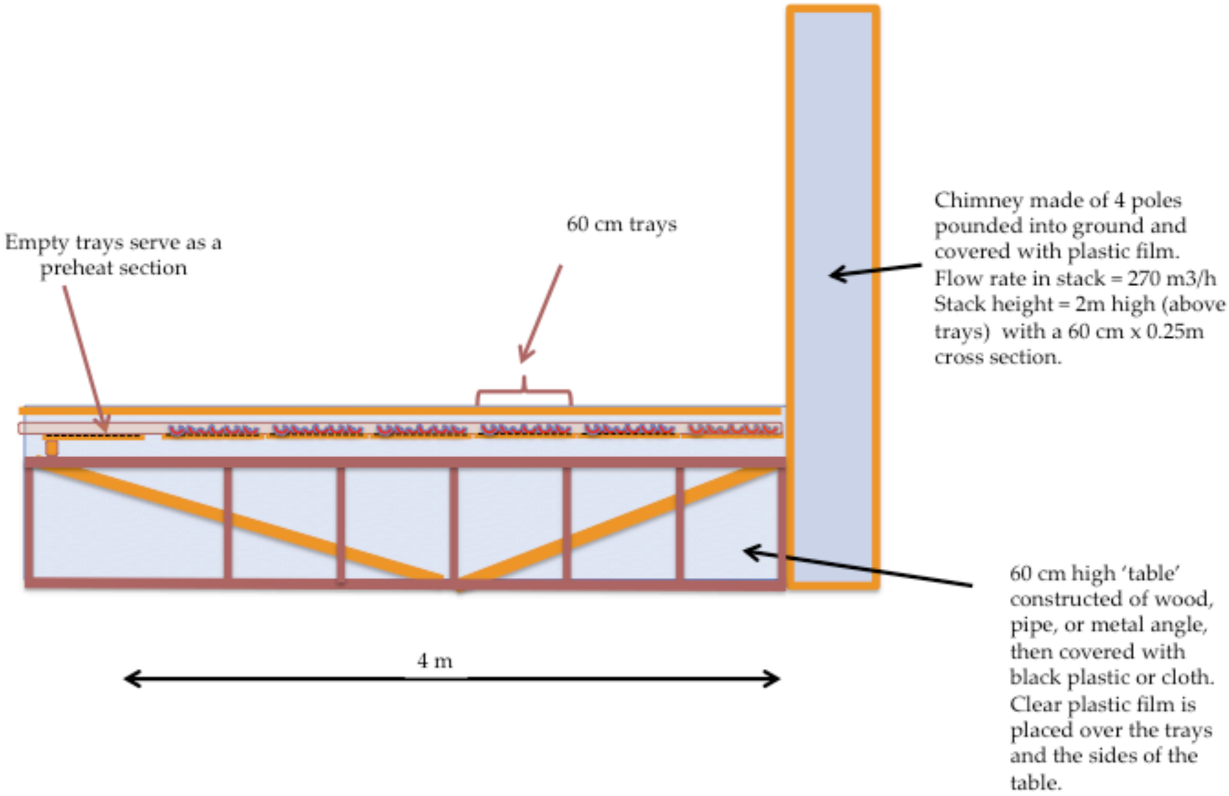


Figure 1. General outline of the UC Davis chimney dryer

carrot and brinjal were selected to observe the performance of UC Davis chimney dryer on drying time savings and nutritional quality of these vegetables. Carrot was collected from the residential areas market and it was washed properly. After that, carrot root pieces make round shaped through sharp knife and sliced 1.5 cm thickness. Two factors experiment conducted following completely randomized design with three replications; where factor A (drying condition: D): D1- UC Davis chimney dryer and D2- open sun drying; factor B (skin condition: S): S1- without skin of carrot, S2- with skin of carrot. Brinjal was collected from the same market and washed properly. Two factor experiment was conducted; factor A (drying condition: D): D1- UC Davis chimney dryer and D2- open sun drying; factor B (thickness of brinjal: T): T1 -one cm thickness and T2-two cm thickness.

2.4 Data collection

Different parameters were studied in both of the experiments at the time of drying and after drying. Those parameters are: temperature (°C) and relative humidity (%) were recorded using Zeal thermo- hygrometer three times in a day at 8.00 am, 1.00 pm and 5.00 pm to observe the variation of temperature and relative humidity during the drying period of vegetables under different dryer conditions (Figs. 2 and 3). Weight of samples (g) were recorded to observe the moisture loss percentage of vegetables, required time to dry (h) was calculated through observing the trend of moisture loss and to fix up the stability of drying condition time and find out the savings of drying time of vegetables through calculating time of dried vegetables under both dryer condition. Moisture content (%) was calculated using the following formula; and dry matter content (%) was found from the deduction moisture content (%) from 100.

$$MC = \frac{IW - FW}{IW} \times 100 \tag{1}$$

where, IW = initial weight of sample before chimney drying and open sun drying (g), FW = final weight after chimney drying and open sun drying (g).

Dried products were preserved in air tight container and observed at regular intervals for up to 4 months. Physical properties of dried products *viz.* color, shape and its acceptance were categorized into excellent, good, fair good and poor through panel test by the total 48 undergraduate and postgraduate students and teachers of BAU through their visual observation.

2.5 Nutritional analysis

Vegetable samples were mixed together to observe the nutritional deterioration of both vegetables due to the use of different drying conditions like UC Davis and open sun dryer condition, so rest one factor was not considered here for this nutritional analysis. Samples were kept in oven to remove moisture totally under oven at 65 °C until a constant mass was reached and ground by a grinding mill machine. Nutrients content like protein, phosphorous (P) and potassium (K) were determined and their details protocol mentioned below. Nitrogen content was calculated by following Kjeldahl method (Bremner and Mulvaney, 1982) and the total protein content was calculated by multiplying of nitrogen content with a conversion factor (6.25). Samples were digested using di-acid mixture (conc. HNO_3: $HClO_4$ = 2:1) according to Singh et al. (2001). About two grams of finely grinded samples were taken and digested with di-acid mixture. The solution was used for the determination of mineral contents (P, K) of vegetables. The phosphorus content of the digest was determined by developing phosphomolybdate blue complex with stannous chloride ($SnCl_2.2H_2O$). Spectrophotometer (Model-T60, PG Instruments, UK) at 660 nm wavelength was used to measure the absorbance of color against standard (Olsen and Sommers, 2015). The content of potassium in the digest was determined with the help of flame emission spectrophotometer. The intensity of light emitted by potassium at 768 nm was directly proportional to the concentration of K present in the sample. The percent emission for the elements was recorded and the K concentration was determined against standards (Knudsen et al., 1982).

2.6 Statistical analysis

The collected data on different parameters were statistically analyzed using Minitab version 17 (Minitab Inc., State College, PA, USA) by analysis of variance (General Linear Model procedure) and Tukey's pair wise comparison test following DMRT ($p < 0.05$).

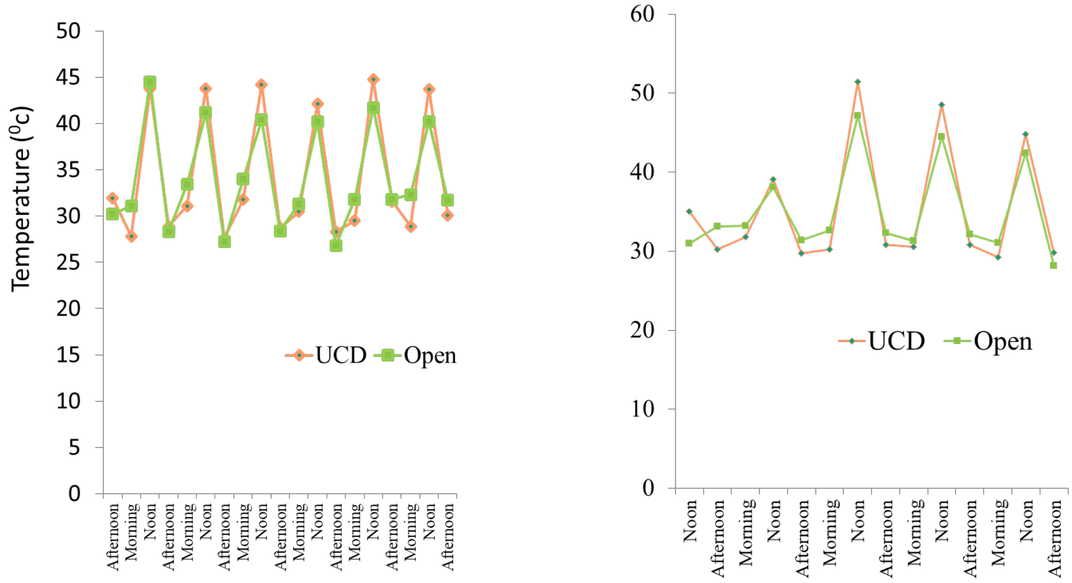
3 Results and Discussion

3.1 Weight loss and drying time

Carrot slices were kept under different dryer conditions to make them dry for longer storage life. Weight of vegetables were recorded to observe the weight loss trend of vegetables and recorded the temperature (°C) and relative humidity (%) at different times (Figs. 2 and 3). During drying process of carrot, we observed the weight loss of carrot occurred rapidly up to 40 hours (h) and then weight loss curve trend showed a bit flattening (Fig. 4). Carrot took less time to dry under UC Davis chimney dryer compared to open sun dryer condition. Weight loss of carrot without skin become stable after 78 h under UC Davis chimney dryer and 118 h using open sun dryer condition. On the other hand, carrot with skin took about 85 and 125 h for drying using UC Davis chimney dryer and open sun dryer condition, respectively (Fig. 4). In both cases, about 34% time saving in UC Davis chimney dryer compared to open sun dryer condition (Table 1). It is mentionable that skin moisture loss of storage carrot quickly compared to without skin i.e. above the portion of vascular cambium contain less moisture and slowly release it. Mwithiga and Kigo (2006) used the solar dryer where the release of weight was very fast at the beginning and became slow after the releasing major part of water from coffee bean.

Remarkably, the weight loss (%) of brinjal occurred very quickly and then it becomes a bit flattened i.e. slowly released the moisture loss from brinjal (Fig. 5). It has been observed that 2 cm sliced thickness brinjal weight loss was slower than 1 cm thickened. Both types thickness slice was drying earlier compared to open sun dryer condition. One cm sliced thickness reached a peak stable condition by 65 and 83 h under UC Davis and open sun dryer condition, respectively. On the other hand, 2 cm sliced thickness took 72 and 86 h under UC Davis and open sun dryer condition, respectively. So, UC Davis chimney dryer save 21 and 25% times to dry the 1 and 2 cm sliced thickness brinjal, respectively (Table 3). Similar result was found in drying onion for different thickness (Lewicki et al., 1998; Sharma and Nath, 1991). It indicates that the more thickness of product will need longer time to dry. Also, some researcher supported this results and mentioned that used of chimney dryer/solar dryer faster and saves 17.4% time to dry carrot, tomato, potato, onion, mint and fish compared to open sun drying (Perasiriyan et al., 2013; Howard et al., 2019).

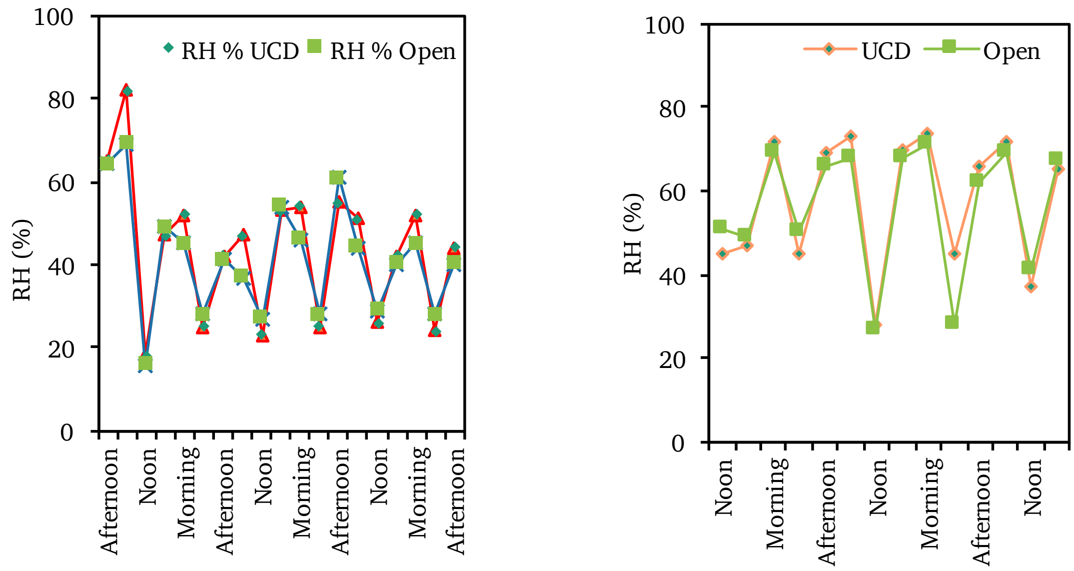
It is articulately indicating the time savings to dry vegetable under UC Davis chimney dryer condition. Because, airflow in the chimney dryer is concentrated in a small cross section to cause high airspeed past product. Black plastic has been used in the chimney dryer which absorbed heat, increased temperature observed in the weather recoding data of our experiment (Fig. 2). Temperature and relative humidity recorded data showed that noon time creates different some days depending upon the climatic condition. Ultimately, warm climate continued up to the afternoon to help to increase the flow rate of moisture from the surface of vegetables for reducing the time of drying. Even though, UC Davis principles to trap solar energy and warm temperature and air flow reduce the duration of drying vegetables. This savings time can indirectly help to reduce the labour cost. Similarly, Mwithiga and Kigo (2006) save 2 days out of 5-7 days to dry coffee bean using solar dry compared to normal sun dry. On the other hand, Bolaji and Olalusi (2008) reported that the solar dryer temperature increase after the noon (12 pm) which support our experiment also. However, UC Davis chimney dryer protects the products from uncertain rain, insects and dust which is lacking in open sun dryer condition and deteriorate the quality. Under



(a) Carrot

(b) Brinjal

Figure 2. Temperature variability (°C) in UC Davis chimney dryer and open sun dryer condition for carrot and brinjal in the drying experiment



(a) Carrot

(b) Brinjal

Figure 3. Relative humidity variability (%) in UC Davis chimney dryer and open sun dryer condition for carrot and brinjal in the drying experiment

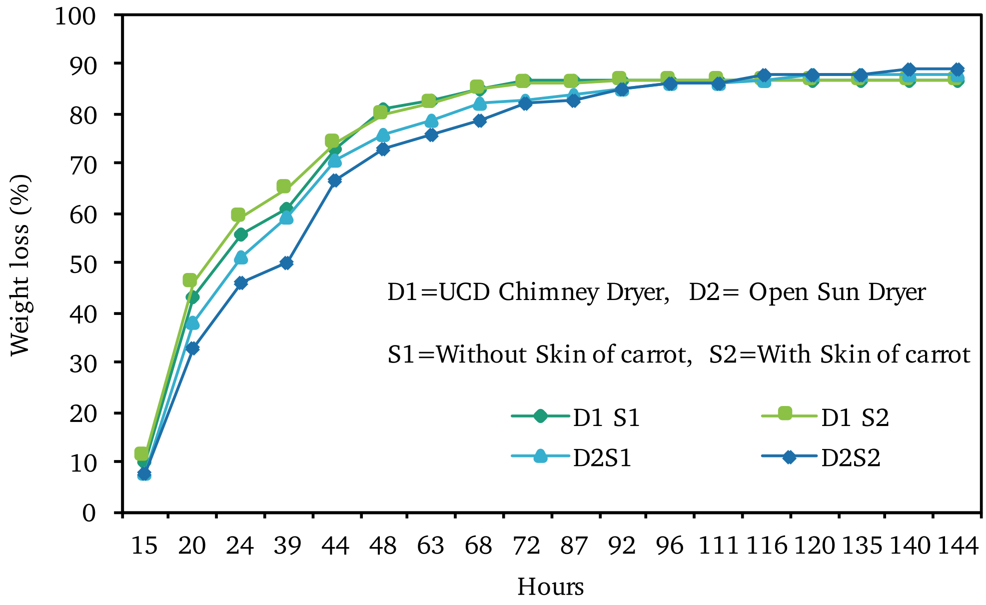


Figure 4. Weight loss (%) of the slices of dried product of carrot

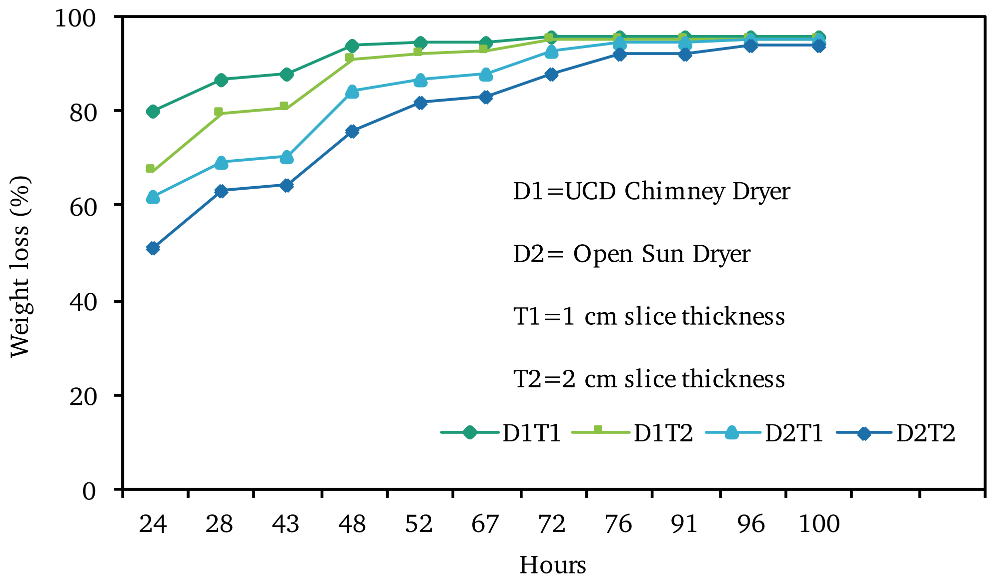


Figure 5. Weight loss (%) of the slices of dried product of brinjal

Table 1. Combined effect of dryer and skin condition on the required time to dry, moisture and dry matter content of carrot

Treatment	Required time to dry (h)	Moisture content (%)	Dry matter (%)
D1S1	78.67	87.33	12.67
D1S2	85.33	87.33	12.67
D2S1	118.67	88.00	12.00
D2S2	125.33	89.00	11.00
LSD0.05	15.71	1.33	1.33

D1 = UC Davis chimney dryer, D2 = Open sun dryer, S1 = Without skin of carrot, S2 = With skin of carrot

Table 2. Combined effect of dryer and slice thickness on the required time to dry, moisture content and dry matter content of brinjal

Treatment	Required time to dry (h)	Moisture content (%)	Dry matter (%)
D1T1	65.33	95.67	4.33
D1T2	72	95	5
D2T1	82.67	95	5
D2T2	96	94	6
LSD0.05	14.89	0.58	0.58

D1 = UC Davis Chimney dryer, D2 = Open sun dryer, T1 = 1 cm thickness, and T2 = 2 cm thickness

open sun dry condition, the main obstacle is the product is destroying by bird. Considering this, we used net under open sun drying condition on the product to keep away birds from product.

3.2 Moisture and dry matter content

Moisture percentage and dry matter content (%) of carrot did not give any significant different under UC Davis chimney dryer and open sun dryer condition (Table 1). Although, UC Davis chimney dryer increased temperature enable to reach in the same moisture content (87.33 %) of carrot considering with or without skin carrot. So, dry matter content of carrot drying under open sun drying condition found 12.67% (Table 1). Carrot with or without skin drying under open sun drying condition loss the moisture about 88 to 89%, and 1% moisture loss was more found in with skin carrot. These results are very consistent with other findings (Howard et al., 1962; Gill and Kataria, 1974). They found moisture and dry matter (%) range of carrot are 86 to 89% and 11-14%. Under UC Davis chimney drying having 1 and 2 cm of sliced brinjal showed the moisture loss 95.67 and 95.0%, respectively whereas the dry matter content was 4.33 and 5.0%, respectively. Similarly, open sun drying condition having 1 and 2 cm sliced of brinjal showed 95% and 94% moisture loss, whereas the dry matter content was 5% and 6%, respectively. Similar pattern of brinjal moisture range in this study are almost similar with the study of Khan et al. (2015) which strongly support our drying process. Dry matter (%) of carrot and brinjal indicate that the carrot contain higher amount of dry matter compared to brinjal; and it indicates that the higher amount of solid materials like lipid, antioxidant and protein etc. in carrot compared to brinjal (Singh et al., 2001; Khan et al., 2015).

3.3 Nutritional quality of vegetables

Protein content was not significantly influenced by drying ($p<0.05$); indicated the no deterioration of protein influenced by higher temperature raised in UC Davis chimney dryer compared to open sun dryer. Determination of carrot drying under UC Davis chimney dryer and open sun dryer condition are 6.07% and 7.23%, respectively under UC Davis chimney dryer and open sun dryer condition which are not significantly different (Table 3). Agiriga et al. (2015) also found the similar amount protein in carrot after drying in different temperature. Protein content in brinjal was found 3.27% and 4.20% from the drying under UC Davis chimney dryer and open sun dryer, respectively. It seems protein content in brinjal is less compared to carrot. Naturally, protein content is lower in brinjal compared to carrot because the protein content in brinjal and carrot are found in different studies (Naeem and Ugur, 2019; Agiriga et al., 2015).

Phosphorus content of carrot was 0.36% and 0.41% from drying under UCD chimney drying and open sun dryer condition. Similarly, phosphorus content in brinjal was higher in 0.43% and 0.53% under drying process of UC Davis chimney dryer and open sun dryer condition. Hasan et al. (2014) conducted an experiment to determine the P of brinjal where they got the similar trend of P in brinjal. K content in carrot was not significantly different but brinjal gave the significant different value of K. K content of carrot was 1.88% and 1.91% drying under UCD chimney drying and open sun dryer condition, respectively. K content of brinjal was 1.93% and 2.92% drying under UCD chimney drying and open sun dryer condition, respectively. So, nutritional quality was not influenced by dryer. Although, a bit higher nutrient content like protein, P and K in both vegetables found under open sun dryer compared to UC Davis chimney dryer. This can be due to a bit higher temperature in UC Davis chimney dryer compared to open sun dryer. Nindo et al. (2003) also dried asparagus using different types of dryers and they got the total antioxidant (TAA) content variation in different dryers due to heated air inherently exposes the products to oxidation, ultimately reducing their TAA.

3.4 Properties of dried vegetables

Both the products of carrot and brinjal were panel tested. Color, shape and overall acceptance of dried products were analyzed for different combination

Table 3. Effect of dryer on different mineral contents of dried carrot and brinjal

Dryer	Carrot			Brinjal		
	% Protein	% P	%K	% Protein	% P	% K
D1	6.07 a	36.08 a	1.88 a	3.27 a	43.02 a	1.93 b
D2	7.23 a	41.47 a	1.91 a	4.20 a	52.96 a	2.92 a

Same letter in a column are not significantly different at 5% level by DMRT. D1 = UC Davis Chimney Dryer, D2 = Open sun dryer

Table 4. Physical properties of the dried products of both carrot and brinjal

Properties	Categories (%)	Treatment combinations							
		Carrot				Brinjal			
		D1S1	D1S2	D2S1	D2S2	D1T1	D1T1	D1T2	D2T2
Color	Excellent	52.08	39.58	4.17	0	56.25	6.25	37.5	0
	Good	31.25	41.67	35.42	14.58	39.58	31.25	45.83	16.67
	Fair good	10.42	6.25	41.67	20.83	4.17	45.83	4.17	25
	Poor	6.25	12.5	18.75	64.58	0	16.67	12.5	58.33
Shape	Excellent	54.17	41.67	14.58	0	58.33	16.67	39.58	0
	Good	29.17	43.75	43.75	16.67	25	41.67	45.83	18.75
	Fair good	10.42	10.42	31.25	25	10.42	29.17	8.33	27.08
	Poor	6.25	4.17	10.42	58.33	6.25	12.5	6.25	54.17
Overall acceptance	Excellent	83.33	45.83	8.33	0	79.17	8.33	47.92	0
	Good	10.42	43.75	17.5	18.75	12.5	14.5	39.58	10.42
	Fair good	6.25	4.17	15.42	20.92	8.33	16.58	8.34	25
	Poor	0	6.25	58.75	60.33	0	60.59	4.16	64.58

through panel test. Overall, the color, shape and acceptance were found excellent in drying product of UC Davis Chimney dryer compared to open chimney dryer (Table 4). Khatun et al. (2019) prepared the jackfruit leather of different cultivars and they got the good quality considering color, shape and taste were found from the drying product of UC Davis dryer. In our experiment, carrot and brinjal color, majority of the respondent like 52.08% and 56.25%, respectively response that carrot without skin and brinjal 1 cm sliced thickness drying under UC Davis chimney dryer are excellent color compared to other treatments combinations. The reasons behind that skin of carrot become dark or black after drying and less thickness (1 cm) sliced brinjal becomes less shrinkage after drying. Carrot with skin drying under open sun dryer has been considered as poor color by the majority respondents (64.58%). Similarly, in case of brinjal 58.33% respondent response that open sun dryer with 2 cm thickness slice showed poor color compared to other treatment combinations.

Shape was excellent of carrot without skin under UC Davis chimney dryer and it had been responded by 54.17% and the second highest i.e similar number respondents (43.75%) agreed the good shape of carrot with and without skin under UC Davis and open sun dryer and the least shape of carrot identified by the 58.33% respondents where carrot with skin dried under open sun dryer condition (Table 4). Brinjal shape was preferred 1 cm thickness brinjal the highest number respondents (58.33%) given score as excellent and the moderate shape preference (45.83%) drying was 2 cm under open UC Davis chimney dryer. However, the lowest preference categories of shape scored by the respondents (54.17%) were 2 cm sliced thickness drying under open sun dryer condition. Overall, the respondents accept the product drying under UC Davis chimney dryer for carrot without skin (83.33%) and brinjal 1 cm thickness (79.17%), and the poor acceptance was open sun dryer for carrot with skin (60.33%) and brinjal 2 cm thickness (64.58%).

4 Conclusions

This experiment was conducted to investigate the performance of UC Davis chimney dryer on drying of carrot and brinjal. UCD chimney drier was very effective to dry in advance than open sun drying condition. Without skin condition of carrot and brinjal sliced thickness (1 cm) is preferable to dry under UC Davis chimney dryer condition. This chimney dryer can save times (21-34%) compared to drying using open dryer condition. On the other hand, protein, phosphorus, potassium content of carrot and brinjal were not significantly different after drying; and notably, no deterioration of nutrient of dried products due to high temperature in UC Davis chimney dryer. Rather, it can maintain food safety and avoid some undesirable conditions like exposure of the foodstuff to rain, direct sunlight which is undesirable for some foodstuffs; infestation by insects; attack by animals; dust contamination. Overall, panel test of carrot and brinjal under UCD chimney drier had higher acceptance as color (%), shape (%) and overall acceptance (%) compared to open sun drying condition. This UC Davis dryer is cheap and easily possible to be afforded and the poor people of Bangladesh will be able to manage this dryer. It will be very effective for quick drying of vegetables and nutritional loss is not too much due to drying which will ensure supply of nutrients year round for the people of Bangladesh. So, it may be recommended that UC Davis chimney drier would be helpful and more suitable for drying carrot and brinjal compared to open sun drying method.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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