STUDY ON DRYING CHARACTERISTICS AND NUTRITIONAL COMPOSITION OF WHITE RADISH BY SOLAR CABINET DRYERS, TRAY DRYER AND OPEN SUN DRYING METHODS

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Abstract

Solar energy, a form of sustainable energy, has been claimed as a great potential for drying of fruits and vegetables since it is naturally accessible. Solar dryers using natural convection or forced convection are used for drying of agricultural products. In this research, white radishes were dried by distributed solar cabinet dryer (DSCD), forced convection solar cabinet dryer (FCSCD), Tray Dryer (TD) and by sun drying (SD). The dryers were fabricated by locally available materials such as plywood, corrugated galvanized iron sheet and glass. The dry bulb and wet bulb temperature (^{o}C), relative humidity (%) and rate of drying (g/hr. sq.cm) were determined as drying characteristics during the drying process. A rather effective of solar radiation in lowest tray of DSCD and FCSCD was observed. The effects of four drying method on the physico-chemical properties and nutritional values, minerals and heavy metals constituents and rehydration ratios of dried white radishes were investigated and compared with fresh and commercial products. The determination of water activity and microbial load were examined to extend the shelf-life of dried products. The organoleptic properties of rehydrated white radish were also determined by 9-point Hedonic Scale Rating Test. The findings suggested that the commercial scale use of DSCD for drying of vegetables during off-season.

Keywords: white radish, drying characteristics, 9-point Hedonic Scale Rating

Introduction

Solar drying comprises the application of heat to vapourise moisture and some means of removing water vapour after its separation from the food products. It is thus a combined and simultaneous heat and mass transfer operation for which energy must be supplied. It brings about substantial reduction in weight and minimise packaging, storage and transportation costs and enables storability of the product under ambient temperatures (Hii & Mujumdar, 2012).

Solar drying is different from "open sun drying". In solar drying, equipment is used to collect the sun's radiation in order to harness the radiated energy for drying applications. (Prakash & Kumar, 2013) Open sun drying has some disadvantages, of which are, unnecessary exposure of products to weather elements such as rain, ultraviolet rays, and contamination by wind-borne dirt and dust. Others include infestation of insects, rodents, pests and other animals as well as degradation by bacteria. (Adelaja & Babatope, 2013)

Solar drying is advantageous over normal convective dryers like hot air dryer, which requires enormous fuel and energy cost (Hii & Mujumdar, 2012). Solar dryers can process the vegetables and fruits in clean, disinfected and hygienic conditions. This can be used also to promote renewable energy sources. (Prakash & Kumar, 2013) There has been a steady evolution of a solar dryer technology from natural convection types to forced convection types. (Adelaja & Babatope, 2013)

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In Myanmar, people enjoy consuming vegetables in daily diet. However, there is almost no post-harvest technology to prevent the nutritional and economic losses during seasons. In this regard, solar drying technology seems to be one of the most promising alternatives to reduce the post-harvest losses. (Mohanraj & Chandrasekar, 2009).

White radish (*Raphanus sativus* L.), Myanmar name Mone-lar-u is an edible root vegetable belonging to family Brassicaceae. Radish is originally native to Southeast or continental East Asia. They are eaten raw and have a mild flavour, or they can be sliced and cooked (Daikon, The Free Encyclopedia, 2014). Radish is a rich source of carbohydrates, potassium, magnesium, copper, calcium, vitamins and antioxidants like ascorbic acid and folic acid etc. These nutrients make it a very effective cancer-fighting food (Dr. Nishadh & Mathai, 2014). In Myanmar, white radishes are extensively grown in Shan State, Delta Region and Yangon Region.

The objective of this work is to utilize solar energy in drying of fruits and vegetables such as white radish under hygienic condition and, at the same time, to compare the various drying methods so that the results can be reliable by the small- and medium-scale enterprises.

Materials and Methods

Raw Materials

White radishes (*Raphanussativus* L.) were purchased from Hmawbi Township, Yangon Region. Sodium metabisulphite and ascorbic acid were purchased from Shwema Chemical Shop, Pabeden Township, Yangon Region. All are analytical grade.

Methods

Preparation of Dried White Radish

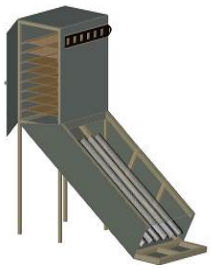
The cleaned radishes were peeled and cut into slices of 2mm thickness and the sliced radishes were weighed 200g. The radish slices were evenly spread on the trays of distributed solar cabinet dryer (DSCD) with temperature ranging from 35-65^{o}C, in forced convection solar dryer (FCSCD) with temperature ranging from 35-60^{o}C and in tray dryer (TD), the temperature was calibrated at 50^{o}C±4. For sun drying, 200g of radish slices were spread on the plastic sieve trays and sun dried. At equal time interval of 30 minutes, the samples were withdrawn and were weighed using a digital weighing machine to monitor weight reduction due to loss of moisture in the samples. After drying processes have taken place, dried white radishes were put into the air-sealed plastic boxes and stored in a dry place away from direct sunlight. The organoleptic properties, physico-chemical properties, nutritional value, minerals and heavy metals composition, water activity and microbiological analysis of dried white radishes were determined.

Effect of Food Additives on Drying of White Radish

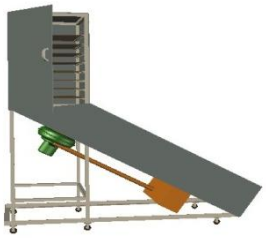
The effects of concentration of sodium metabisulphite solution, ascorbic acid solution and dipping time on the drying of white radishes were determined by organoleptic properties and shelf-life.

Determination of Drying Conditions of Distributed Solar Cabinet Dryer

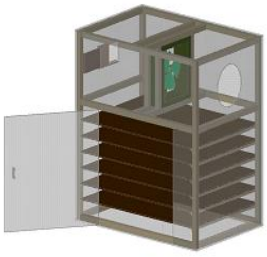
The drying conditions of Distributed Solar Cabinet Dryer (DSCD) such as solar radiation intensity, temperature, air velocity and humidity were measured and the efficiencies of solar dryers such as system drying efficiency, collection efficiency and pick-up efficiency were calculated.



Isometric view of DSCD



Isometric view of FCSCD



Isometric view of TD

Results and Discussion

The changes in moisture content of fresh white radish with respect to time using DSCD was measured for tray one (lowest tray) to four. The data obtained were mentioned in Tables (1a) to (1d). It was pointed out that the longer the drying time the smaller the moisture content in the drying sample and lesser the rate of drying in DSCD. According to Table (2), the pick-up efficiency and system drying efficiency were higher in first tray than the upper trays. Therefore, the first tray could remove more moisture than upper trays. The bottom tray exhibited the fastest drying rate as expected since evaporated moisture from this tray accumulated on the upper trays. Thus, the upper trays exhibited slower drying rates as their ambient condition was surrounded by humidified air. It can be deduced that the drying efficiency of tray one in DSCD was chosen as the best tray among the others. The test was also done in tray one of FCSCD, TD and SD. The drying rate curve and drying curve of white radish in DSCD, FCSCD, TD and by sun drying are illustrated in Figures (1), (2), (3) and (4) respectively.

To choose the optimum food additive in solar cabinet dryers, experiments were done by varying the ratio (% w/v) of sodium metabisulphite and ascorbic acid based on immersing time variation and the effect of those additives on organoleptic properties were determined. Tables (3) and (4) showed that 0.1 (% w/v) of sodium metabisulphite and 0.04 (% w/v) of ascorbic acid with six minutes immersing time gave the most suitable condition for pretreatment of the samples. From those results, it was found to choose 0.04 (% w/v) of ascorbic acid for the pretreatment, the consideration was based on the white colour and fluffy texture of the white radish samples.

The comparison of the organoleptic properties of white radish with respect to different types of dryers was carried out (Table 6) and it was clear that the use of DSCD gave desirable colour and texture among others. Similarly the rehydration ratios for dried white radish (Table 7) with 50 minutes rehydration time based on 3g of dried samples were tested and the results showed that the rehydration ratio used by DSCD gave the highest values. The rehydration ratios of dried samples were gradually high with respect to time.

The determination of the physico-chemical properties and nutritive values of dried white radish were carried out and the results obtained were mentioned in Table (8). From the results of Table (9), by comparing fresh and dried white radish, except manganese and zinc, other minerals decreased after drying. There are no heavy metals present such as arsenic, lead and cadmium in fresh and dried white radishes in all drying modes. The minerals compositions of dried samples are less than fresh because of pretreatments before drying such as washing and slicing operation and may be due to drying.

In this research work, the determination of water activity also played an important role to estimate the shelf-life of the samples of white radish (Table 10). It was found that the results using DSCD were a_w=0.27 for dried white radish. At the room temperature (35^{o}C), most bacteria require a water activity in the range of about 0.90 to 1.00. Some yeasts and moulds grow slowly at a water activity down to as low as about 0.65. Water activity of the dried samples was 0.49 which is lower than 0.65 therefore yeast, mould and bacteria could not grow in this condition.

For the preparation of dried food, determination of microorganisms also is very significant for health. The results obtained were mentioned in Table (11) and the amounts were acceptable limit. According to the analysis of residual pesticides in fresh white radish, the results showed that there are no residual pesticides in all samples. The rehydrated white radishes of DSCD were prepared as salad and Table (12) showed the sensory evaluation results for white radish salad. The appearance, colour and texture were obtained higher average scores and 7.6 of overall acceptability were achieved.

Table 1(a) Changes in Moisture Content of Fresh White Radish on varying the Drying Time using Distributed Solar Cabinet Dryer (1st Tray)

Sr. No.	Drying Time (hr.)	Moisture Content (% w/w)	Drying Rate (g/hr. sq.cm)	Temperature (^{o}C)		RH (%)
				D.B	W.B	
1	0.5	53.39	0.1000	45	29	40
2	1.0	9.23	0.0677	45	28	37
3	1.5	14.77	0.0562	47	28	34
4	2.0	8.01	0.0478	47	27.5	33
5	2.5	5.83	0.0399	47	27.5	33
6	3.0	1.74	0.0339	44	27	25

D.B: Dry Bulb, W.B: Wet Bulb, RH: Relative Humidity

Table 1(b) Changes in Moisture Content of Fresh White Radish on varying the Drying Time using Distributed Solar Cabinet Dryer (2nd Tray)

Sr. No.	Drying Time (hr.)	Moisture Content (% w/w)	Drying Rate (g/hr. sq.cm)	Temperature (^{o}C)		RH (%)
				D.B	W.B	
1	0.5	28.73	0.0617	46	29	38
2	1.0	21.38	0.0538	47	28	34
3	1.5	19.61	0.0499	47	28	34
4	2.0	10.59	0.0431	47	27.5	33
5	2.5	7.97	0.0379	45	27.5	33
6	3.0	2.38	0.0324	44	27	25

Table 1(c) Changes in Moisture Content of Fresh White Radish on varying the Drying Time using Distributed Solar Cabinet Dryer (3rd Tray)

Sr. No.	Drying Time (hr.)	Moisture Content (% w/w)	Drying Rate (g/hr. sq.cm)	Temperature (°C)		RH (%)
				D.B	W.B	
1	0.5	26.77	0.0574	44	28	46
2	1.0	20.30	0.0504	46	28	45
3	1.5	14.13	0.0438	46	27.5	40
4	2.0	15.55	0.0412	46	27.5	36
5	2.5	6.36	0.0358	45	27	30
6	3.0	4.74	0.0315	45	27	28

Table 1(d) Changes in Moisture Content of Fresh White Radish on varying the Drying Time using Distributed Solar Cabinet Dryer (4th Tray)

Sr. No.	Drying Time (hr.)	Moisture Content (% w/w)	Drying Rate (g/hr. sq.cm)	Temperature (°C)		RH (%)
				D.B	W.B	
1	0.5	29.02	0.0623	43	28	42
2	1.0	23.06	0.0559	44.5	28	39
3	1.5	16.95	0.0494	45	27.5	33
4	2.0	12.02	0.0435	46	27.5	30
5	2.5	5.86	0.0372	45	27	28
6	3.0	3.98	0.0324	45	27	25

Table 2 Drying Condition of Distributed Solar Cabinet Dryer for White Radish

Location		University of Yangon			
Crop		White Radish			
Drying Period		March 2015			
Maximum Drying Temperature in Dryer (°C)		~ 60			
Drying Time (hr.)		5			
Total Insolation (kWh/m^2/day)*		6.02			
Items		1st Tray	2nd Tray	3rd Tray	4th Tray
Ambient Air Temperature (°C)	High	35	35	35	35
	Low	21.7	21.7	21.7	21.7
	Mean	28.35	28.35	28.35	28.35
Ambient Air Relative Humidity	High	76	76	76	76
	Low	69	69	69	69
	Mean	73	73	73	73
Air Flow (ms^{-1})	High	0.3	0.3	0.3	0.3
	Low	0.1	0.1	0.1	0.1
	Mean	0.2	0.2	0.2	0.2
Weight or Moisture Content of Batch (g)	Start	300	300	300	300
	End	15.28	28.00	35.63	27.85
Pick up Efficiency (%)		3.68	3.55	3.41	3.55
Collection Efficiency (%)		0.2	0.2	0.2	0.2
System Drying Efficiency (%)		3.73	3.60	3.47	3.60

* (Boxwell, 2015)

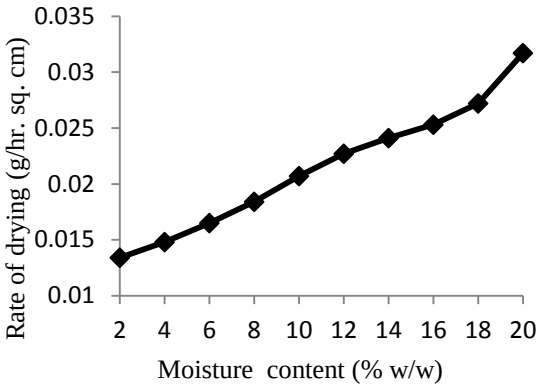


Figure 1 Drying Rate Curve of Fresh White Radish using Distributed Solar Cabinet Dryer

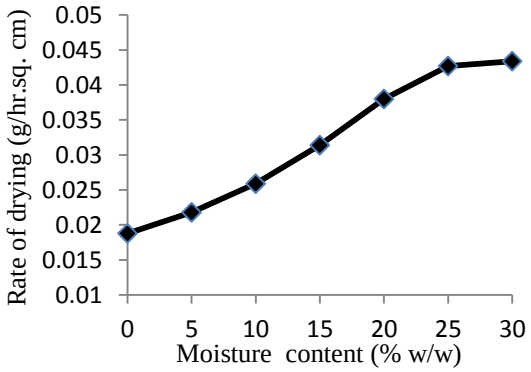


Figure 2 Drying Rate Curve of Fresh White Radish using Forced Convection Solar Cabinet Dryer

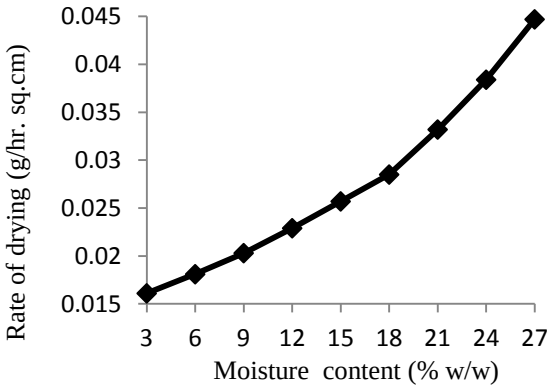


Figure 3 Drying Rate Curve of Fresh White Radish using Tray Dryer

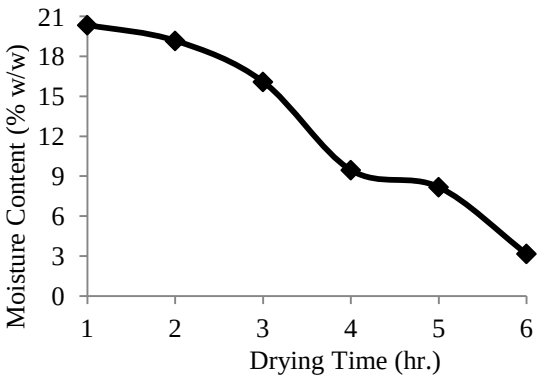


Figure 4 Drying Curve of Fresh White Radish by Sun Drying

Table 3 Effect of Sodium Metabisulphite on Organoleptic Properties of Dried White Radish using Solar Cabinet Dryer

Sample No.	Sodium metabisulphite (% w/v)	Organoleptic Properties		Remarks
		Colour	Texture	
1	0.05	light cream	Crisp	Up to 30 days changes in colour and texture noted
2*	0.1	light cream	Fluffy	Up to 30 days no changes in colour and texture noted
3	0.15	Cream	Crisp	Up to 30 days no changes in colour and texture noted
4	0.2	pale yellow	Hard and crisp	Up to 30 days changes in colour and texture noted

* Most suitable condition

Table 4 Effect of Ascorbic Acid on Organoleptic Properties of Dried White Radish using Solar Cabinet Dryer

Sample No.	Ascorbic acid (% w/v)	Organoleptic Properties		Remarks
		Colour	Texture	
1	0.02	Light cream	Crisp	Up to 30 days changes in colour and texture noted
2	0.03	Light cream	Crisp	Up to 30 days changes in colour and texture noted
3*	0.04	Light cream	Fluffy	Up to 30 days no changes in colour and texture noted
4	0.05	Cream	Crisp	Up to 30 days no changes in colour and texture noted
5	0.06	Cream	Crisp	Up to 30 days no changes in colour and texture noted

* Most suitable condition

Table 5 Effect of Dipping Time of Ascorbic Acid on Organoleptic Properties of Dried White Radish using Solar Cabinet Dryer

Sample No.	Dipping time (min.)	Organoleptic Properties		Remarks
		Colour	Texture	
1	2	light cream	Crisp	Up to 30 days changes in colour and texture noted
2	4	light cream	Crisp	Up to 30 days changes in colour and texture
3*	6	light cream	Fluffy	Up to 30 days no changes in colour and texture noted
4	8	Cream	Crisp	Up to 30 days no changes in colour and texture noted
5	10	Cream	Crisp	Up to 30 days no changes in colour and texture noted

* Most suitable condition

Table 6 Effect of Dryer Types on Organoleptic Properties of Dried White Radish

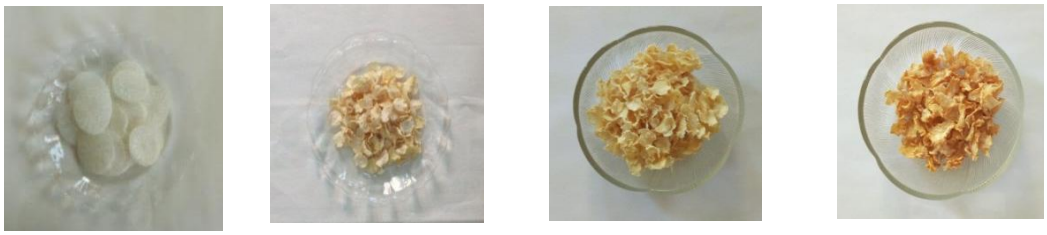
Sample No.	Drying Modes	Organoleptic Properties		Remarks
		Colour	Texture	
1	FCSCD	White	Crisp	Change in colour but no change in texture within three months
2*	DSCD	White	Fluffy	Change in colour but no change in texture within three months
3	TD	White	Crisp	Change in colour but no change in texture within three months
4	SD	Yellowish White	Fluffy	Change in colour and texture within 30 days

* Most suitable condition

Table 7 Effect of Dryer Types on Rehydration Ratio of Dried White Radish

Weight of dried white radish - 3g
Volume of water - 100 ml

Sr. No.	Drying Modes	Rehydration Ratios				
		Rehydration Time (min.)				
		10	20	30	40	50
1	FCSCD	5.33	6.41	6.72	7.4	7.68
2	DSCD	5.92	6.45	7.22	7.56	8.12
3	TD	5.80	6.36	6.86	7.74	7.61
4	SD	4.55	4.95	5.07	5.35	5.63



(a) Fresh White Radish **(b)** Dried by DSCD **(c)** Dried by FCSCD **(d)** Dried by TD

(e) Dried by SD **(f)** Rehydrated **(g)** Salad

Figure 5 White Radish

Table 8 Physico-chemical Properties and Nutritional Value of White Radish

Sr. No.	Properties	Fresh White Radish		Dried White Radish			
				Types of Dryer			
		Literature value*	Experimental value	DSCD	FCSCD	TD	SD
1	Moisture content (%w/w)	95.69	94.84	18.41	12.56	16.09	29.85
2	Ash content (%w/w)	0.52	0.29	8.48	8.12	6.16	5.62
3	Crude fibre content (%w/w)	1.64	0.55	7.57	6.25	8.31	6.97
4	Crude protein content (%w/w)	0.69	0.76	8.06	9.67	9.58	8.01
5	Crude fat content (%w/w)	0.09	0.01	0.18	0.15	0.32	0.11
6	Carbohydrate (%w/w)	3.45	3.55	57.30	63.85	59.54	49.44
7	Energy value (Kcal)	18.6	20	262	295	283	229
8	pH	-	5.6	5.1	5.8	5.8	5.6
9	Colour intensity	-	0.43	0.51	0.50	0.51	0.56

* Daikon, The Free Encyclopedia, 2014

Table 9 Minerals and Heavy Metals Composition in White Radish

Sr. No.	Constituents	Fresh (ppm)	Dried White Radish (ppm)				Limit of Detection (ppm)
			Types of Dryer				
			DSCD	FCSCD	TD	SD	
1	Sodium	7.12	5.67	5.58	6.09	5.54	0.002
2	Potassium	6.18	4.48	4.66	4.94	4.21	0.002
3	Calcium	12.54	7.25	7.51	7.84	7.15	0.002
4	Manganese	< LOD	< LOD	< LOD	< LOD	< LOD	0.009
5	Magnesium	9.14	6.39	6.38	6.91	6.29	0.002
6	Zinc	< LOD	< LOD	< LOD	< LOD	< LOD	0.013
7	Iron	8.29	5.64	5.61	6.12	5.29	0.006
8	Arsenic	< LOD	< LOD	< LOD	< LOD	< LOD	0.026
9	Lead	< LOD	< LOD	< LOD	< LOD	< LOD	0.015
10	Cadmium	< LOD	< LOD	< LOD	< LOD	< LOD	0.007

LOD: Limit of Detection

Table 10 Water Activity of White Radish

Sr. No.	Items	Dried White Radish	
		Equilibrium Relative Humidity (%)	Water activity (a_w)
1	Fresh	87	0.87
2	DSCD	27	0.27
3	FCSCD	25	0.25
3	TD	44	0.44
4	SD	41	0.41

The sample obtained in different days.

Table 11 Microorganisms in Dried White Radish and Dried Fermented White Radish

Sr. No.	Microorganisms	Dried White Radish			
		DSCD	FCSCD	TD	SD
1	Yeasts and moulds (cfu)	1.0×10^6	1.0×10^4	1.0×10^3	2.3×10^4
2	Salmonella (cfu)	ND	ND	ND	ND
3	Coliform (cfu)	ND	ND	ND	ND

cfu: Colony Forming Unit, ND : Not Detected

Table 12 Sensory Evaluation for Dried White Radish

Sr. No.	Organoleptic Properties	Average Scores
1	Appearance	7.6
2	Colour	7.7
3	Texture	7.6
4	Overall Acceptability	7.6

Conclusion

The dried white radish can maintain its appearance and organoleptic properties nearly one month without using additives. By using ascorbic acid, it was found that the shelf life extended to three months whereas use of sodium metabisulphite gave unattractive smell and colour of finished product. It can be concluded that the effect of additive (ascorbic acid) on white radish can attain longer shelf life and attractive colour and smell than that of sodium metabisulphite. The most suitable condition for dried white radish in DSCD chosen were 0.06 (% w/v) of ascorbic acid as food additive, immersing time 6 minutes, drying time 5 hr. and drying temperature 55^{o}C.

It was observed that the rehydration ratio was increased with the increased soaking time in all four drying methods. Compared with other three methods, Sun dried white radish showed the lowest rehydration ratio. Since sun drying took longer time, it affects the texture and reduces the transport properties of water during rehydration.

The water activity of dried white radish was nearly the same by using DSCD, FCSCD, TD and SD. It was less than 0.65 therefore yeast, mould and bacteria could not grow. From the view point of physico-chemical properties and nutritional values, it is clear that solar dried products using solar cabinet dryer have higher nutritional value in comparison to open sun dried products. The quality of product depended upon the removal of moisture during drying process.

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References

Adelaja, A. O., & Babatope, B. I. (2013). Analysis and Testing of a Natural Convection Solar Dryer for the Tropics. *Journal of Energy*.

Boxwell, M. (2015). *The Solar Electricity Handbook.* Greenstream Publishing.

Daikon, *The Free Encyclopedia*. (2014). Wikipedia: https://en.wikipedia.org/wiki/daikon

Dr. Nishadh, A., & Mathai, L. (2014, Feburary). Osmostic Dehydration of Radish in Salt and Sucrose Solutions. *International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3*

Hii, C. L., Jangam, S. V., Ong, S. P., & Mujumdar, A. S. (Eds.). (2012). *Solar Drying: Fundamentals, Applications and Innovations.* Singpore.

Mohanraj, M., & Chandrasekar, P. (2009). Performance of a Forced Convection Solar Dryer Integrated with Gravel as Heat Storage Material for Chili Drying. *Journal of Engineering Science and Technology, Vol.4*(3), pg. 305-314.

Prakash, O., & Kumar, A. (2013). Historical Review and Recent Trends in Solar Drying Systems. *International Journal of Green Energy*.