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Comparative evaluation of sun, solar cabinet and electric cabinet drying methods for drying of lesser known leafy vegetables in Jharkhand

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Abstract

Leafy vegetables are the most important diet component of different tribal and local communities of Jharkhand as they are rich source of nutrients and micronutrients. Most of the leafy vegetables are highly perishable. Drying reduces the moisture content to a safety level and allows storage over a long period. In the present study, performance of thee drying methods *viz*. conventional sun drying (SD), solar cabinet dryer (SCD) and electric cabinet dryer (ECD) were evaluated in drying of six lesser known leafy vegetables *viz*., *Moringa oleifera*, *Polygonum plebeium*, *Centella asiatica*, *Limnophila conferta*, *Bauhinia variegata* and *Amaranthus viridis*. Study revealed that in SCD the average temperature was 5^0C higher over SD method which allowed faster removal of moisture from the vegetable leaves. Among the three drying methods, ECD was the fastest (drying time 2.2-3.0 hr) method followed by SCD and SD (3.4-10.0 hr) methods. Initially, moisture content decreased at faster rate which was slowed down gradually with time. Drying rate constant was higher for SD (0.12-0.50 hr^{-1}) followed by SCD (0.03-0.20 hr^{-1}) and ECD (0.0002-0.014 hr^{-1}) methods. The rate of drying efficiency was recorded highest in ECD method followed by SCD and SD methods irrespective of all the leafy vegetables. Keeping in view the erratic power supply, drying time, hygiene and safety, SCD can be better alternative to sun drying. On the basis of portability and cost effectiveness, the solar cabinet dryer is recommended for small farmers of the Jharkhand.

Keywords: Lesser known, Leafy vegetables, Sun drying, Solar cabinet dryer, Electric cabinet dryer

Introduction

Leafy vegetables occupy an important position in the Indian diet. Leafy vegetables are treasure trove of nutrients and micronutrients and are available at low cost (Karva 2008). Leafy vegetables provide fiber, â-carotene, ascorbic acid, vitamin E, selenium and flavonoids and act as an antioxidant. They offer protection against many life style related chronic diseases like heart diseases, obesity, diabetes, hypertension and certain type of cancers. Green leafy vegetables also provide a variety of phytonutrients- leutin and zeaxanthin which protect our cells from damage and age-related problems (Rajeswari 2010).

Most of the leafy vegetables are highly perishable and available in a particular season. Drying increases the shelf life of leafy vegetables upon storage (Eklou et al. 2006) and ensures round the year availability of these vegetables (Mishra 2003). Leafy vegetables containing high moisture content undergoes microbial attack soon after harvesting and start deteriorating immediately within a day after harvest (Sobukola et al. 2007). Drying allows storage of leafy vegetables over a longer period and prevents the growth of mould and fungi and thus minimizing microbial degradation (Chong and Law 2010; Doymaz 2011). It also reduces microbiological activity and minimizes physical and chemical changes in leaves (Araujo et al. 2004; Vega-Galvez et al. 2007). Drying also brings about substantial reduction in weight, volume, packaging, storage and transportation costs (Chan et al. 2012).

Among many methods of drying, sun drying is a conventional drying method used in most of the developing countries of tropical and sub-tropical region. Sun drying has disadvantages such as long drying time, exposure to contamination from dust, soil, sand particles and insects (Folaranmi 2008). To overcome these problems, it is necessary to use alternative drying methods. Solar drying is an embellishment of sun drying and is quite hygienic, renewable, cheap and environmentally friendly (Bala and Woods 1994; Basunia and Abe 2001). On an average, India receives about 449 cal/cm^2/day solar radiation (Mishra 2003) which can be efficiently used in drying through better drying

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techniques. Variety of dryers have been designed and developed and their performance was evaluated in terms of drying time and drying constants. Many researchers compared the performance of cabinet type of dryers with natural sun drying. There is no specific study focusing on the performance of different drying methods (electric dryers, solar dryers and direct sun drying) in respect of leafy vegetables. This article aims at evaluating the performance of these three drying methods in drying of six leafy vegetables cultivated in the eastern region of India. The article also reports on economic evaluation of these dryers.

Materials and Methods

Species studied: Six major seasonal lesser known leafy vegetables *viz*., *Moringa oleifera* (Munga; F: Moringaceae), *Polygonum plebeium* (Chimti; F: Polygonaceae), *Centella asiatica* (Beng; F: Apiaceae), *Limnophila conferta* (Muchari; F: Scrophulariaceae) *Bauhinia variegata* (Koinar; F: Fabaceae) and *Amaranthus viridis* (Hara Gandhari; F: Amaranthaceae) were selected for the study. The leaves of these vegetables were collected from local markets of Jharkhand and subjected to drying process in the laboratory.

Drying methods: All the lesser known leafy vegetables were washed thoroughly with running tap water to remove dust. The moisture on the wet sample surface was removed with filter paper and 100 g samples were dried to a constant weight using the thee different drying methods *viz*., sun drying (SD) (35-50^{0}C), solar cabinet drying (SCD) (30-54^{0}C) and electric cabinet drying (ECD) (100^{0}C). Samples were spread evenly during the drying operations to ensure effective drying.

In SD, the leafy vegetables were spread on a clean cloth and dried under open sun. The solar drying was done in a specially manufactured solar cabinet dryer which (Fig 1 and Fig 2) is a closed chamber made up of compressed wood having glass cover of 95 x 100 cm size. The SCD had two air inlets at the base of front side and two air outlets at upper backside of the dryer. The leafy vegetables to be dried were spread in the black colour coated perforated aluminium tray fitted inside the dryer. Weight of the vegetables was recorded at one hour interval to determine the moisture loss patterns. One thermometer was fitted inside the drying chamber and another one was fixed outside the dryer to measure the inside and outside temperature. The dryer had a capacity of drying 2.5 kg leafy vegetables per batch. In ECD, mechanical drying was done using hot air at a temperature of 100^{0}C. The leafy vegetables to be dried were spread in the tray inside the cabinet dryer (M/s Reico Equipment & Instrument Pvt. Ltd, Kolkata, India).

Drying of leaves of one particular species of the vegetable was carried out on the same day. The samples were weighed at one hour interval and the moisture content was calculated from the weight loss until a constant weight was obtained. In the event where drying continued for two days, the samples were kept inside desiccators during night time to prevent moisture reabsorption. Drying curves (time Vs moisture content) and drying rate constants were developed from initial moisture content and equilibrium moisture content of six lesser known leafy vegetables.

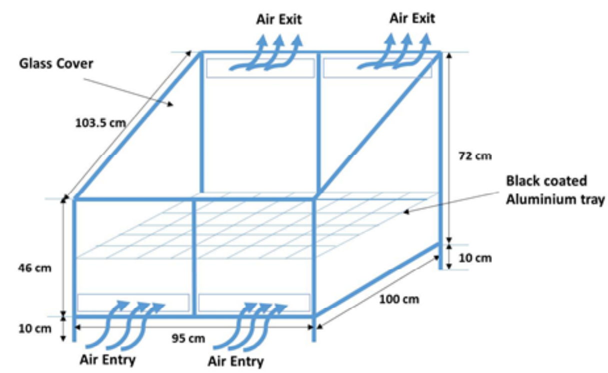

Fig 1: Schematic diagram of the SCD

Fig 2: Drying operation of leafy vegetables using SCD

Moisture content: The moisture content of leafy vegetables was determined by drying until the weight of the dried sample become stable (AOAC 1984). The moisture content of the dehydrated leafy vegetables was expressed as:

$$\text{Moisture content of dehydrated sample (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

Drying rate constant (k): In drying process, the rate of drying is expressed in the form of an exponential equation (Eq.1). This equation was simplified (Eq. 2-5) to get the equation for drying constant (Eq.6). Slope of the line ln (M_0-M) denotes the drying constant.

$dM/dt = e^{-kt}$ .... (1)

Where M = moisture content (%) at time t; t = time; k = drying rate constant

From the above equation, it is obvious that

$dM = e^{-kt} dt$ .... (2)

Integrating using appropriate limits, we arrive at

$$\int_{m0}^{m} dM = \int_{t0}^{t} e^{-kt} dt \text{--} \quad (3)$$

Since the negative power of e shows that $M_0 > M$ and because $t_0 = 0$

We can write: $(M_0 - M) = e^{kt}$ .... (4)

Where M_0 is the initial moisture content of the samples.

Applying the natural logarithms, we arrive at:

$\ln (M_0 - M) = kt$ ....(5)

$k = \ln (M_0 - M)/t$ ....(6)

Rate of drying efficiency of different drying methods: In the present experiment, the ECD consisting of 24 trays had the capacity of drying 4 kg leafy vegetables per tray. The SCD had the capacity to dry 2.5 kg vegetables per batch. The same amount of capacity for SD was considered to calculate the rate of drying efficiency. The capacity of the dryer was considered as input. Drying efficiency rate per hour of the dryers was calculated from the following formulas:

$$\text{Drying efficiency (\%)} = \frac{\text{Output (Dry weight)}}{\text{Input (Fresh weight)}} \times 100$$

$$\text{Rate of drying efficiency (per hour)} = \frac{\text{Drying efficiency}}{\text{Drying time}}$$

Results and Discussion

In ECD, constant temperature of 100°C was maintained throughout the drying period but in SCD and SD, initially the temperature increased as the day time proceeds but the temperature drops suddenly during afternoon time. In SCD, the average temperature was 5°C higher over SD method which allowed faster removal of moisture from the vegetable leaves (Fig 3).

The drying times required by different drying methods are shown in Table 1. Among the three drying methods, ECD was the fastest method for drying of leafy vegetables. *Moringa oleifera* leaves took minimum time to dry under ECD method (2.23 hr) followed by *Polygonum plebeium* leaves (2.42 hr). Maximum time was taken by SD method. In SD, the leafy vegetable *Polygonum plebeium* dried earliest at 3.42 hr followed by *Moringa oleifera* leaves (3.82 hr). *Bauhinia variegata* leaves took maximum time to dry under open sun (11.00 hr). SCD method took more time than ECD method but less time than SD method. In case of SCD also, the leafy vegetable *Polygonum plebeium* dried earliest at 3.42 hr followed by the vegetable *Moringa oleifera* (3.82 hr). Whereas, maximum time to dry under SCD was taken by *Amaranthus viridis* leaves (9.00 hr).

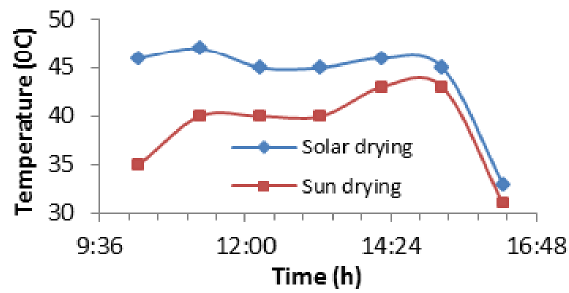

Fig 3: Hourly temperature variations in solar (SCD) and sun drying (SD) methods

Table 1: Drying time (hr) in different drying methods of six lesser known leafy vegetables

Drying methods	Moringa oleifera	Polygonum plebeium	Centella asiatica	Limnophil a conferta	Bauhinia variegata	Amaranthus viridis
SD^	3.82	3.42	5.75	5.75	11.00	10.00
SCD†	3.82	3.42	4.75	4.75	7.00	9.00
ECD*	2.23	2.42	2.75	2.75	3.00	3.00

Where: ^Sun drying, †Solar cabinet dryer, *Electric cabinet dryer

Drying curves (time Vs moisture content): The drying curves of six leafy vegetables with respect to time Vs moisture (Fig 4) revealed that moisture expulsion was initially faster and the moisture content decreased continuously with enhancement of time. All the graphs showed rate of periodic removal of moisture at regular intervals. Moisture removal from the leafy vegetables increases as the drying periods proceed. The rate of moisture removal was found to be the highest during the initial period because in initial stages, wet plant tissues behave like surfaces saturated with water (Brennan et al. 1990) and later stagger (Doymaz 2005; Meisamiasl et al. 2010).

ECD leads to considerable reduction of drying time. In the vegetable *Moringa oleifera*, moisture expulsion was found to be faster initially up to 2.23 hr in SD method while in SCD and ECD methods, up to 1.13 hr faster removal of moisture took place. In *Polygonum plebeium* leaves, initially up to 2.42 hr moisture exclusion was found to be faster in all the drying methods. After that there was constant moisture content observed approximately after 3.42 hr. The vegetable *Centella asiatica* showed faster removal of moisture after 3.75

hr in both SD and SCD methods, whereas in ECD methods after 1.75 hr, there was faster removal of moisture initially. In *Limnophila conferta* leaves, moisture expulsion was found to be faster initially up to 3.75 hr in both SD and SCD method but in ECD methods up to 1.50 hr, faster removal of moisture took place. Whereas, the leaves of *Bauhinia variegata* recorded faster moisture removal up to 8.00 hr in SD method and 4.00 and 2.00 hr in SCD and ECD methods, respectively. In the vegetable *Amaranthus viridis*, moisture expulsion was found to be faster initially up to 8.00 hr, 7.00 hr and 2.00 hr in SD, SCD and ECD methods, respectively.

molecular bond of the moisture and as constant energy was supplied, it took longer time to break, therefore drying rate decreased (Ndukwu 2009). Among all the drying methods, SD gives the maximum drying rate constant followed by SCD and ECD methods. In SD of six leafy vegetables, *Moringa oleifera* had the maximum drying rate constant (0.5035 hr^{-1}) followed by *Centella asiatica* leaves (0.4726 hr^{-1}). In case of SCD, the vegetable *Limnophila conferta* (0.214 hr^{-1}) followed by *Amaranthus viridis* (0.2115 hr^{-1}) gave maximum drying rate constant. Whereas, in ECD method, *Centella asiatica* leaves (0.0149 hr^{-1}) showed the highest drying rate constant.

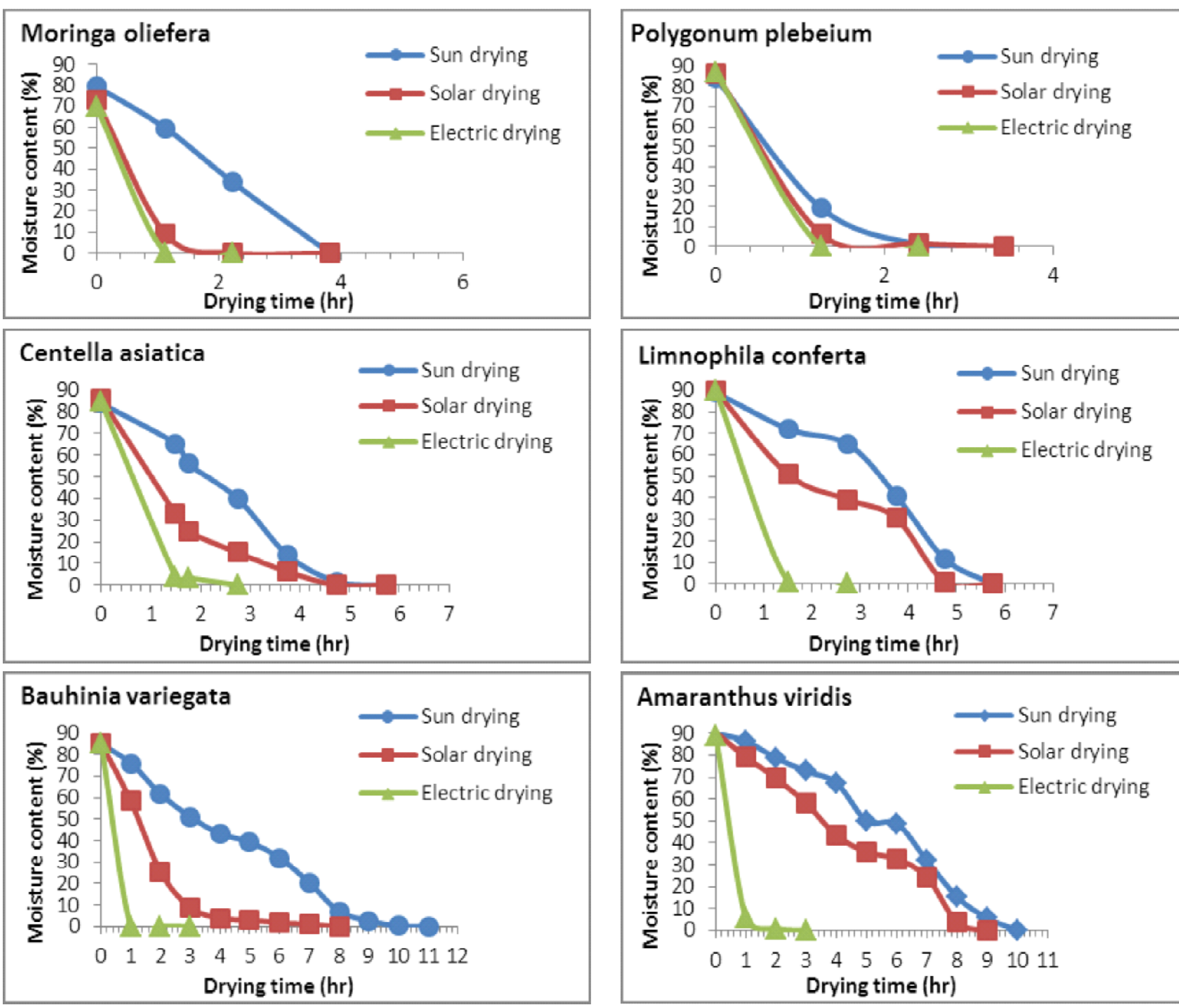

Fig 4: Effect of different drying methods on moisture content of six lesser known leafy vegetables

Drying rate constant (k): The drying rate constant was calculated from the slopes of drying curves of Fig 5 plotted based on equation 6 for the different drying temperatures and presented in Table 2. As the drying progressed, more energy was required to break the

Drying rate efficiency of different drying methods: The drying rate efficiency of three drying methods was compared and presented in Table 3. The ECD had the capacity to dry 96 kg of leafy vegetables per batch. SCD made up of base size of 95 x 100 cm had the

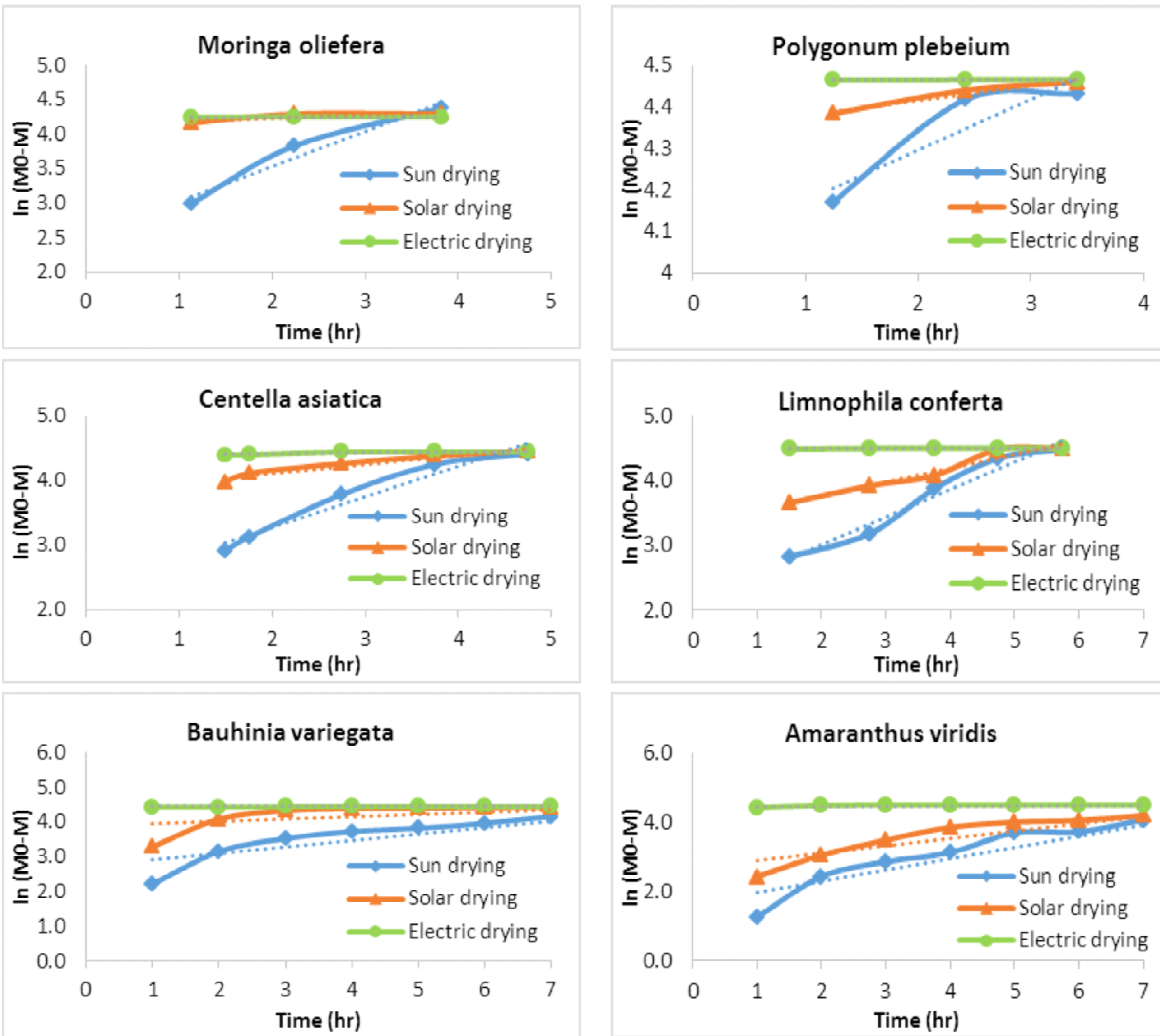

Fig 5: ln (M_0-M) Vs time graphs for six lesser known leafy vegetables

Table 2: Drying rate constant (*k*) of six lesser known leafy vegetables

Leafy vegetables	Drying rate constant		
	SD^	SCD†	ECD*
Moringa oleifera	0.5035	0.0458	0.003
Polygonum plebeium	0.1229	0.0356	0.0004
Centella asiatica	0.4726	0.1378	0.0149
Limnophila conferta	0.4263	0.214	0.0022
Bauhinia variegata	0.1867	0.0693	0.0002
Amaranthus viridis	0.3231	0.2115	0.0039

Where: ^Sun drying, †Solar cabinet dryer, *Electric cabinet dryer

capacity to dry 2.5 kg of leafy vegetables per batch. The same amount of capacity for SD was considered to calculate the drying rate efficiency. The results showed that the rate of drying efficiency was recorded highest in ECD method followed by SCD and SD methods irrespective of all the leafy vegetables. Among the leafy vegetables, *Moringa oleifera* had highest rate of drying efficiency (7.04, 7.39 and 13.53 in SD, SCD and ECD methods, respectively) followed by *Polygonum plebeium* (3.81, 3.95 and 6.55 in SD, SCD and ECD methods, respectively). Though ECD method was found best for rate of drying efficiency but is costlier than the SCD and SD technique but when time, quality and safety are considered, the ECD and SCD method give better result as compare to SD. So, the SCD method if adopted by poor tribal farmers of Jharkhand, would ensure a steady availability of leafy vegetables all the year round by utilizing the easily available huge amount of solar radiation per year and farmers would be able to get more price in off season.

Table 3: Rate of drying efficiency of different drying methods

Particulars	*Moringa oleifera*			*Polygonum plebeium*			*Centella asiatica*			*Limnophila conferta*			*Bauhinia variegata*			*Amaranthus viridis*		
	SD^	**SCD†**	**ECD***	**SD**	**SCD**	**ECD**	**SD**	**SCD**	**ECD**	**SD**	**SCD**	**ECD**	**SD**	**SCD**	**ECD**	**SD**	**SCD**	**ECD**
Input (FW, Kg)	2.50	2.50	96.00	2.50	2.50	96.00	2.50	2.50	96.00	2.50	2.50	96.00	2.50	2.50	96.00	2.50	2.50	96.00
Moisture (%)	1.83	1.79	67.04	2.17	2.16	80.79	2.12	2.05	77.22	2.12	2.07	78.35	2.13	2.13	81.75	2.26	2.25	85.67
Output (DW, Kg)	0.67	0.71	28.96	0.33	0.34	15.21	0.38	0.45	18.78	0.38	0.43	17.65	0.37	0.37	14.25	0.24	0.25	10.33
Drying time (hr)	3.82	3.82	2.23	3.42	3.42	2.42	5.75	4.75	2.75	5.75	4.75	2.75	11.00	7.00	3.00	10.00	9.00	3.00
Drying efficiency (%)	26.88	28.24	30.16	13.01	13.50	15.84	15.25	17.94	19.56	15.14	17.09	18.39	14.66	14.70	14.85	9.44	9.86	10.76
Rate of Drying Efficiency (per hour)	7.04	7.39	13.53	3.81	3.95	6.55	2.65	3.78	7.11	2.63	3.60	6.69	1.33	2.10	4.95	0.94	1.10	3.59

Where: ^Sun drying, †Solar cabinet dryer, *Electric cabinet dryer

Conclusion

Drying time and rate are significantly impacted by the methods of drying. The ECD was the fastest drying method as compared to SCD and SD methods. But ECD method is expensive and out of the purchasing power of the poor tribal farmers. Whereas, sun drying was the cheapest and easy-to-use drying method, but it took longest time to dry the vegetables. Solar drying is most suitable technology and alternate to sun drying method as it is inexpensive and environmental friendly. On the basis of portability and cost effectiveness, the SCD can be recommended for small farmers of the Jharkhand.

सारांश

पत्तेदार सब्जियाँ झारखण्ड के विभिन्न जनजातीय एवं स्थानीय समुदायों के भोजन का सर्वाधिक महत्वपूर्ण अंग है क्योंकि इन में प्रचुर मात्रा में पोषक एवं सूक्ष्म पोषक तत्व पाए जाते हैं। अधिकांश पत्तेदार सब्जियाँ शीघ्र खराब हो जाती हैं। उन्हें सूखाने पर अथवा उनका सुखौता बनाने पर, उनमें नमी की मात्रा घटकर एक ऐसे सुरक्षित स्तर पर लायी जाती है कि शीघ्र सड़ने वाली सब्जियों का भी लंबे समय तक भण्डारण किया जा सके। प्रस्तुत अध्ययन में छः गौण पत्तेदार सब्जियाँ जैसे–*मोरिंगा ओलिफेरा*, पॉलीगोनम प्लेबियम, *सेन्टेला एशियाटिका*, *लिम्नोफिला कॉन्फर्टा*, *बहौनिया बेराइगेटा* तथा *अमैरेन्थस बिरडिस* को सूखाने की तीन विधियों जैसे– पारंपरिक धूप में सूखाने की विधि (एस.डी.), सोलर कैबिनेट ड्रायर विधि (एस.सी.डी.) तथा विद्युत कैबिनेट ड्रायर विधि (ई.सी.डी.) का मूल्यांकन किया गया है। अध्ययन से पता चला कि एस.सी.डी. विधि में औसत तापमान एस. डी. विधि से 5 डिग्री सेंटीग्रेड अधिक था जिससे सब्जियों की पत्तियों से नमी शीघ्र दूर हो गयी। सूखाने की तीनों विधियों में सर्वाधिक त्वरित विधि ई.सी.डी. (सूखाने का समय 2.2–3.0 घंटा), फिर उसके बाद एस.सी.डी. तथा एस.डी. (3.4–10.0 घंटा) पायी गयी। शुरूआत में नमी सूखने की दर तेज रही थी जो समय बीतने के साथ कम होती गयी। सूखने की दर सर्वाधिक स्थिर एस.डी. विधि में (0.12–0.50 प्रति घंटा) रही, फिर एस.सी.डी. में (0.03–0.20 प्रति घंटा) तथा ई. सी.डी. में (0.0002–0.014 प्रति घंटा) रही। हालांकि बिजली की बाधित आपूर्ति, सूखाने की अवधि, स्वच्छता तथा सुरक्षा के दृष्टिकोण से एस.सी.डी. विधि, एक बेहतर विकल्प हो सकती है। वहनीयता एवं लागत के प्रति किफायत के आधार पर झारखण्ड के छोटे किसानों के लिए सोलर कैबिनेट ड्रायर की अनुशंसा की जाती है।

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