RESEARCH ARTICLE

Performance of Solar Drying and Evaluation of Phytochemical Profile in an Underutilized Fruit (*Capparis Decidua*) Ker

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Abstract

Ker (C. decidua) is an important, underutilized fruit crop occurring in the arid region of western Rajasthan. This has gained special importance due to phytochemicals present in it with predominant medicinal properties. In the present study, the drying experiment of fresh *ker* fruit was conducted for 80 hours in phase change material (PCM) based solar dryer to retain its original colour and other important quality attributes such as phenols, flavonoids, β-carotene, saponins and ascorbic acid. Colour of *ker* retained as per CIE scale *'L', 'a' and 'b'* value 29.43, -11.2, and 12.15 respectively, in case of solar drying. It was observed that the β-carotene (4.38 mg), saponin (18.56 mg), and ascorbic acid (10.80 mg) decreased in pretreatments and solar drying compared to direct sun drying. On the contrary, the level of phenols (70.87 µg GAE/g) and flavonoids (18.56 µg RE/g) increased in blanching and solar drying. The level of β-carotene was found enough in one hundred gram of dried *ker* to meet the Recommended Dietary Allowances of this important precursor of vitamin–A.

Key Words: β-carotene, Flavonoids, *Ker*, Phenolics, Phytochemical, Saponin.

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Introduction

*Capparis decid*e commonly known as 'ker,' is a dominating genus of family' Capparidaceae' which is an essential medicinal plant extensively found in arid regions of Africa, Middle East, and southern Asia, including *'Thar'* desert of India.

Capparis sp. is xerophytic, growing in a wide range of climatic conditions such as deserts to cooler terrains of mountains either as shrubs, trees, or creepers (Joseph and Jini, 2011). In the rural desert areas of India, fruits and vegetables are not available as commonly for consumption due to scanty waterfall, poor transportation, and high prices. Rural populations, therefore, have to depend upon locally available vegetation for food and fodder. Fresh fruits of *C. decidua* are used in pickle formation and as a vegetable because of the presence of important nutritional ingredients like proteins, fatty acids, β-carotene, vitamins, and minerals. The ripened fruits are rich in carbohydrates (71%), protein (15-18%), fats (5%) and crude fibre (1%) including Ca (20%), Zn (4%), Fe (6%) and Mn (2%) (Rai and Rai, 1987). Interestingly, it is the most abundant source of β-carotene among arid vegetations (Chaturvedi and Nagar, 2001).

The daily requirement of β-carotene is 2500–3000 µg, as recommended by ICMR (Gopalan et al., 1996). The deficiency of vitamin-A leads to impaired cellular functioning since it has an essential role in numerous physiological processes in humans (Machlin, 1984). Carotenoids are the precursor of vitamin-A, and those commonly occurring in nature include, α, β and γ-carotene, lycopene, and cryptoxanthin (Goodwin,1986). Among these precursors, a major proportion of vitamin-A activity is accounted for β-carotene. *Capparis decidua* fruit is also a rich source of vitamin-C (Chauhan et al.,1986).

The plant is reported to contain phytochemicals such as tannins, saponins, alkaloids, terpenoids, and some fatty acids. The plant has significant pharmacological activities such as antidiabetic, anti-inflammatory, analgesic, hypocholesterolemic, antimicrobial, antihelmintic, and purgative activities. Consumption of *C. decidua* decreases lipid peroxidation and alters free radical scavenging enzymes such as superoxide dismutase and catalase in erythrocytes, liver, and kidney in diabetic alloxan-induced rats (Agrawal and Chauhan, 1988; Yadav et al.,1997). In the traditional system of medicine, the root, leaves, fruits, and bark has been proved useful in the treatment of various chronic and degenerative diseases. High level of saponin in the *ker* fruit directly correlates with its use as a medicine for various ailments such as cancer, rheumatism, etc. as reported by Athanasiadis and Moral (2013). Study of Joseph and Jini (2011) indicated that methanolic fraction of *ker* fruit seeds contains a highly antibacterial volatile compound, 'methyl isothiocyanate' while the unsaponifiable fraction of fruit and seeds also contain N-pentacosane, β-sitosterol, and β-carotene which further shows that *ker* has been a very important crop in traditional medicine. In most cases, processing causes a reduction in the nutritional and phytochemical constituents of foods.

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Direct sun-drying has its disadvantages as it causes significant blackening and odor in *ker* fruits. Due to plenty of sunshine availability in an arid region of India, solar drying of *C. decidua* can be a better option. Further, processing influences the level of phytochemicals in fruits and vegetables. It is, therefore, pertinent to determine the effect of processing on the phytochemical content of solar-dried *ker* and make these data available for nutritionists and researchers.

Materials and Methods

Sample

Capparis decidua (ker) fruits were purchased from the local market of Jodhpur in bulk according to seasonal availability in the month of March-June. Fruits were washed and blotted with muslin cloth then subjected to pretreatment i.e., soaking in 20% NaCl Soln for 14-hour followed by blanching at 80°C with aqueous soln (0.1 % NaOH) for 1-minute to inactivate enzymes. Pre-treated samples of C. *decidua* were again blotted with muslin cloth and put on the shelves of PCM based solar dryer for drying (Figure 1). The drying experiment was performed in the month of April-May. The inside temperature of the dryer cabinet was ranged from 50°C (daytime) to 40°C (night time). The drying of samples was performed for 72 hour. Dried samples of *ker* were then packed in the zip-lock plastic pouches of 100 g, placed in airtight containers, and stored in the refrigerator for further analyses.

Description of Solar Dryer

Solar dryer with PCM thermal energy storage has been used for drying of the *ker* (Figure 2). This dryer has the unique feature of storing the excess heat simultaneously with drying during the day time and supply of stored heat after sunset hours to continue the drying operation. The dryer consist of a flat plate collector as an absorber, packed bed PCM thermal energy storage, drying chamber with six drying trays, and a natural convection collector. The system assumed to face the midday sun (Jain and Tewari, 2015).

The hot air was generated in the absorber by falling solar radiation (Figure 3). The higher temperature of the air was utilized in the heating and melting of PCM as thermal storage, and remaining were passed over to the drying trays during sunshine hours. During off sunshine hours, the heat stored in PCM released latent heat, which was utilized by drying during off sunshine hours to continue the process for 5–6 hours. The basic aim was to reduce the time while simultaneously utilizing maximum available energy.

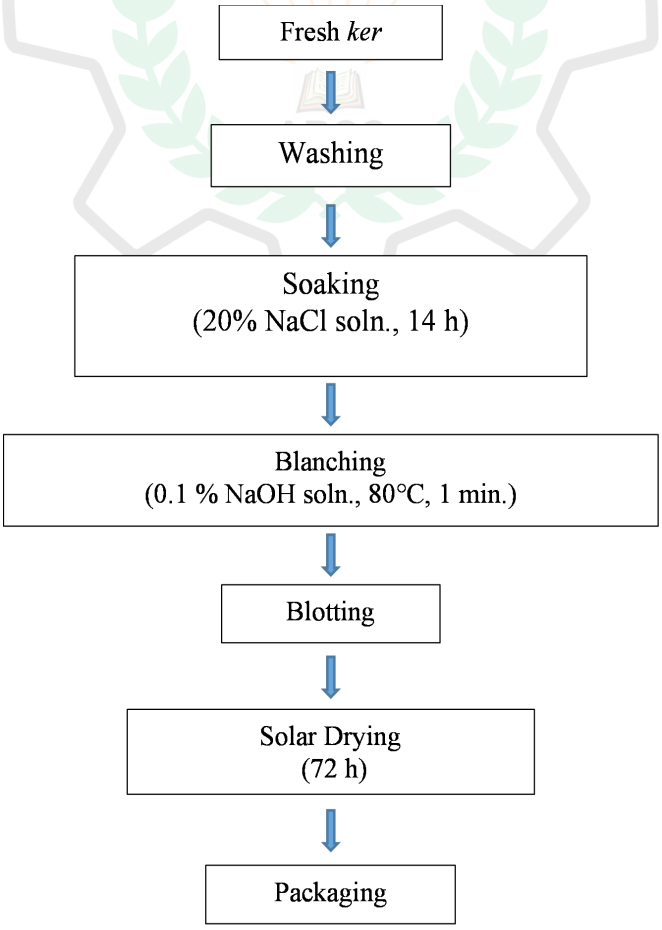

Figure 1: Flow chart for processing of *Capparis decidua* **(***ker)*

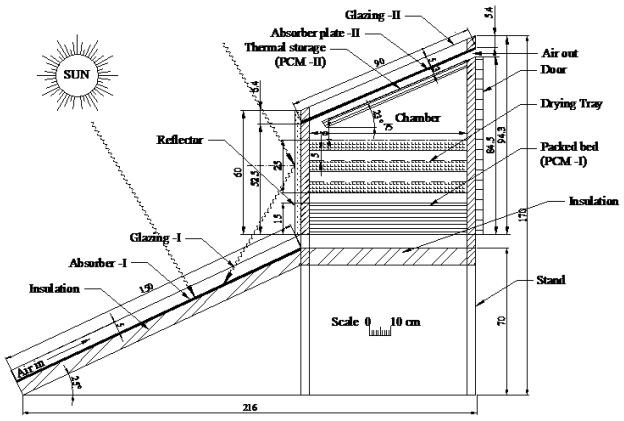

Figure 2: Schematic diagram of PCM.

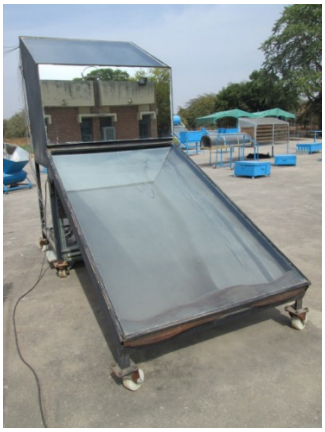

Figure 3: PCM based solar dryer based solar dryer

Drying Equation

Drying operation is an exponential decreasing and expressed with the Page's equation as:

$$M_t = M_o.exp(-k.t^n) \quad (1)$$

Where, M_o &M_t, initial and intermittent moisture content at a time interval (kg[H2O]/ kg[total weight]); *k*, drying coefficient (h^{-1}); t, time (h); *n*, power coefficient.

Color value

The color of fresh and dried products was estimated with image processing on the CIE scale (values L, *a*, *b*) to determine the color change (Hunter and Harold, 1987; Pathare et al. 2012). 'L' is an approximate measurement of luminosity, which is the property according to which each color can be considered as equivalent to a member of grayscale, between black (0-50) and white (51-100). Parameter *'a'* takes positive values for redness (0 to 50) color and negative values for greenness (0-50). Whereas, *'b'* takes positive values for yellowness (0-50) color and negative values for blueness (0-50). Total color difference ΔE ($\Delta E = \sqrt{(\Delta a^2 + \Delta b^2 + \Delta L^2)}$) has been monitored as the modulus of the distance vector between the initial color values and the actual color coordinates.

Determination of Total saponin

Total saponin content was determined according to the standard method (Van-Burden and Robinson, 1981). Crushed sample of 5.0 g was mixed with 50 ml of 20% ethanol in 250 ml conical flask, heated with continuous stirring on a hot water bath at 55°C for 5-hour. The solution was filtered using Whatman filter paper No. 1 (150 mm). The process was repeated with solid residue. Combined extracts were placed on a hot water bath at 90°C till the volume was reduced to 10 mL. Diethyl ether (10 mL) was mixed and transferred to separating funnel and shaken vigorously. The aqueous layer was recovered carefully. The purification process was repeated with 15 mL of n-butanol. The n-butanol extract was mixed with a 5% aqueous NaCl solution and heated on a water bath at 50°C. The concentrated extract was dried in the oven up to a constant weight. The saponin content was calculated as a percentage.

Determination of β-carotene

β-carotene content was determined according to the standard method (AOAC, 1980) described in detail in the supplementary material.

Determination of Ascorbic acid

The ascorbic acid in fresh and dried *ker* was estimated by the titration method (Osborne and Voogt, 1978) described in detail in the supplementary material.

Determination of Total phenolics

The Folin-Ciocalteu method, as quoted by (McDonald et al., 2001), was used to determine the total phenolic compounds. One g of sample was ground with a 10 times volume of 80% ethanol. The homogenate was then centrifuged at 10,000 rpm for 20 minutes. The supernatant was collected, and the residue was re-extracted five times the volume of the 80% ethanol. Pooled supernatants were evaporated to dryness. The residue was dissolved in a known volume of distilled water (5mL). Different aliquots were taken (0.2-2.0 mL) into test tubes, and volume was made up to 3.0 ml with water. 0.5 mL of Folin–Ciocalteau reagent was added in each tube, and after 3 minutes, 2.0 mL of 20% Na_2CO_3 was also added. The contents were mixed thoroughly and placed in a boiling water bath for exactly one minute. After cooling, absorbance was measured at 650 nm against a reagent blank. Total phenols values were expressed in terms of Gallic acid equivalent (GAE mg/g of dry extract).

Determination of Total flavonoid

Total flavonoid content was measured by AlCl3 colorimetric assay according to the method of Tacouri et al. (2013). Briefly, 500 µL of extract and 2 ml of distilled water was mixed with 150 µL of 5% sodium nitrate. After 5 minutes, 150 µL of 10% AlCl3 was added. A total of 2000 µL of sodium hydroxide (1 M) was added after 1 minute and followed by 1200 µL of distilled water. The mixture was incubated for 30 minutes. The absorbance was measured at 510 nm against a prepared blank. The yellow color indicated the presence of flavonoids. A calibration curve was calculated using the rutin standard (0.1 mg/mL). Total flavonoid content of samples

was determined in triplicates, and the results expressed on a dry weight basis (db) as mg, and rutin equivalents (RE) per g of each sample.

Statistical analysis

Mean and standard deviation (SD) were calculated, and a student's t-test was used to see the hypothesized mean difference at $p < 0.05$, indicated at appropriate places to show the significant difference between the samples.

Results and discussion

Performance of solar drying of ker

Drying experiments of *ker* were conducted with fresh fruits and pre-treated (soaking + blanching) fruits followed by direct sun drying and solar drying in PCM based solar dryer, respectively. All the experiments were conducted in June. Solar radiation, ambient temperature, and temperature of the drying chamber were recorded at the interval of 15 minutes with the help of a data logger and presented in Figure 4. The graph was plotted for 24 hours of observations from 06:00 hours (denotes 01 on the abscissa) in the morning to 5:45 hours (denotes 96) in the next morning. The maximum solar radiation was recorded as 1000 Wm^{-2} at 13:00 hours. The ambient temperature varied between 30–37°C and dryer temperature between 30–52°C, and the maximum temperature was attained from 14:00 to 15:00 hours.

The solar drying parameters of *ker* are presented in Table 1. The initial moisture content of fresh fruit was 85.1% (w.b.), which was dried in the direct open sun. The moisture content after pretreatment was found 92.8% (w.b.); those were dried in the PCM based solar dryer. Drying experiments were conducted for 80 hours, as presented in Figure 5. The observations on moisture content were recorded from 10:00 to 18:00 hours at every 02 h interval of the day. The final moisture content in the direct sun-dried and solar dried *ker* fruits were found 7.9 and 5.8%, respectively.

The drying trend revealed that the direct sun drying occurs faster during the initial day hours due to high intensity of solar radiation, but slower after sunset. Whereas, in PCM based solar dryer, the drying occurs in a relatively continuous manner during the day and night hours due to maintenance of the uniform temperature in the dryer chamber. This results in the lower final moisture content of fruit after 80 h of drying. The Page equation appropriately represented the

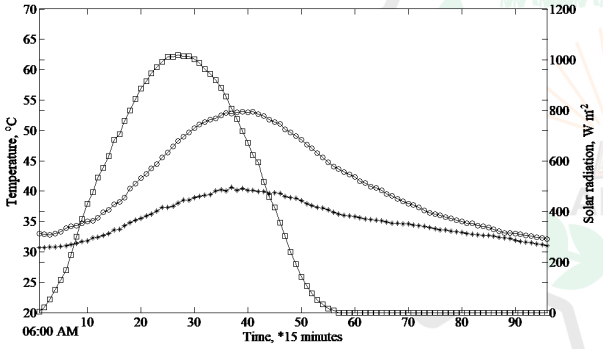

Figure 4: Solar radiation and temperature during experimental days for June
(-⁎- ambient temperature; -o- drying chamber temperature; -□- solar radiation)

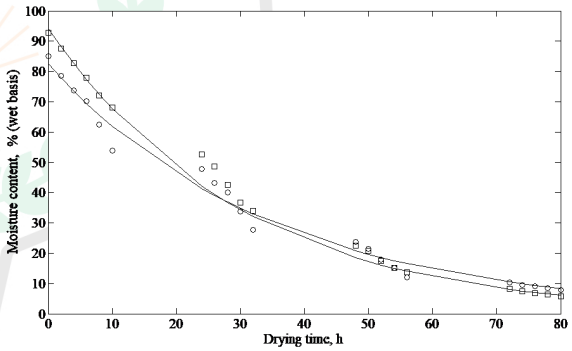

Figure 5: Drying curve presented for solar drying of ker as moisture content dependence on drying time

Table 1: Parameters of solar drying of *ker*

Parameter		*1*	*2*
Month of drying		June	June
Pretreatment (after washing)		Fresh *ker*	Soaking and blanching
Initial moisture content, % (kg[H_2O]/kg[total weight])		85.1	92.8
Final moisture content, % (kg[H_2O]/kg[total weight])		7.9	5.4
Drying time (h)		80	80
Drying equation $M_t = M_o.\exp(-k.t^n)$	k	0.0289	0.03135
	n	0.9981	1.0200
	r^2	0.9839	0.9913
	rmse	3.3720	2.8960

drying process with the coefficient of correlation (r) 0.9839 and 0.9913 for direct sun and solar drying of *ker*.

Color analysis

The color of any fruit is the most important attribute that highly affects its acceptability. Color is an indicator of heat treatment severity and can be used to predict the corresponding quality deterioration resulting from heat exposure. The L, *a*, *b* value of the fresh *ker* sample were 41.49 ± 5.53, -4.18 ± 2.17, 29.17 ± 5.49, respectively. However, for direct sun-dried *ker* the 'L' value (18.35 ± 5.78) and *'a'* value (+2.54 ± 1.94) was also indicative of the significant darkening occurred in the sample. For this, the sample *'b'* value was also quite lower (5.90 ± 3.78), which again indicates the absence of yellowness in the sample. Particular darkness in the direct sun-dried *ker* prepared may be due to enzymatic browning, which produces dark pigments, as reported by Nguyen and Schwartz (1999).

In the case of *ker* dried after soaking and blanching in solar dryer L, *a, b* values were were (29.47 ± 10.21, -11.2 ± 2.39, 12.15 ± 5.11) was revealing of particular greenness and lighter color. The total color difference between fresh and direct sun-dried *ker* was calculated as Δ E = 34.51. The total color difference between fresh and solar dried *ker* as Δ E = 24.48. When the color values were compared of both the samples, a distinct difference owing to *'a'* value of -11.2 was reflected, which indicated particular greenness of the later sample. When the difference in the perceivable color was analytically classified, both the samples occurred in the very distinct class as the Δ E > 3 (Pathare et al. 2012).

Phytochemical characteristics

Table 2 contains the saponin β- carotene, lycopene, phenolics, ascorbic acid and flavonoid content of the fresh, blanched, solar-dried and direct sun-dried samples. Saponins are amphipathic glycosides having one or more hydrophilic glycoside moieties combined with a lipophilic triterpene derivative. The presence of saponins cause a bitter taste in *ker* which affect the consumer acceptance of this particular arid fruit (Yuanita, 2016). Partial removal of the bitterness is an important step to make *ker* fruit acceptable for consumption. As indicated earlier, soaking in 20% NaCl Soln. for 14-hour was done to remove the bitterness of *ker* fruit partially. However, saponins are considered as anti-nutritional (Nkafamiya, 2006) are important because of its hypolipidemic and anticancer activity. It reacts with the cholesterol-rich plasma membrane of various cancer cells to arrest the proliferation. High level of saponin 21. 89 g/100g was found in fresh *ker*.

The level of saponin decreased (18.67g) after blanching, which may be due to the effect of soaking and heat treatment given to *ker* during blanching. Athanasiadis (2013) also indicated that some anti-nutritional factors like saponins, HCN, tannins, and oxalic acid reduced during soaking and blanching process. According to study of Yuanita, (2016) blanching proved to reduce saponin content from 6.5g/100g to the lowest 3.9g/100g in moringa leaves at temperature 85°C for 7.5 minutes. Blanching ($p < 0.05$, $t = 7.12$) and solar drying ($p < 0.05$, $t=8.43$) decreased saponin content significantly when compared to fresh *ker*. Saponin content in the solar-dried *ker* was almost the same as the level which was found after blanching. However, direct sun drying did not show any significant decrease ($p < 0.05$, $t = 0.13$) in the saponin content.

The findings indicated that fresh (8.07) and direct sun-dried (7.30) *ker* contained a significant amount of β-carotene. The level of β-carotene decreased during blanching and solar drying. Blanching caused major loss of β-carotene ($p < 0.05$, $t=38.42$) while the difference between the β-carotene content of blanched and solar dried *ker* was non-significant ($p < 0.05$, $t = 1.77$). Direct sun-drying also effected the β-carotene content negatively ($p < 0.05$, $t=4.38$), but the extent was much lesser in comparison to solar-dried *ker* ($p < 0.05$, $t = 29.62$), which may be due to blanching used as a pretreatment before solar drying. However, in the case of solar drying, blanching showed a significant effect on color retention in dried *ker*. The daily requirement of β-carotene of an adult person ranges from 2500 to 3000 ug as recommended by ICMR (Gopalan et al. 2000) is sufficient to fulfill the requirement of vitamin-A in the body. According to a study by Chaturvedi and Nagar (2001), 100 gm serving of fresh *ker* contains 2.45 mg/100 g of β carotene, which can meet out the same. Looking at the effects of selected processing on β-carotene content of *ker* in this study, blanching caused a significant ($p < 0.05$, $t = 38.42$) decrease.

Drying, on the contrary, had varying effects on this carotenoid. β-carotene content of solar-dried *ker* decreased by almost 46.0% compared to the fresh while, in case of direct sun drying, the losses were on the lower side. This loss can be attributed to exposure of *ker* to high temperature, as indicated earlier, ker underwent blanching in aqueous soln. of (NaOH 0.1 %) at 80°C. This loss clearly demonstrated the lability of β-carotene to heat. Yadav and Sehgal (1997)

Table 2: Phytochemical constituents in fresh blanched, solar-dried and direct sun-dried *C. decidua*

Parameters	*Fresh*	*Blanching*	*Blanching + Solar Dried*	*Direct sun-dried*
Saponins (g/100g)	21.89 ± 1.11	18.67 ± 0.56	18.56 ± 0.56	21.87 ± 0.82
β-carotene (mg/100g)	8.07 ± 0.17	4.46 ± 0.14	4.380 ± 0.22	7.30 ± 0.20
Ascorbic acid (mg/100g)	15.30 ± 0.20	11.78 ± 0.21	10.80 ± 0.32	14.02 ± 0.09
Phenolics (µg GAE/g extract)	78.82 ± 0.39	83.27 ± 0.46	70.87 ± 0.75	61.56 ± 0.65
Total flavonoid (µgRE/g extract)	23.22 ± 0.35	21.23 ± 0.10	18.56 ± 0.11	12.02 ± 0.08

indicated that blanching for a short time results in better retention of β-carotene in Bathua and Fenugreek. Padmavati (1992) also reported that when preparing time was optimal and exposure to heat and air was minimal, the loss was lower. Most important factors that influence the stability of carotenoids include elevated temperature, exposure to oxygen, light, metallic ions (eg. Cu2+ and Fe 3+), extreme in pH, and active surfaces (Scita, 1992; Henry, 1998).

However, the β-carotene content decreased during solar drying; the level (4.38mg/100g) was found enough to meet the RDA of this important precursor of vitamin-A. These results also indicate that vitamin A deficiency, which is common in Rajasthan, could potentially be corrected by emphasizing the liberal consumption of these indigenous sources. Results also showed that in spite of the loss of β-carotene in blanching and solar drying, the carotenoid level was appropriate for consumption.

The ascorbic acid content of fresh, blanched, solar-dried, and open sun-dried *ker* was 15.30, 11.78, 10.80, and 14.02, respectively (Table 1). Lower ascorbic acid was reported in soaked and blanched ker, which may be due to the water solubility and heat-labile nature of ascorbic acid. Higher destruction of ascorbic acid in blanched (23.08%) followed by solar drying of *ker* (42.58%) was reported in comparison to fresh *ker*. More amount of ascorbic acid may be loss due to its heat sensitivity during solar drying. Yadav and Sehgal, (1997) also reported the losses of ascorbic acid increased with the increase in blanching period. Higher reduction of 70-75% in ascorbic acid content after was reported during blanching of spinach leaves for 5–10 minutes, and 41–51% during blanching of amaranth leaves for 3–5 minutes (Ajayi et al. 1980; Akpapunam, 1984; Paul and Ghosh, 2012). There was a significant difference between the ascorbic acid content of solar-dried ($p < 0.05$, t=33.44) and direct sun-dried ($p < 0.05$, t = 10.57) *ker* compared to fresh *ker*. A significant difference ($p < 0.025$, t = 23.33) has also seen between the ascorbic acid content of solar-dried and sun-dried *ker*.

Fresh *ker* contained 78.82 µg GAE/mg extract of phenolic compounds, which was quite higher. Blanching affected positively, as the phenolic content present in *ker* increased up to 83.27 µg GAE/mg. Direct sun-drying effected phenolic contents level (61.56 µg GAE/mg) more adversely than the solar-dried sample (70.87 µg GAE/mg). In connection to this, a study by Turkmen et al. (2005) found that several cooking methods (including boiling) caused increases (2–26%) in the phenolic content of peppers. Increments of phenolic content of vegetables by cooking have been attributed to improved extractability of phenolics from the food (Turkmen et al. 2005; Vongsak et al. 2013).

Drying of *ker* with direct sun drying induced a significant decrease, as the phenolic content becomes 61.56 µg GAE/mg compared to solar-dried *ker*. The loss of phenolic compounds with traditional direct sun drying methods may have been caused by enzymatic processes that occurred during drying. These drying methods could not inactivate the degradative enzymes such as polyphenol oxidases therefore they are able to degrade phenolic compounds during long-time drying procedures. The application of heating inactivates enzymes rapidly, but they may simultaneously degrade heat-sensitive phenolic compounds (Lim and Murtijaya, 2007; Orphanides et al. 2013). Recent works also demonstrated that the temperature affects the stability of phenolic compounds in herbal infusions (Riehle et al., 2013). Phenolic content of solar-dried and open sun-dried *ker* differed significantly ($p < 0.05$, t = 19.70), and a higher level of phenolic compounds was seen in solar drying. A significant difference also existed between fresh and blanched *ker* ($p < 0.05$, t = 32.16), but the level of phenolic content always increased with blanching.

Total flavonoid content of fresh, blanched, solar-dried, and direct sun-dried *ker* was 23.22, 21.23, 18.56, and 12.02, respectively. Regarding the total flavonoid concentration, even short temperature treatment (blanching) caused a significant decrease (8.13% of total flavonoids) in their concentration. Prolonged temperature treatment in direct sun drying resulted in drastic reductions of flavonoid concentrations, about 48.23%, while in the case of solar drying it was 20.00 %compared to fresh *ker*. Significant difference were found in flavonoid content among fresh vs blanched ($p < 0.05$, t = 13.49), solar-dried ($p < 0.05$, t = 20.21) and open sun-dried ($p < 0.05$, t = 68.93) *ker*. A highly significant difference between flavonoid level in solar and open sun-dried *ker* were also seen ($p < 0.05$, t = 86.62) while the level of flavonoids was found much higher in solar dried in comparison to direct sun dried *ker*.

It is not well understood which processes are responsible for the observed flavonoid losses. This could be due to flavonoid breakdown during the heating and/or extraction of glycosides by the soaking and heating. Such processes were reported in other research where flavonoid-containing plant material was thermally processed. Cooking both tomatoes and onions resulted in lowered quercetin content, although less so following frying than boiling or microwave cooking (Crozier et al. 1997; Vongsak et al., 2013).

Conclusion

The study emphasized the effect of selected pretreatments (soaking and blanching) and solar drying in *ker*. Results were compared with direct sun-dried samples to understand the effect of both kinds of drying methods on visual color and phytochemicals level in comparison to fresh *ker*. However, the level of β-carotene, which is an important nutritional component in case of *ker* decreased significantly during processing, the remaining level of β-carotene, i.e., 4.38 mg was sufficient to meet the daily RDA of this important precursor of Vitamin-A in the body. The levels of phenolic compound increased during blanching. During the solar drying of *ker,* the level of phenolic compounds and flavonoids were found quite higher when compared to direct sun drying. Keeping in view, the higher color retention, green color, and uniform quality selected pretreatments, and solar

drying can be recommended for drying of *ker*. The other advantages of solar drying over direct sun drying make it strongly sustainable for getting a product of superior color and uniform quality.

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