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ORIGINAL ARTICLE

Effect of drying and storage on bioactive components of jambhul and wood apple

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Abstract Jambhul and wood apple were subjected to two different drying methods to examine the effect of drying temperatures (80 °C and 60 °C) and influence of storage conditions viz., room temperature (25 °C) and refrigeration temperature (4 °C) on bioactive constituents of jambhul and wood apple powder for 90 days. Results showed that retention of phenolics, ascorbic acid and antioxidant capacity such as ABTS, DPPH and FRAP in jambhul and wood apple were high at 80 °C as compared to 60 °C in both tray and IR drying. Anthocyanin and flavonoid significantly ($p<0.05$) decreased at 80 °C. Jambhul showed retention of 30.83 % TPC, 10.40 % TFC, 9.31 %, TMAC, 12.75 % ascorbic acid, 19.26 % ABTS activity, 98.71 % DPPH activity, and 27.78 % FRAP activitys in IR drying; whereas wood apple showed more retention of 25.74 % TPC, 61 % ascorbic acid, 10.31 % ABTS, 36.45 % DPPH and 0.27 % FRAP in tray drying (TD). During storage bioactive constituents in jambhul powder were preserved at refrigeration temperatures whereas in wood apple they were retained at room temperature.

Keywords Tray drying · Infrared drying · Jambhul · Wood apple · Antioxidant capacity

Abbreviations

TD	Tray drying
IRD	Infra red drying
TPC	Total phenolic content
TFC	Total flavonoid content
TMAC	Total monomeric anthocyanin content
DPPH	(2, 2-diphenyl-1-picrylhydrazyl)
ABTS	(2, 2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt)
FRAP	Ferric reducing antioxidant power
DW	Dry weight

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Introduction

Jambhul (*Syzygiumcumini L.*) and wood apple (*Limoniaacidissima*) are indigenous minor fruits of India. The fruit concentrate of jambhul has medicinal importance and has a large market for the treatment of chronic diarrhea and other enteric disorders, including its use as an antimicrobial (Migliato 2005). The fruit is used in the preparation of juices, squashes, Ready to Serve (RTS) beverages, jam and jellies (Koley et al. 2011). There are very few reports available on the quantification of bio active components from Jambhul. In our previous study we observed that the fresh jambhul pulp contained TPC (87.37 mg/g), TFC (227.38 mg/g), ascorbic acid (22.04 mg/g), anthocyanin (27.40 mg/g) and antioxidant capacity in the form of ABTS (141.20 μM/g), DPPH (396.04 μM/g), and FRAP (196.06 μM/g) (Sonawane and Arya 2013a). Further efforts were also made to utilize dried jambhul powder in the development of bioactive enriched milk kulfi (Sonawane et al. 2013). The milk kulfi with 3 % jambhul powder had TPC (78.68 %), TFC (100 %), anthocyanin (100 %), ABTS capacity (66.20 %) and DPPH (91.22 %). Thus bioactive enriched milk kulfi was prepared with very good sensory overall acceptability with a score of 6.57 compared to control kulfi sample. Wood apples are utilized in the preparation of chutney, jam and jelly. It has shown hypoglycemic, antitumor, larvicidal and antimicrobial and hepato-protective activity (Kangralkar et al. 2010; Vidhya

and Narain 2011). Our efforts were successful in the preparation of khattamitha (ready to serve) beverage from wood apple (Sonawane and Arya 2013b).

Fruits and vegetables come under the category of highly perishable commodities which contain 80 % moisture. Nearly 30 % of fruits are lost due to spoilage, handling, transportation and lack of cold storage and processing techniques (Singh et al. 1994). It is necessary to employ modern food processing methods to extend shelf life for better distribution and utilization in the off-season in both large scale and small scale (Bhattacharyya and Bhattacharjee 2007).

In recent years consumer demand has been increased for health promoting food products which has led to development of novel functional beverages (Verschuren 2002; Katan and De Roos 2004). The high phenolic content of plants and the consumer drive towards natural products demonstrate that these extracts would be ideal ingredients for incorporation into functional beverages with potential anti-inflammatory properties.

Hot-air drying is the most widely used method for production of dehydrated vegetables and fruits due to low investment and operating cost. However, the disadvantage of hot-air drying is it takes longer time, even at high temperature, which in turn may cause serious damage to the product's quality attributes, such as flavor, color, texture, nutrient status and beneficial substances to health (Nijhuis et al. 1998; Tsami et al. 1999).

Infrared radiation (IR) can be used as a deliberate heating source and is also gaining popularity as a safe drying method giving a better quality product (Wang and Sheng 2006). The drying time can be reduced by IR energy, which is rapidly absorbed by the water molecules in the product, resulting in rapid evaporation of the water and thus a higher drying rate. Moreover, IR application has been reported to improve product qualities, faster and better rehydration (Skjoldebrand 2002).

In the present study efforts were made to dehydrate jambhul and wood apple pulp by tray and IR drying (IRD). The drying was performed at 2 different temperatures viz. 80 and 60 °C to find out the impact of drying on the nutritional components of jambhul and wood apple powders. Further effect of storage period on shelf stability of bioactive component of these was studied.

Materials and method

Materials

Jambhul and wood apple were purchased in the large quantity during month of July and November 2011 from local market of Mumbai, Maharashtra, India. These fruits were stored at −20 °C until their final usage to prevent spoilage and to maintain uniformity in the quality throughout the entire research.

Chemicals

Folin-Ciocalteau reagent, sodium carbonate anhydrous, sodium hydroxide was purchased from FINAR Chemicals, Mumbai, India. Vanillin, 2, 4, 6-tripyridyl-S-triazine (TPTZ), $FeCl_3$, Pet ether (60–80 °C) was purchased from Hi-Media, Mumbai, India. HCl, gallic acid, L-ascorbic acid, 2, 6 dichloroindophenol, meta-phosphoric acid, sodium bicarbonate, sodium acetate, potassium chloride, potassium per sulphate, glacial acetic acid were purchased from SD Fine Chemicals, Mumbai, India. 2, 2-azinobis (3-ethylbenzothiazoline-6-sulphonic acid) diammonium salt (ABTS), 1,1-diphenyl-2-picrylhydrazyl (DPPH), Trolox, catechin were obtained from Sigma–Aldrich. Methanol (HPLC grade) purchased from Merck and Ethanol from SD Fine Chem., Mumbai, India. All other chemicals and reagents used in the present study were of analytical grade.

Drying of jambhul and wood apple

A lab scale convective hot air dryer (Sakova Pvt. Ltd, Mumbai, India) was used, having drying cabinet fitted with 10 electrical heating coils (a total of 4.5 kW) and a blower for air circulation. The re-circulation ratio of hot air was optimized to 0.67 in preliminary studies and the air velocity over trays was 0.2 m/s. A laboratory scale IR dryer was used for dehydration (Dryer purchased from Gel Engineering India Pvt. Ltd). The drying temperature and time were controlled by using a control knob. IR dryer (Gel Engineering Pvt. Ltd. Mumbai) was used for the drying operation IR dryer having size 600 mm (W)×300 mm (D)×300 mm (H) was equipped with three IR emitters (1 kW) having total electrical consumption of 3 kW was used for experimental work. These IR emitters emit short waves which causes generation of heat within the samples, leads to removal of surface moisture at faster rate. A suitable blower was fitted for air circulation in the drying chamber with partial air recirculation, leading to an air velocity of 2 m s-1 over the trays.

Homogenized pulp of jambhul and wood apple was subjected to TD and IR dryer at 60 °C and 80 °C until the constant weight of the sample was obtained. The initial moisture content of jambhul pulp was 760 g and for wood apple pulp it was 660 g. The pulp was dried till their moisture content was reduced to 120 g and 180 g respectively. The dried pulp was powdered using analytical mill. Prepared powders were kept in airtight plastic jars placed in desiccators at two different storage conditions: room temperature (25±1 °C) and refrigeration temperature (4±1 °C) for 0, 30, 60 and 90 days and analyzed for TPC, TFC, ascorbic acid, anthocyanin and antioxidant activity by ABTS, DPPH & FRAP.

Extraction of phenolics

One gram of fruit powder was extracted for 3 h with 10 ml of methanol solvent in an orbital shaker set at 180 rpm (30± 1 °C). The extract obtained after shaking was further centrifuged at 10,000 rpm at 37 °C. The supernatant was collected and stored at 4±1 °C in amber colored bottles until further analysis. The analysis was carried out within 3 days of extraction of samples. The storage conditions (time and temperature) were same for all types of fruits.

Determination of total phenolic content

Total phenolic content (TPC) was measured by Folin – ciocalteau method explained by Singleton and Rossi (1965). For phenolics gallic acid was used as a standard. Methanol extracts of phenolics (0.2 ml) from jambhul and wood apple were added with 1 ml of diluted Folin –ciocalteau reagent (1:10). Sodium carbonate (7.5 %) 0.8 ml was added to this mixture. This mixture was allowed to stand for 30 min at room temperature in dark and absorbance was measured at 765 nm. The standard curve was linear between 0 and 100 μg/ml gallic acid. Results were represented as mg of Gallic Acid Equivalent (GAE)/g DW of fruit.

Determination of total flavonoid content

The total flavonoid content (TFC) was measured by Vanillin-HCl method as explained by Rebecca et al. (2010). Methanol extracts of phenolics (0.5 ml) from jambhul to wood apple was dispensed into test tube and 2.5 ml of vanillin reagent (8 % HCl in methanol and 4 % vanillin in methanol, 1:1, *v*/*v*) was added to the sample and incubated in water bath for 20 min at 30 °C. The absorbance was measured at 500 nm. The standard curve was linear between 0 and 250 μg/ml catechin. The flavonoids were represented as mg of Catechin Equivalent (CE)/g DW of fruit.

Determination of ascorbic acid content

The total ascorbic acid content was measured by direct colorimetric method as explained in Ranganna (1999). Initially sample was extracted with 2 % of meta-phosphoric acid (1:10, w/v). 0.5 ml of extract was dispensed into the test tube and 1 ml of dye solution (containing 2, 6-dichlorophenol-indophenol and sodium bicarbonate) was added to the extract and red color was measured at 518 nm within 10 to 15 s. The standard curve was linear between 0 and 100 μg/ml L-AAE. The ascorbic acid represented as mg of L-Ascorbic acid Equivalent (AAE)/g DW of fruit.

Total monomeric anthocyanin pigment content

The samples were analyzed for total monomeric anthocyanin pigment content (TMAC) by pH differential method (Lee et al. 2005). A test portion added to the buffer of pH 1.0 and pH 4.5 at 520 and 700 nm until absorption within the linear range of the spectrophotometer which was measured within 20–50 min of preparation. Results of anthocyanin pigment concentration were expressed as cyanidin-3-glucoside equivalents, and calculated and expressed as follows:

$$\text{Anthocyanin pigment} = \left(A \times MW \times DF \times 10^3 / \varepsilon \times l\right)$$

Where A=(A520 nm−A 700 nm) pH 1.0 – (A520 nm–A700 nm) pH 4.5; MW (molecular weight)=449.2 g/mol for cyanidin-3-glucoside (cyd-3-glu); DF = dilution factor established in D; l=path length in cm; ε=26 900 M extinction coefficient, in L mol–1 cm–1, for cyd-3-glu; and 10^3=factor for conversion from g to mg.

Antioxidant capacity determined by ABTS

Antioxidant capacity was measured using a Hitachi spectrophotometer with improved ABTS methods (Re et al. 1999). The ABTS reagent was freshly prepared and was used within 2 days. The reagent made by mixing 7 mM ABTS and 2.45 mM potassium persulfate and incubated for 16 h at 37 °C. The ABTS cations diluted with ethanol to set O.D. at 0.7 (±0.02) at 734 nm (1:30, *v*/*v*). 3.9 ml (absorbance of 0.700±0.02) added to the 0.1 ml of test sample and mixed uniformly and absorbance was measured at 734 nm immediately after 6 min. The standard curve was linear between 0 and 20 μM Trolox. Results expressed in μM Trolox equivalents (TE)/g DW of fruit.

Antioxidant capacity determined by DPPH

The ability to scavenge DPPH free radicals determined based on the method of Sharma and Bhat (2009) and Sahreen et al. (2010) with slight modification in the mixture of test sample concentration and DPPH concentration. 0.1 mM of DPPH prepared in ethanol was diluted to set the absorbance below 1.2 (±0.02) at 517 nm and added to the 1 ml of test sample in test tube and it was vigorously shaken and kept for 15 min for incubation in dark room. The absorbance measured at 517 nm. The standard curve was linear between 0 and 30 μM Trolox. Results were expressed in μM Trolox equivalents (TE)/g DW.

Antioxidant capacity determined by ferric reducing antioxidant power (FRAP)

Ferric reducing antioxidant power (FRAP) assay was performed by Benzie and Strain (1996) method with slight

modifications in the mixture of test sample concentration and FRAP reagent concentration. Firstly, FRAP reagent was prepared by mixing the following solutions: 10 fold 300 mM acetate buffer+1 fold TPTZ (10 mM in 40 mMHCl)+1 fold $FeCl_3$ (20 mM) which was further diluted with methanol (1:3 *v*/*v*). This diluted 3 ml of FRAP reagent was added to the 0.1 ml of sample extract which was then vigorously shaken and the absorbance was measured at 593 nm after incubation of 30 min. The standard curve was linear between 0 and 500 μM Trolox. Results were expressed in μM Trolox equivalents (TE)/g DW.

Statistical analysis

All determinations obtained from triplicate measurements and expressed as mean±standard deviation. The Statistical Package for Social Sciences (SPSS) for Windows version (16.0) was used to analyze the data (SPSS Inc., Chicago, IL). Statistical significance was declared at $p<0.05$.

Results and discussion

Effect of tray and IR drying on the bioactive components of jambhul and wood apple pulp

Jambhul and wood apple pulp samples were subjected to two different drying i.e. TD and IR drying at two different temperatures 60 °C and 80 °C. From Table 1 it can be seen that total phenolic content, ascorbic acid and antioxidant capacity in terms of ABTS, DPPH, and FRAP in jambhul powder was high at (80 °C) as compared to 60 °C for both TD and IR dried samples. This was due to the temperature differences and inactivation of enzyme. During the dehydration process PPO activity remains high for longer periods when the drying temperature is around 55–60 °C, whereas shorter exposure period are needed to inactivate the enzyme at temperatures of 75–80 °C (Arslan et al. 1998). Madrau et al. (2009)) observed the activity of enzymes in apricots which was high at 55 °C and enzyme activity was inactivated at 75 °C. In jambhul, TFC and TMAC content decreased at 80 °C as compared to 60 °C. TD at 80 °C resulted into retention (Table 2) of TPC of 26.9 %, TFC of 10.06 %, TMAC 13.36 % and ascorbic acid content was 9.65 %. Further retention of antioxidant activities in terms of ABTS, DPPH and FRAP was observed 17.68 %, 89.68 %, and 24.50 % respectively. When jambhul were dried at 60 °C, TPC, TFC, TMAC and ascorbic content retention was 21.72 %, 13.97 %, 19.45 %, and 6.35 % respectively. Further the antioxidant activity in terms of ABTS, DPPH, FRAP was also found to be higher viz, 16.66 %, 86.08 %, 20.72 % respectively.

When jambhul pulp was subjected to IR drying at 80 °C; retention of 30.83 % TPC, 10.40 % TFC, 9.31 %, TMAC and

Table 1 Effect of tray and IR drying on the bioactive components of jambhul powder and wood apple powder[a]

Sample	Drying technique	Drying temperature (°C)	Drying time (Minute)	TPC (mg/g)	TF (mg/g)	TMAC (mg/g)	Ascorbic acid (mg/g)	ABTS (μM/g)	DPPH (μM/g)	FRAP (μM/g)
Jambhul	Whole pulp	–		87.37±0.53^{a}	266.85±0.93^{a}	27.4±0.09^{a}	22.04±0.03^{a}	141.20±0.47^{a}	396.09±0.77^{a}	196.06±0.54^{a}
	TD	80	392	23.50±0.45^{b}	27.35±1.30^{b}	3.60±0.16^{b}	2.15±0.12^{b}	25.17±1.31^{b}	340.94±4.42^{b}	43.30±1.13^{b}
		60	506	18.98±0.52^{c}	37.78±1.98^{c}	5.05±0.06^{c}	1.40±0.03^{c}	23.52±0.82^{c}	334.66±4.80^{b}	35.50±0.54^{c}
	IR	80	145	27.61±1.38^{d}	28.75±1.31^{b}	2.59±0.09^{d}	2.81±0.04^{d}	27.19±0.59^{b}	375.32±3.71^{c}	47.60±1.26^{d}
		60	165	19.90±0.07^{c}	33.13±1.08^{d}	4.29±0.14^{e}	2.67±0.07^{e}	25.56±1.15^{b}	352.04±0.63^{d}	36.87±0.68^{e}
Wood apple	Whole pulp	–		38.61±1.38^{a}	–	–	4.18±0.06^{a}	23.58±1.03^{a}	78.99±3.15^{a}	47.55±1.94^{a}
	TD	80	400	9.94±0.30^{b}	–	–	2.55±0.02^{b}	2.43±0.06^{b}	28.79±0.53^{b}	0.13±0.01^{b}
		60	511	7.58±0.09^{e}	–	–	1.40±0.05^{c}	1.80±0.07^{e}	25.14±0.64^{c}	0.06±0.01^{c}
	IR	80	150	7.34±0.34^{e}	–	–	2.25±0.01^{d}	2.27±0.07^{d}	25.16±0.04^{c}	1.25±0.06^{d}
		60	178	7.19±0.14^{e}	–	–	1.68±0.08^{e}	1.85±0.05^{b}	25.19±0.12^{c}	0.80±0.02^{e}

N. B: *TD* tray drying, *IR* infra red drying, *TPC* total phenolic content, *TF* total flavanoids, *TMAC* anthocyanin content, *DPPH* (2,2-diphenyl-1-picrylhydrazyl), *ABTS* (2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt), *FRAP* Ferric reducing antioxidant power

Mean value ± standard deviation of 3 replicates

Mean in the same column with different alphabetical letters is significantly different ($p<0.05$

Table 2 Retention of bioactive components in Jambhul and wood apple powder on % (w/w) basis

Sample	Drying technique	Drying temperature (°C)	TPC (%)	TF (%)	TMAC (%)	Ascorbic acid (%)	ABTS (%)	DPPH (%)	FRAP (%)
Jambhul	TD	80	26.9[a]	10.06[a]	13.36[a]	9.75[a]	17.68[a]	89.66[a]	24.50[a]
		60	21.72[b]	13.97[b]	19.45[b]	6.35[b]	16.66[b]	86.08[a]	20.72[b]
	IR	80	30.83[c]	10.4[a]	9.31[c]	12.75[c]	19.26[a]	98.71[b]	27.78[c]
		60	22.78[b]	12.67[c]	15.66[d]	12.11[d]	18.11[a]	94.76[c]	21.52[b]
Wood apple	TD	80	25.74[a]			61.00[a]	10.31[a]	36.45[a]	0.27[a]
		60	19.63[b]			33.49[b]	7.63[b]	31.83[b]	0.15[b]
	IR	80	19.01[b]			53.83[c]	9.63[c]	33.08[b]	2.69[c]
		60	18.62[b]			38.52[d]	7.85[a]	31.89[b]	1.51[b]

N. B: *TD* tray drying, *IR* infra red drying, *TPC* total phenolic content, *TF* total flavanoids, *TMAC* anthocyanin content, *DPPH* (2,2-diphenyl-1-picrylhydrazyl), *ABTS* (2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt), *FRAP* Ferric reducing antioxidant power

Mean in the same column with different alphabetical letters is significantly different ($p<0.05$)

12.75 % ascorbic acid was observed. Further antioxidant activities in terms of ABTS, DPPH and FRAP observed as 19.26 %, 98.71 %, and 27.78 % respectively. When drying performed at 60 °C it was observed that TPC, TFC, TMAC and ascorbic content was 22.78 %, 12.67 %, 15.66 % and 12.11 %, respectively. Further the antioxidant activity in terms of ABTS, DPPH and FRAP observed was 18.11 %, 94.76 % and 21.52 % respectively (Table 2). The more phenolic and ascorbic acid lost along with the antioxidant capacity found in the TD system as compared to IR drying system.

In case of wood apple 25.74 % TPC, 61 % ascorbic acid was retained in TD at 80 °C. Further the antioxidant activity observed in terms of ABTS, DPPH, FRAP was 10.31 %, 36.45 %, 0.27 % respectively. When the drying was performed at 60 °C TPC was 19.63 % whereas ascorbic acid content was 33.49 %. Further the antioxidant activity in terms of ABTS, DPPH, FRAP was 7.63 %, 31.83 %, and 0.15 % (Table 2). IR drying at 80 °C showed 19.01 % TPC and ascorbic acid was 53.83 %. Further antioxidant activities in terms of ABTS, DPPH and FRAP observed 9.63 %, 33.08 %, 2.69 %. When IR drying performed at 60 °C it was observed that 18.62 % TPC, 38.52 % ascorbic acid. Further antioxidant activities in terms of ABTS, DPPH and FRAP retained 7.85 %, 31.89 % and 1.51 % respectively (Table 2). Higher phenolic were retained along with antioxidant capacity in the TD as compared to IR drying.

Nindo and Mwithiga (2010) reported that during infrared drying, the O-H bonds in water absorb IR energy and start to rotate with the same frequency as the incident radiation. This transformation of IR radiation to rotational energy causes the evaporation of water. When IR radiation strikes a surface, part of it may be reflected, absorbed, or transmitted which depends on the nature of material. If the material is perfectly black body will absorbs all radiation. Jambhul showed more phenolics, flavonoids, anthocyanin, ascorbic acid and antioxidant in terms of ABTS, DPPH and FRAP compared to tray drying whereas wood apple showed highest phenolics, ascorbic acid and antioxidant in terms of ABTS, DPPH and FRAP in tray drying as compared to IR drying because jambhul is dark colored fruit and wood apples is light colored fruit. Hence as per the above explanation the maximum radiations were absorbed in case of jambhul thus took 120 min in drying even if it contained 86.19 % moisture. Wood apple contained 73.97 % of moisture hence it took 150 min for drying at 80 °C which is comparable with tray drying. From the above results it was concluded that IR drying was effective in case of jambhul and tray drying was effective in case of wood apple.

Changes in the bioactive nutrients after drying

The changes in phenolic compounds after tray drying and IR drying are represented in Table 3. Tray and IR drying of jambhul and wood apple at 80 °C resulted into higher phenolic content as compared to those dried at 60 °C. The difference in phenolic content could be due to lower drying temperature. Degradation of phenolic compounds in our experiment could be because of polyphenol oxidase (PPO) enzymatic activity. Many researchers had reported that during process of dehydration; PPO activity remains high for longer periods when the drying temperature is around 55–60 °C, whereas shorter exposure period are needed to inactivate the enzyme at temperatures of 75–80 °C (Raynal et al. 1989). The phenolic content of jambhul was higher at IR drying as compared to TD. Inchuen et al. (2010) found that microwave-dried samples of red curry powder had greater phenolic content than hot-air dried samples. Further the explanation for this was given by them as the heat generated from microwave creates a high vapor pressure and temperature inside plant tissue which breaks plant cell wall polymers which released phenolics or bound phenolics causes more phenolics to be extracted as compared to hot air drying. Our results matches with the findings of Madrau et al. (2009) who observed that the chlorogenic acid and neochlorogenic acid of 75 °C dried apricots were higher than those dried at 55 °C.

Table 3 Storage stability of dried powder of jambhul and wood apple[a]

Sample	Storage temperature (°C)	Storage period (days)	TPC (mg/g)	TF (mg/g)	Anthocyanins (mg/g)	Ascorbic acid (mg/g)	ABTS (μM/g)	DPPH (μM/g)
Jambhul	Control	0	27.61±1.38[a]	28.75±1.31[a]	2.59±0.09[a]	2.81±0.04[a]	27.19±0.59[a]	375.32±3.71[a]
	RT	30	26.45±0.81[a]	17.80±0.75[b]	1.83±0.05[b]	2.80±0.04[a]	23.35±1.09[b]	276.33±7.05[b]
		60	17.90±0.84[b]	11.38±0.45[c]	1.17±0.02[c]	2.66±0.07[b]	23.88±0.90[c]	273.72±4.10[b]
		90	24.21±0.59[c]	9.93±0.38[d]	1.02±0.03[d]	1.86±0.07[c]	16.68±0.91[d]	278.61±0.42[c]
	FT	30	24.57±0.31[d]	22.43±0.21[e]	1.98±0.07[e]	2.73±0.01[a]	25.65±0.19[a]	258.01±3.06[d]
		60	29.07±1.04[a]	23.05±0.43[f]	2.19±0.11[f]	2.65±0.04[a]	25.80±0.69[a]	269.07±2.94[e]
		90	25.51±1.49[d]	18.40±1.05[g]	2.20±0.12[g]	1.85±0.04[d]	22.40±0.92[e]	266.63±2.07[f]
Wood apple	Control	0	9.94±0.30[a]	–	–	2.55±0.02[a]	2.43±0.06[a]	28.79±0.53[a]
	RT	30	9.88±0.57[b]	–	–	2.10±0.09[b]	1.78±0.06[b]	27.66±0.27[a]
		60	6.55±0.20[c]	–	–	2.47±0.03[c]	1.32±0.02[c]	23.81±0.49[b]
		90	8.33±0.36[d]	–	–	1.46±0.05[d]	2.21±0.11[d]	27.02±0.14[c]
	FT	30	9.75±0.22[a]	–	–	2.29±0.12[e]	2.32±0.12[a]	23.56±0.31[d]
		60	6.65±0.30[e]	–	–	2.27±0.12[e]	1.38±0.07[e]	23.44±0.18[d]
		90	7.90±0.45[f]	–	–	1.21±0.04[f]	2.30±0.13[a]	24.02±0.44[e]

N. B: *RT* room temperature (30 °C), *FT* freeze temperature (4 °C), *TPC* total phenolic content, *TF* total flavanoids, *TMAC* total monomeric anthocyanin content, *DPPH* (2,2-diphenyl-1-picrylhydrazyl), *ABTS* (2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt)

Mean value ± standard deviation of three replicates

Mean in the same column with different alphabetical letters is significantly different ($p<0.05$)

From Table 1 it can be seen that the flavonoid content of jambhul at 60 °C was higher than 80 °C at both the TD and IR drying. The flavonoid content loss was more in TD samples as compared to IR dried samples. It showed a totally opposite behavior than phenolic acid. This was due to the fact that the flavonoid is temperature dependent (Madrau et al. 2009). The degradation of flavonoid was found higher at 80 °C as compared to 60 °C in TD as well as IR drying. Madrau et al. (2009) found that catechin, epicatechin, and rutin had same behavior which we found in our investigation. The degradation of flavonoids occurs during storage due to the enzymatic and non-enzymatic reaction. Glycosidase and polyphenol oxidase and peroxidase is responsible for degradation of flavonoids (Odriozola-Serrano et al. 2009; Terefe et al. 2009).

From the Table 1 it was observed that total monomeric anthocyanin content of jambhul dried at 60 °C was higher than those dried at 80 °C in tray drying as well as IR drying. Whereas, anthocyanin content of jambhul was retained by tray drying as compared to IR dried jambhul. Degradation of anthocyanin during drying and storage is due to the enzymatic and non-enzymatic reaction (Wrolstad 2004). Shahidi and Naczk (2004) found that enzymes i.e. glycosidase and polyphenol oxidase which is responsible for degradation of phenolic.

Retention of ascorbic acid in jambhul was higher in IR drying as compared to TD sample (Table 1). This could be due to long exposure of jambhul to air drying temperature. However this was observed very controversial in case of wood apple; more losses were found in IR drying which showed that the ascorbic acid is more sensitive to heat generated by radiation which is due to the wood apple takes more time to dehydration as compared to jambhul. In case of wood apple more retention of ascorbic acid in TD sample was observed as compared to IR dried sample. In our study, ascorbic acid in jambhul and wood apple at 80 °C was high as compared to those sample dried at 60 °C in tray dried as well as in IR drying. Madrau et al. (2009) found that the ascorbic acid in apricot at 75 °C air flow cabinet dried highest to those dried at 55 °C. Gregory (2008) reported that the loss in vitamin C content during drying involves oxidation and hydrolysis. The ascorbic acid is oxidized to dehydroascorbic acid, followed by hydrolysis to 2, 3-diketogulonic acid and further oxidation and polymerization to form a wide range of other nutritionally inactive products.

From Table 1 it can be seen that the antioxidant capacity of jambhul and wood apple by ABTS, DPPH and FRAP was high at 80 °C as compared to the one which dried at 60 °C by both Tray and IR drying. From the Table 1 it is clear that high antioxidant capacity in the sample at high temperature is due to the phenolic content and ascorbic acid which was high at 80 °C.

Influence of storage on IR dried jambhul powder

The IR dried jambhul powder at 80 °C showed more retention of polyphenol, ascorbic acid and more antioxidant capacity as compared to tray dried powder kept for two different storage conditions. From Table 3 it can be seen that total phenolic

content in jambhul significantly decreased ($p<0.05$) at room temperature and maintained at refrigeration temperatures; but phenolic content in jambhul powder kept at room temperature for 30 days and sample stored at refrigeration temperatures for 60 days showed no significant difference by ANOVA (LSD). Total phenolic content after 30 days at room temperature decreased and after 60 days it was significantly increased. Hence it can be said that phenolic content in the jambhul powder was more retained at refrigeration temperature upto 60 day and afterwards degradation was observed. This is because the stability of polyphenol in food and beverages is influenced by many external factors such as exposure to light, air, or different storage temperatures (Van der et al. 2005). Syamaladevi et al. (2012) and Wu et al. (2010) observed an increase in total phenolics in canned blueberries and blackberries during storage. This increase in the concentration of phenolic content is mainly due to the improved extraction efficiency due to cell destruction during storage. Our results matches with the findings of Siah et al. (2011) who observed the increase in total phenolic content in *Centellaasiatica* drinks packed in different packaging kept at ambient temperature. Klimczak et al. (2007) first observed a decrease in the total phenol content after 4 months storage, followed by an increase at 6 months storage. It is possible that during storage, some compounds are formed that reacted with the Folin-Ciocalteau reagent and enhanced the phenolic content. Rao et al. (2011) observed the increase in total phenolic content in White aril powder and Pink aril powder during storage period of 6 months at room temperature which was packed in Polyethylene and Metallized polyester polyethylene laminated pouches. This could be due to increase in moisture content, which might have released the bound phenols from the cell wall during storage.

From Table 3 it can be seen that the total flavonoids content in jambhul significantly decreased during storage but it was mostly preserved at refrigeration temperature. The degradation of total flavonoids content at room temperature storage condition was faster as compared to refrigeration temperature with respect to initial value of flavonoid. Total flavonoids content in the jambhul at refrigeration temperature stored for 90 days were 18.40 mg/g which was twice than room temperature storage i.e. 9.93 mg/g. At room temperature jambhul powder showed significant decrease in the flavonoid content and at refrigeration temperature after 30 days it showed slight increase and further after 60 days it showed decrease in the flavonoid content. Zafrilla et al. (2003) reported the decreased flavonoid content due to the oxidative degradation, precipitation, or hydrolysis of the flavonols.

Total monomeric anthocyanin content also significantly decreased during storage; but showed more retention at refrigeration temperature as compared with the room temperature. Total monomeric anthocyanin content at refrigeration temperature was 2.20 mg/g at 90 days of refrigeration temperature which was twice than room temperature. Somers and Pocock (1990) found decrease in the total monomeric anthocyanin content faster when stored at higher temperature. Many researchers also reported that the presence of oxygen would also increase anthocyanin degradation (Ribéreau-Gayon et al. 2000). The decrease in the total monomeric anthocyanin contents of *Pinotage* and Cabernet Sauvignon wines due to oxidative degradation and condensation reactions with other phenolic compounds such as flavanols and hydroxycinnamates was observed by Timberlake and Bridle (1976); Somers and Pocock (1990); Ribéreau-Gayon et al. (2000). A similar trend was also noticed during the storage of White aril powder and Pink aril powder by Rao et al. (2011).

Ascorbic acid content significantly decreased in the sample of jambhul stored for 90 days at both storage conditions (Table 3). From the Table 3 it can be seen that ascorbic acid in jambhul powder kept for 30 days at room temperature and for 30, 60 days at refrigeration temperature statistically didn't showed any significant difference ($p<0.05$) as compared with control sample. Hence it can be concluded that ascorbic acid was stable upto 60 days storage at refrigeration temperature where as it decreased after 30 days at room temperatures. The degradation of ascorbic acid follows both aerobic and anaerobic pathways. The oxidation of ascorbic acid occurs mainly during the processing of citrus juices, whereas anaerobic degradation, which is particularly observed in thermally preserved citrus juices, mainly appears during storage (Burdulu et al. 2007). As other authors suggest, the changes observed in the ascorbic acid concentration of the samples stored under refrigeration, suggest the continuation of the oxidative degradation reactions of ascorbic acid to other oxidized forms such as dehydroascorbic acid, which also presents biological activity as vitamin C (Rusell 2004).

Antioxidant capacity by ABTS found significantly ($p<0.05$) decreased from 0 to 90 days at room temperature with 16.68 μM/g at 90 days. Whereas the antioxidant capacity at 30 and 60 days at refrigeration temperature did not show significant differences when compared to the control at 90 days (at a refrigeration temperature) 22.40 μmol/g (Table 3). Antioxidant capacity shown by ABTS at room temperature significantly decreased which may be due to the decrease in the total flavonoid content, total monomeric anthocyanin content and ascorbic acid content. Whereas at refrigeration temperature total phenolic content and total flavonoid content are responsible for the decrease in the antioxidant capacity by ABTS. Whereas Antioxidant capacity by DPPH was significantly ($p<0.05$) decreased by both room temperature and refrigeration temperature. But it is mostly preserved at room temperature.

Influence of storage on tray dried wood apple powder

The tray dried (TD) wood apple powder stored at 80 °C showed more retention of polyphenol content and antioxidant

capacity as compared to IR dried powder kept for 2 different storage conditions. From the Table 3 it can be seen that total phenolic content in wood apple at room temperature significantly ($p<0.05$) decreased. Total phenolic content of sample store for 30 days at refrigeration temperature did not show any significant difference as compared to control and after that it significantly decreased. Hence it can be said that phenolic content in wood apple was more stable at room temperature than that of sample store at refrigeration temperature.

Ascorbic acid content of samples kept at refrigeration temperature for 30 and 60 days were 2.29, 2.27 respectively which didn't showed a significant difference with respect to control sample. The sample which was kept for 90 day at room temperature showed significantly ($p<0.05$) higher phenolic content (1.46) than the sample kept at refrigeration temperature (1.21). Hence it can be concluded that ascorbic acid content in wood apple was more stable at room temperature as compared to refrigeration temperature.

Antioxidant capacity by ABTS was significantly ($p<0.05$) decreased in the sample stored from 0 to 90 days at room temperature that was 2.21 μM/g at 90 days. Whereas antioxidant capacity at 30, 90 day at refrigeration temperature did not show any significant difference as compared to control and at refrigeration temperature 2.30 μM/g at 90 days (Table 3.). Hence, it can be concluded that antioxidant capacity which was estimated by ABTS was significantly higher at refrigeration temperature than room temperature sample.

Antioxidant capacity by DPPH was significantly ($p<0.05$) decreased at both room temperature and refrigeration temperature. Antioxidant capacity shown by DPPH was mainly contributed by total phenolic content at room temperature; whereas at refrigeration temperature it mainly contributed by total phenolic content and flavonoid content.

Correlation of TPC, TFC, TMAC and ascorbic acid to antioxidant capacity

In case of jambhul TFC, TMAC and ascorbic acid was strongly correlated with ABTS i.e. 0.82, 0.75 and 0.79 respectively while a very poor correlation with DPPH was observed (Table 4). In case of wood apple TPC was correlated with antioxidant activity in the, ABTS and DPPH. Ascorbic acid content was negatively correlated with ABTS and a very poor correlation was observed with DPPH. These results highlight the contribution of phenolics to in vitro antioxidant activity and further studies on comparison and/or multiplicity of antioxidant assays to rank antioxidant activity is needed.

Table 4 Correlation of TPC, TFC, TMAC and ascorbic acid to antioxidant capacity

Parameters	Jambhul		Wood apple	
	ABTS	DPPH	ABTS	DPPH
TPC	0.27	0.28	0.71	0.68
TFC	0.82	0.55	–	–
TMAC	0.75	0.47	–	–
Ascorbic acid content	0.79	0.29	−0.36	0.07

Conclusions

From the above study, it is clear that the suitable drying method used for the preservation of fruits is depending on the type of fruit and its bioactive nutrients. For dehydration of jambhul infrared drying and for wood apple tray drying was most applicable to preserve bioactive nutrients. Higher temperature was more preferable in both drying methods to retain more phenolics. Hence to preserve bioactive nutrients in fruit powders it is necessary to store them under proper storage temperature conditions. Jambhul powder was more preserved at refrigeration temperature whereas wood apple was preserved at room temperature to maintain bioactive nutrients.

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