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ORIGINAL ARTICLE

Drying kinetics and physico-chemical characteristics of Osmo- dehydrated Mango, Guava and *Aonla* under different drying conditions

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Abstract Mango (*Mangiferra indica* L), guava (*Psiduim guajava* L.) slices and *aonla* (*Emblica officinalis* L) segments were osmo-dried under four different dying conditions viz., cabinet drier (CD), vacuum oven drier (VOD), low temperature drier (LTD) and solar drier (SD) to evaluate the best drying condition for the fruits. It was found that vacuum oven drying was superior to other mode of drying as it holds maximum nutrients like acidity, ascorbic acid, sugar and water removal and moisture ratio of products. It was found through regression analysis that drying ratio and rehydration ratio was also superior in vacuum drying followed by cabinet drying. In addition, descriptive analysis on sensory score was also found best with vacuum drying while the Non-enzymatic browning (NEB), which is undesirable character on dried product, was more with solar drier.

Keywords Mango · Guava · *Aonla* · Drier · Osmotic-dehydration · Drying ratio · Rehydration ratio · Sensory quality

Introduction

India is endowed with a climate that can produce wide variety of fruits. Horticultural crops cover just 8.5% of the gross cropped area but contribute to almost 30% of the agricultural GDP and 52% of the export earnings from agriculture (NHB 2011). The post harvest technology of fruit and vegetable processing has been one of the most neglected fronts in agricultural development and policy till recently. India processes little above 2% of fruit and vegetables production, which needs to increase the level of processing in order to avoid market glut, ensure income security to farmers and bring nutritional security. Traditional techniques such as chilling, freezing, convective drying, pasteurization and sterilization are the major processes employed for food preservation (Nicoli et al. 1999). Among the techniques, drying can be best suited to the developing countries like India where it's very uncommon to establish most sophisticated techniques. Among drying and dehydration, osmotic dehydration gained attention recently due to its potential application in the food processing industry. This allows development of new product; make them storable without refrigeration with minimum energy input (Wang and Xi 2005).

Food processing methods, such as freezing and dehydration, have a significant impact on the stability of various health promoting antioxidant components in processed products. Dehydration is by far the best and widely used preservative method to extend the shelf life of highly perishable produces. In recent years, there has been a considerable improvement in drying technology. Various combination technologies including osmotic dehydration and conventional air drying are being extensively evaluated to reduce drying time and energy consumption and improve the final product quality (Prabhanjan et al. 1995; Funebo and Ohlsson 1998; Chua and Chou 2005). Mango, guava and *aonla* are most popular fruits among Indians. The fruits are highly nutritive and rich source of β- carotene, ascorbic acid, pectins, tannins

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and minerals like Ca, Fe and P. But unfortunately these are bound by seasonality and are highly perishable. Thus, osmotic dehydration is the best technique to extend their availability even in the off-season (Sagar and Suresh Kumar 2010). The objective of this study is to investigate the thin layer drying kinetics of various fruits and identifying the best drying condition for maximum retention of physico-chemical characteristics of final dried produces.

Materials and methods

Raw material & preparation The fruits of mango (cv. *Amrapali*), guava (cv. *Allahabad Safeda*) and *aonla* (cv. *Chakkaiya*) were obtained from the Division of Fruit & Horticulture Technology, Indian Agricultural Research Institute, New Delhi. Water sinker fruits of mango and guava were selected and washed thoroughly with water and peeled manually with stainless steel knife. About six slices from one fruit lengthwise were prepared. While, *aonla* fruits were blanched in alkali (2% NaOH) for 5–8 min, the lye treated fruits were washed thrice in tap water and soaked in citric acid (0.5%) for 20 min to neutralize the alkali and to remove the astringency. The blanched fruits were dipped in cold water for 2 min for easy separation of segments and removal of seeds.

Osmotic treatment To facilitate the water removal and to minimize the direct drying effects on products osmotic dehydration was used as pre-treatment. Fruit slices and segments were suspended in sugar solution containing 0.05% potassium meta bisulphite (KMS) and 0.1% citric acid in the stainless vessel. The temperature (60 °C) and sugar concentration (60^0B) of the solution was maintained at pre-set value. The ratio of the fruits and osmotic solution was maintained as 1:4 in order to ensure proper soaking of samples. Samples were withdrawn from osmotic solution after 6 h of immersion time and drained quickly and wiped gently with tissue paper to remove the sugar solution from outer surface of the segments.

Dehydration The pretreated samples were spread on perforated aluminum trays with tray load of 0.40 g/cm^2 and were kept in the vacuum drier (Model 358, temperature of 40±2 °C), a cross flow cabinet drier, (Kilburn make, Model – 0248, temperature of 58±2 °C and the air flow rate was 0.12 to 0.16 m/sec), a low temperature drier designed and fabricated by M/s. Cool connection, New Delhi (40±2 °C temperature and 25–40% RH) and Solar drier (40–50 °C and 60–80% RH). The samples were turned over at every 1 h interval for uniform drying to a final moisture content of 9–11%.

Drying parameters

Moisture ratio

The moisture ratio or dimensionless mass loss of samples during the drying process was calculated from the Lewis equation (Jayas et al. 1991).

$$\text{Dimensionless mass loss} = \frac{M_t - M_e}{M_i - M_e}$$

where M_t is the sample moisture content at time t (% wb, wet basis), M_e is the equilibrium moisture content (% wb) and M_i initial moisture content (% wb)

Drying rate

The drying rate of sample was determined using the equation

$$\text{Drying rate} = \frac{W_{t+dt} - W_t}{dt}$$

where W_t is the sample weight at time t (% wb, wet basis), dt is the time interval between two consecutive measurements.

Drying ratio

Drying ratio was calculated as net dry weight obtained from fresh weight of the material (Ranganna 2002).

$$\text{Drying ratio} = \frac{\text{Fresh weight of the material}}{\text{Net dry weight obtained}}$$

Rehydration ratio

Ten gram of the osmo-dehydrated sample was taken into a beaker and 50 ml 30^0B warm sugar syrup (50°C) was added into it. After 1 h, the drained weight of the rehydrated material was taken. Rehydration ratio was calculated as

$$\text{Rehydration ratio} = \frac{\text{Drained weight of rehydrated sample (g)}}{\text{Weight of dehydrated sample (g)}}$$

Physico- chemical analysis The moisture content was determined by drying a known weight of the sample in a hot air oven at 60±5 °C to a constant weight and expressed as per cent. Acidity, β-carotene, ascorbic acid, total sugar, reducing sugar, drying ratio, rehydration ratio, tannin and non enzymatic browning (NEB) were determined according to the procedure given by Ranganna (2002).

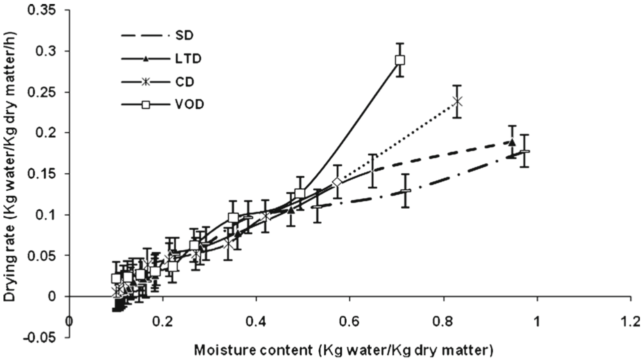
Sensory analysis Descriptive sensory evaluation was carried out to determine the effect of osmo-drying on the sensory quality attributes of dehydrated mango, guava fruit slices and *aonla* segments. A 6-member sensory panel was used to evaluate the various descriptors for colour, texture and taste of dried fruits. Attributes were scored for degree of liking on 9-point hedonic scale of 1 to 9 (1=dislike extremely, 9=like extremely), score of 5.5 and above were considered acceptable.

Statistical analysis The data obtained in the present study was subjected to factorial CRD statistical analysis with three replications (Gomez and Gomez 1984). The critical difference (C.D) value at 5% level of probability was compared for making the comparison among different treatments.

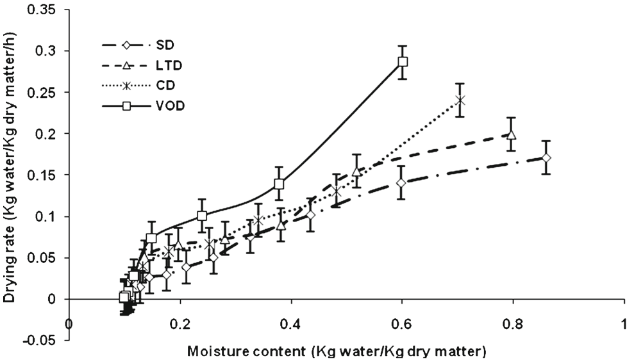
Results and discussion

The experimental drying rate (kg water/kg dry matter/h) of mango, guava and *aonla* are represented as a function of moisture (kg water/kg dry matter) (Fig. 1). The drying rates were higher in the beginning of the process, when the air stream could probably easily remove the moisture from the surface of the fruits. Constant rate drying was nonexistent and all the drying took place in the falling rate period. The drying rate decreased from 0.288 kg water/kg dry matter/h to 0.021 kg water/kg dry matter/h in mango under vacuum drier and it was reduced from 0.177 kg water/kg dry matter/h to 0.002 kg water/kg dry matter/h under solar drier. In guava, the drying rate was reduced from 0.24 to 0.004 kg water/kg dry matter/h under cabinet drier. While, *aonla* recorded reduction from 0.283 kg water/kg dry matter/h to 0.004 kg water/kg dry matter/h under the same condition. Faster drying was observed in *aonla* followed by guava and mango. The variation among different fruits in their drying behaviour was due to their intrinsic cellular structure and tissue rigidity.

a) mango slices



b) guava slices



c) *aonla* segments

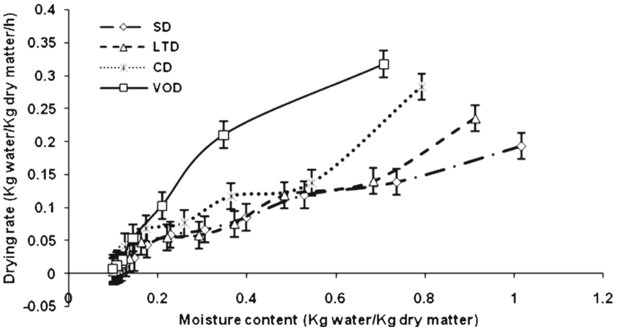


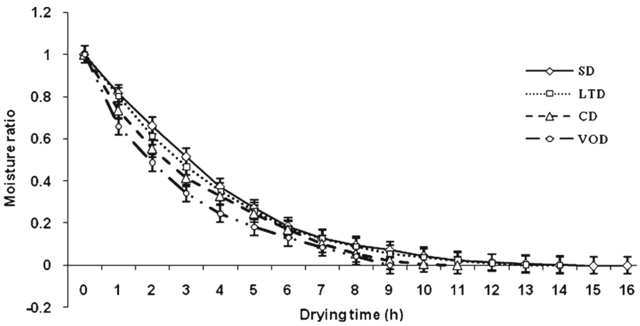
Fig. 1 Drying rate of osmo-dehydrated fruits $n=3$. **a** mango slices, **b** guava slices, **c** *aonla* segments

The presence of the clear falling rate period confirmed that the moisture removed was driven internally by energy absorption and the internal mass resistance which controls the drying process. Under such circumstances, it was assumed that water transportation occurs via diffusion (Sanjuan et al. 2003). Thin structure and large surface area of prepared fruit slices facilitate rapid loss of moisture and thus a falling rate period. Similar results have been obtained by several other workers (Sharma and Prasad 2002; Wang and Xi 2005; Akpinar and Bicer 2005; Chua and Chou 2005). The drying rate was significantly affected by the size of the food material to be dried. This may be due to increase in external resistance caused by the pericarp or the epidermal tissue of the raw material as per size of the food material to be dried and as a consequence constant rate drying period is detected. During the last stages of drying, the drying rate was lower, presumably due to collapse or shrinkage of the tissue structure resulting in low transport rate of water and prolonged drying time (Kostaropoulos and Saravacos 1995). It was concluded that vacuum drying was faster in water removal than other drier. This was due to the fact that the vacuum created by the vacuum drying made rapid and uniform removal of water from the osmosed slices. Cabinet drier followed the vacuum drying on drying rate of fruit slices.

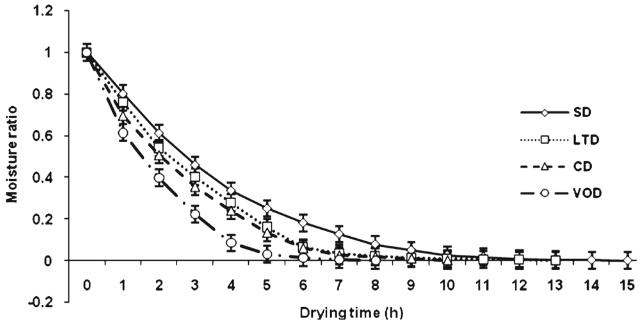
Moisture ratio studies on the fruits with different driers revealed that faster removal of moisture could be achieved through vacuum oven drier followed by cabinet drier irrespective of fruits (Fig. 2). Among the fruits, mango took more time to remove required amount of moisture followed by guava and *aonla*. It may be due to the structural complexity of mango slices compared to other fruits.

In general, superior drying ratio was obtained in the fruits, dried in vacuum drying followed by cabinet drier (Table 1). Drying ratio was too little with low temperature for all the three kinds of fruits used. Guava and *aonla* showed similar tendency in drying ratio with the respect to driers. The better result of vacuum drying is due to faster removal of water and less heat used to remove the moisture while the good results of cabinet drier was due to high temperature, low RH and constant air flow (Jayaraman et al. 1999; Sharma and Prasad 2002). However, regression coefficient of osmo-dried fruits showing that mango responded well according to the change in drier as the drying relation with different driers were highly significant followed by guava while change in mode of drying had very little effect on drying ratio of *aonla* segments. This is due to higher surface area, which enhances the drying efficiency of driers and soft tissue nature, which is useful to remove water from inner tissues to outer wall, of mango and guava than *aonla*. Similar results have been obtained by several other workers (Akpinar and Bicer 2005; Sanjuan et al. 2003; Wang and Xi 2005). The rehydration characteristics of dried products are widely used as the quality index. It is evident from Table 1 that rehydration ratio elevated in vacuum dehydrated materials and it was relatively poor in low temperature drier. Nonetheless, the differences in rehydration ratio among driers were statistically not significant. In practice, most changes caused by pre-drying and drying treatments are irreversible, and rehydration cannot be considered as simply as a process reversible to dehydration (Lewicki 1998; Feng and Tang 1998). The poor regression values showed that driers almost act similarly on the account of rehydration of slices and segments. However, the vacuum dried material has the better rehydration capacity and low temperature drier which showed poor result in drying ratio recorded poor in rehydration also. Higher rehydration displayed by vacuum oven drying which might be due to the faster drying process that cause less cellular and structural changes in the final product while, rehydration ratio was comparatively poor in low temperature drier and solar drier. This may be due to longer time for drying, poor texture of the product, poor RH maintenance and fluctuation in air flow. Loss of texture was the main reason for the poor rehydration ratio of low temperature and solar drier. Lower ratio of rehydration in solar dried samples might be due to degradation of pectic polysaccharides during drying procedure (Khedkar and Roy 1988). The desorption isotherm of fruits (data not shown) revealed that the EMC increased with an increase in ERH, while it decreased with the increase in temperature at the same aw (ERH). The result

a) Mango slices



b) Guava slices



c) *aonla* segments

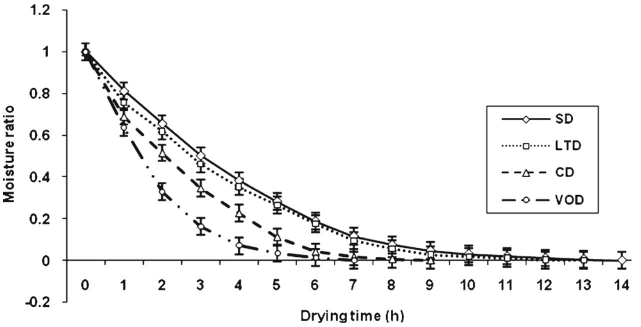


Fig. 2 Moisture ratio of osmo-dehydrated fruits $n=3$. **a** Mango slices, **b** Guava slices, **c** *aonla* segments

Table 1 Effect of driers on drying and rehydration ratio of fruits*

Driers	Drying ratio			Rehydration ratio		
	Mango	Guava	*Aonla*	Mango	Guava	*Aonla*
SD	$2.7:1^{a}$	$3.1:1^{b}$	$3.6:1^{b}$	1:2.7	1:2.8	1:2.8
CD	$2.6:1^{a}$	$2.9:1^{a}$	$3.2:1^{a}$	1:2.8	1:2.8	1:2.9
VD	$3.1:1^{b}$	$3.5:1^{c}$	$3.8:1^{bc}$	1:2.6	1:2.7	1:2.7
LTD	$3.5:1^{c}$	$3.7:1^{cd}$	$4.1:1^{d}$	1:2.6	1:2.7	1:2.8
SEm±	0.03	0.03	0.02	0.32	0.36	0.35
p (0.05)	0.07	0.06	0.05	NS	NS	NS

SD solar drier, *CD* cabinet drier, *VD* vacuum drier, *LTD* low temperature drier

* In each column, means with same superscripts do not vary significantly ($p=0.05$) by DMRT ($n=3$)

Table 2 Effect of driers on chemical constituents of osmo dried fruits (Dry weight basis)*

Crop	Drier	Moisture%	Acidity%	Ascorbic acid mg/100 g	Reducing sugars%	Total sugars%	SO_2 ppm	NEB O.D at 420 nm
Mango	SD	9.2	0.94	125.4^{a}	30.5^{a}	68.4^{a}	220.2^{a}	0.164^{c}
	CD	9.1	0.91	148.9^{b}	33.9^{c}	71.8^{c}	238.7^{c}	0.156^{a}
	VD	9.0	0.89	160.7^{c}	34.9^{d}	73.4^{d}	245.4^{d}	0.152^{a}
	LTD	9.5	0.93	143.8^{b}	32.9^{b}	69.8^{b}	229.1^{b}	0.159^{ab}
	SEm ±	0.42	0.07	8.94	1.36	2.48	3.26	0.003
	P (0.05)	NS	NS	20.61	2.07	4.56	5.14	0.007
Guava	SD	9.34	0.69	887.9^{a}	25.4^{a}	55.7^{a}	211.7^{a}	0.065^{b}
	CD	9.08	0.61	980.1^{b}	27.9^{c}	59.5^{c}	228.4^{c}	0.061^{a}
	VD	9.02	0.59	1001.7^{c}	28.9^{d}	61.3^{d}	233.6^{d}	0.059^{a}
	LTD	9.54	0.63	979.7^{b}	26.3^{b}	57.0^{b}	219.3^{b}	0.061^{a}
	SEm ±	0.48	0.04	23.97	2.03	1.92	2.58	0.003
	P (0.05)	NS	NS	43.09	2.40	2.03	5.43	NS
Aonla	SD	9.52	7.98^{c}	3074.6^{a}	12.0^{a}	44.3^{a}	223.9^{a}	0.254^{d}
	CD	9.19	7.69^{a}	3391.8^{bc}	12.9^{bc}	47.2^{c}	241.7^{c}	0.231^{ab}
	VD	9.09	7.64^{a}	3465.6^{d}	13.1^{c}	47.8^{c}	258.3^{d}	0.226^{a}
	LTD	9.67	7.75^{b}	3308.1^{c}	12.2^{ab}	45.7^{b}	237.5^{b}	0.245^{c}
	SEm ±	0.69	0.21	104.32	0.39	0.89	2.13	0.01
	p (0.05)	NS	0.36	154.78	0.62	1.75	4.27	0.023

SD solar drier, *CD* cabinet drier, *VD* vacuum drier, *LTD* low temperature drier

* In each column, means with same superscripts do not vary significantly (p=0.05) by DMRT (n=3)

may be explained that at higher temperatures the kinetic energy of the water molecules was high and water absorption at a given ERH was low. Similar results have been reported in the literature for the sorption isotherm (Basunia and Abe 2001; Mohamed et al. 2004; Ghodake et al. 2007).

Vacuum dried fruit slices and segments maintain a superior quality than the slices and segments dried with other driers (Table 2). Among the driers, solar drier was a mediocre in safeguarding of chemical constituents. The differences in moisture and acidity with respective to driers was statistically not significant. Air temperature had a significant influence on moisture content during solar drying (Jayaraman et al. 1999; Pande et al. 2000; Sagar and Suresh Kumar 2010). Higher values for ascorbic acid and reducing sugars were obtained in vacuum drier compared to other drying condition. Osmo-vac dried fruits showed higher total sugars than fresh fruits. This may be due to the removal of water which in turn increase total sugar content in a concentrated form than in a dilute form and also due to the effect of sugar syrup, used for osmosis (Mehta and Tomar 1980; Gowda et al. 1995 and Suresh kumar et al. 2008). β-

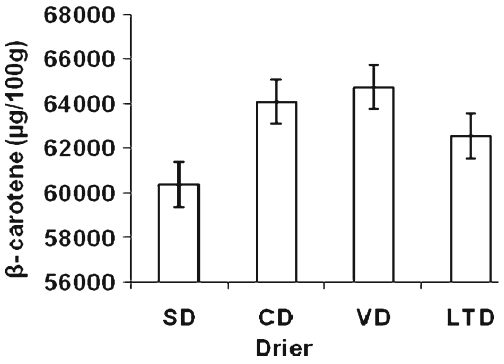


Fig. 3 Effect of driers on β-carotene (µg100 g) content of osmo-dried mango slices n=3

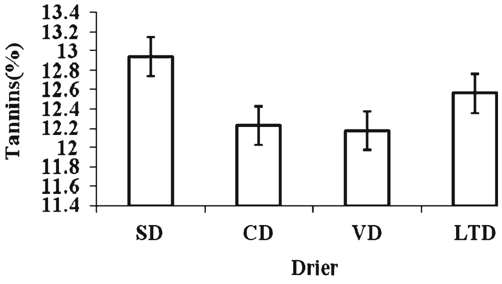
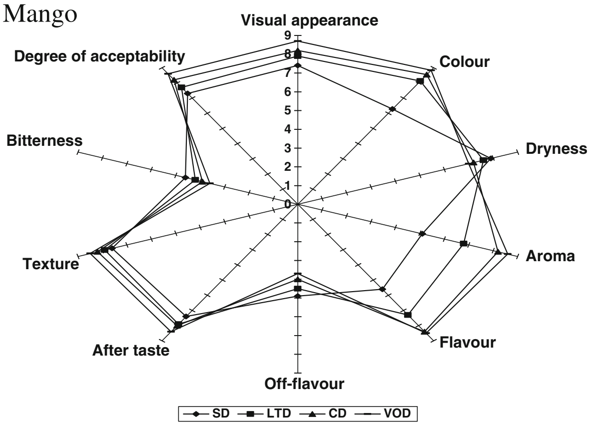
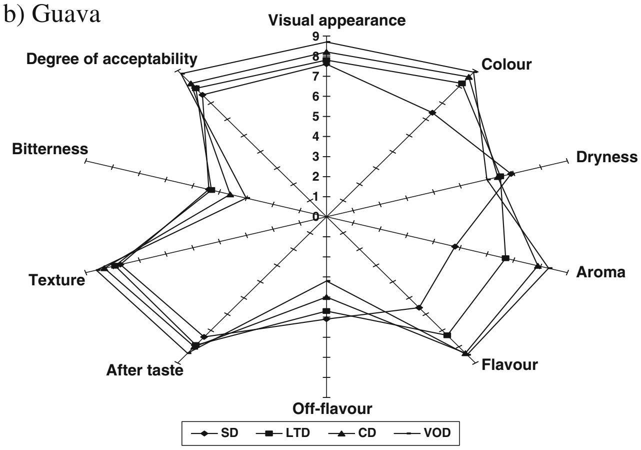


Fig. 4 Effect of driers on Tannin (%) content of osmo-dried *aonla* segments. n=3

a) Mango



b) Guava



c) *Aonla*

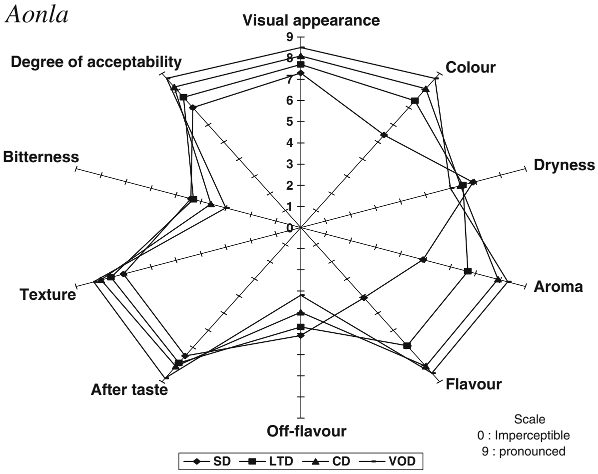


Fig. 5 Descriptive analysis profile of osmo-dehydrated fruits n=3, **a** Mango, **b** Guava, **c** *Aonla*

carotene retention was also higher when the mango slices were dried under vacuum drier (Fig. 3). Similar results were also reported by Jayaraman et al. (1998) that drying by direct exposure to sun resulted in significant loss of pigments due to longer drying time, leading to greater oxidation of carotene. Besides, tannin content in *aonla* segments was also lower with the vacuum dried segments (Fig. 4). This may be due to the faster drying which helped in prevention of forming tannins like material while drying. Similar findings were observed by Jayaraman et al. (1999) in mango and Kumar and Singh (2003) in *aonla*. Longer time and poor drying causes lower retention of SO_2 in solar drier (Table 2). The best retention under vacuum drying may be due to faster drying of materials which cause less degradation of SO_2 by heat than other driers. Similar results were observed by Mehta and Tomar (1980) in pineapple slices, Kumar and Singh (2003) in *aonla* segments and Jayaraman et al. (1999) in solar dried mango and jack slices. However, NEB was higher when the slices were dried with solar drier than vacuum drier. This might be due to prevention of the reaction between amino acid and sugars in vacuum dried material followed by cabinet dried product as these two components are mainly involved in Maillard reaction (Sagar and Suresh Kumar 2010).

Acceptability of dehydrated products by the consumer is highly dependent on its sensory attributes. In addition to visual appearance, colour, flavour and textural attributes are critical in determining their degree of acceptance. It was observed that vacuum dried fruits had highest scores for visual appearance and colour at the end of drying (Fig. 5). The best colour of the dried product might be due to KMS treatment and faster drying of material under vacuum drying followed by cabinet drier (Ahrne et al. 2003; Akpinar and Bicer 2005). Texture of dried samples as revealed by scores of dryness was better than that of cabinet drier. Rapid and controlled loss of moisture, may maintain the cell structure due to uniform heat transfer in vacuum drying which could be a probable factor for contributing high texture scores (Jayaraman et al. 1999). Flavour, aroma and over all acceptability of dried product were also scored higher in vacuum drier. Bitterness was least in vacuum dried samples particularly in case of dehydrated *aonla* segments in comparison to other driers while off flavour development was high in solar dried materials. Bitterness is mainly attributed to presence of phenolic compounds which might have got oxidized during drying and storage (Suresh kumar and Sagar 2009). Generation of off flavour is generally related to the degradation of quality components like sugar, acid and carotenes (Sharma and Prasad 2002).

Conclusion

Faster drying was observed in *aonla* followed by guava and mango. Moisture ratio studies on the fruits with different driers revealed that faster removal of moisture could be achieved through vacuum oven drier followed by cabinet drier irrespective of fruits. Higher values for ascorbic acid and reducing sugars were obtained in vacuum drier. Osmovac dried fruits showed higher total sugars than fresh fruits. Vacuum oven dried materials showed the highest retention of nutrients and better rehydration ratio followed by cabinet drier.

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