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ORIGINAL ARTICLE

Retention of nutrients in green leafy vegetables on dehydration

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Abstract The objective of the study was to investigate the influence of dehydration on nutrient composition of *Amaranthus gangeticus, Chenopodium album, Centella asiatica, Amaranthus tricolor* and *Trigonella foenum graecum*. The green leafy vegetables (GLV) were steam blanched for 5 min after pretreatment and dried in an oven at 60 °C for 10–12 h. The fresh and dehydrated samples were analyzed for selected proximate constituents, vitamins, minerals, antinutrients and dialyzable minerals. Dehydration seems to have little effect on the proximate, mineral and antinutrient content of the GLV. Among the vitamins, retention of ascorbic acid was 1–14%, thiamine 22–71%, total carotene 49–73% and β—carotene 20–69% respectively, of their initial content. Dialyzable iron and calcium in the fresh vegetables ranged between 0.21–3.5 mg and 15.36–81.33 mg/100 g respectively, which reduced to 0.05–0.53 mg and 6.94–58.15 mg/100 g on dehydration. Dehydration seems to be the simplest convenient technology for preserving these sources of micronutrients, especially when they are abundantly available. Irrespective of the losses of vitamins that take place during dehydration, dehydrated GLV are a concentrated natural source of micronutrients and they can be used in product formulations. Value addition of traditional products with dehydrated GLV can be advocated as a feasible food-based approach to combat micronutrient malnutrition.

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Introduction

Green leafy vegetables (GLV) are multi-cultural components used ubiquitously in Indian cuisine. They are rich sources of calcium, iron, β-carotene, vitamin C, dietary fiber and many trace minerals. A large number of leaves from different sources such as perennial trees, aquatic plants and annuals are consumed and especially in rural areas. These vegetables are an economic source to ensure the micronutrient intake. GLV are seasonal and also highly perishable due to their high water content. There are heavy losses due to non-availability of sufficient storage, transport and proper processing facilities at the production point (Pande et al. 2000). There is a need to preserve the nature's storehouse of nutrients through convenient processing techniques. Dehydration seems to be the simplest technology for preserving GLV, especially when they are abundantly available.

Vegetable dehydration is generally done either for preserving the perishable raw commodity against deterioration or to reduce the cost of packaging, handling, storing and transporting. The most serious constraint for shelf-life enhancement is the activity of micro-organisms. Water in food is reduced to a very low level during dehydration, thus achieving better microbiological preservation and retarding many undesirable reactions during storage (Ibarz and Barbosa-Canovas 2000), owing to the reduction in water activity. In the present study dehydration technology is utilized with a different perspective. GLV are rich sources of micronutrients as already discussed earlier and

therefore dehydrating them can provide us a concentrated source of micronutrients. Utilizing these micronutrient-rich GLV in a dehydrated form can be a food-based approach to combat the micronutrient deficiencies, which is prevalent in our populations, especially during seasons of their non-availability.

In recent years, exhaustive efforts have been made for an improvement in the nutrient retention of dried products by altering processing methods and/or pretreatment. Blanching is a prerequisite for preservation of green leafy vegetables. It is necessary to prevent the formation of off-flavors, odors and colors. However, it may cause partial destruction of some nutrients like ascorbic acid. Peroxidase activity is widely used as an index of blanching because peroxidase is the most heat-stable enzyme found in vegetables (Rahman and Perera 1999). Optimum conditions of blanching, time and temperature, are necessary to achieve the desired quality of dried products (Kadam et al. 2008). The protective effect of sodium metabisulphite has been demonstrated by Mulay et al. (1994) and Badifu et al. (1995), which is supported by Singh et al. (1997). The latter reported that the use of potassium metabisulphite (KMS) for pretreatment of the green leafy vegetables can reduce the extent of loss of ascorbic acid. Blanching also results in some degree of chlorophyll degradation with the subsequent formation of pheophytin, which can be prevented by the addition of an alkalizing agent like magnesium carbonate during blanching (Maharaj and Sankat 1996). The extent of chlorophyll conversion is related to the degree of blanching. A combination of chemicals (0.5% potassium metabisulphite + 0.1% magnesium oxide + 0.1% sodium bicarbonate) used for blanching is known to have better retention of ascorbic acid when compared to individual chemicals used for blanching (Patil et al. 1978, Premavalli et al. 2001). Negi and Roy (2000) have reported that water blanching followed by dipping in potassium metabisulphite and drying amaranth and fenugreek in a low temperature drier had the least drastic effect on β-carotene, ascorbic acid and chlorophyll content of the processed product.

The present investigation was therefore undertaken to evaluate the influence of dehydration on the nutritional composition of GLV and to produce a concentrated source of micronutrients in the form of dried greens.

Materials and methods

Selection and preprocessing of GLV Five GLV, namely Amaranth leaves (*Amaranthus gangeticus*), Brahmi (*Centella asiatica*), Bathua leaves (*Chenopodium album*) Kilkeerae (*Amaranthus tricolor*) and Fenugreek leaves (*Trigonella foenum graecum*) were selected to study the changes in composition on dehydration. The fresh GLV were procured from local markets. The leaves were separated from the roots and washed under running water to remove the adhering mud particles followed by double glass-distilled water and drained completely. One set of greens was used as such for analysis. Another set of GLV was steam blanched for 5 min after chemical treatment with a solution of 0.1% magnesium oxide + 0.1% sodium bicarbonate and 0.5% potassium metabisulphite. They were drained after blanching and spread on steel trays for drying in an oven at 60°C for 10–12 h. After drying the GLV were powdered in a mixer, stored in an airtight container and stored in a refrigerator.

Compositional analysis The fresh GLV and dehydrated GLV were analyzed for the following components to study the effect of dehydration. Moisture, ether extractives and ash (minerals) were estimated by standard methods (AOAC 2000). Total iron was analyzed by colorimetric method using α – α bipyridyl (AOAC 1965) and calcium by the method of AOAC (2000). Insoluble and soluble dietary fiber was analyzed by separation of non-starch polysaccharides by the enzymatic gravimetric method (Asp et al. 1983). Ascorbic acid was estimated by the visual titration method of reduction of 2, 6—dicholorophenol-indophenol dye. Total carotene was extracted in acetone; β-carotene was separated by column chromatography and estimated colorimetrically (Ranganna 1986). Thiamine was analyzed by oxidation to thiochrome, which fluoresces in UV light (Raghuramulu et al. 2003). Total oxalate was analyzed by extraction with hydrochloric acid and soluble oxalate with water followed by precipitation with calcium oxalate from deproteinized extract and subsequent titration with potassium permanganate (Gupta et al. 2005). Tannins were extracted in methanol and measured colorimetrically by using vanillin-hydrochloride method (Gupta et al. 2005).

Analysis of in vitro dialyzability of Fe and Ca In vitro dialyzability of iron and calcium from GLV was determined by simulated gastrointestinal digestion using pepsin for the gastric stage followed by pancreatin and bile salts for the intestinal stage (Luten et al. 1996). The proportion of mineral that diffused through a semipermeable membrane was used to measure mineral dialyzability. Exactly 15 g of homogenized green leafy vegetables (5 g in case of dried samples) were placed in a 250 ml Erlenmeyer flask and 80 ml of water was added. The pH was adjusted to 2.0 with 6 M HCl. After 15 min, the pH was checked and readjusted to 2.0, if necessary. Exactly 3 ml of freshly prepared pepsin solution (16% in 0.1 M HCl) was added and the volume was made up to 100 ml with water. The samples were incubated at 37°C for 2 h. The digests were then frozen for 90 min. Titratable acidity was determined in an aliquot of the digest containing 5 ml of pancreatin-bile extract mixture

(0.4% pancreatin + 2.5% bile extract) with 0.2 M NaOH till the pH of 7.5 was attained.

Exactly 20 ml of frozen digests (after thawing) were subjected to simulated intestinal digestion by placing the dialysis tubing (molecular cut off: 8 Kda) in Erlenmeyer flasks. The dialysis tubing contained 25 ml of $NaHCO_3$ (equivalent to moles of NaOH determined by titratable acidity) solution. The flasks were incubated in a shaker water bath at 37°C for 30 min (until the pH reached 5.0), 5 ml of pancreatin - bile extract mixture was added and shaken for another 2 h (until pH reached 7.0). Then the dialysates were carefully transferred to graduated tubes and the volume was measured. The dialysates were analyzed for iron by colorimetric method using α - α bipyridyl (AOAC 1965) and calcium by the method of Raghuramulu et al. (2003). Double glass-distilled water was used for preparation of reagents used in the entire analysis. All chemicals used for the study were of analytical grade.

Statistical analysis The data presented represents the mean of quadruplicate analysis, standard deviation was computed to assess the variation between the replicate values. ANOVA and the students 't' tests were suitably applied to study the compositional differences between the fresh and blanched dehydrated samples. Probability level was set to $P<0.05$. The statistical package used for the above analysis was Minitab 1.32.

Results and discussion

In the present study we have analyzed the effect of dehydration on the nutritive value of GLV. The results of the study are presented in Tables 1, 2, 3, 4 and Fig. 1.

The moisture content of the fresh GLV ranged between 85.7–92.2% (Table 1). On dehydration, the moisture content was found to be in the range of 3.5–7.9%. Drying of GLV seems to have no effect on the ether extract which is evident from the results (Table 1). No significant differences were observed between the ether extact of fresh and dehydrated GLV when *t*-test was applied to check for differences ($P=0.119^{ns}$). When the ash content of the fresh and dehydrated GLV was considered, the maximum amounts were found in *Amarnathus tricolor* in both the fresh and dry forms. In the other GLV, it was found to be in the range of 1.36–1.88 g/100 g in fresh and 1.28–2.02 g/100 g of dry vegetables. As per the student's *t*-test,

Table 1 Proximate and mineral composition of fresh and dehydrated green leafy vegetables

Constituents	Green Leafy Vegetables					F-ratio
	Amaranthus gangeticus	*Chenopodium album*	*Centella asiatica*	*Amaranthus tricolor*	*Trigonella foenum graecum*	
Moisture (%)						
Fresh	87.8 ± 0.49	92.2 ± 0.32	85.7 ± 0.59	88.4 ± 0.56	87.9 ± 0.07	56.16*
Dehydrated	3.6 ± 0.14	5.3 ± 0.23	7.9 ± 0.29	4.5 ± 0.21	3.5 ± 0.49	72.36*
Ether Extract (g/100 g)						
Fresh	0.81 ± 0.01	0.40 ± 0.01	1.01 ± 0.01	0.54 ± 0.01	0.95 ± 0.01	1283.05*
Dehydrated	0.57 ± 0.03	0.52 ± 0.03	0.40 ± 0.01	0.51 ± 0.08	0.83 ± 0.01	27.60*
Ash (g/100 g)						
Fresh	1.88 ± 0.00	1.64 ± 0.00	1.89 ± 0.01	2.39 ± 0.01	1.36 ± 0.01	4798.75*
Dehydrated	2.02 ± 0.06	1.65 ± 0.01	2.00 ± 0.01	2.50 ± 0.00	1.28 ± 0.17	64.81*
Iron (mg/100 g)						
Fresh	16.38 ± 0.00	2.49 ± 0.46	12.46 ± 0.00	17.77 ± 0.68	4.05 ± 0.36	864.37*
Dehydrated	19.71 ± 1.47	1.81 ± 0.00	13.97 ± 0.80	16.08 ± 0.00	4.05 ± 0.36	356.31*
Calcium (mg/100 g)						
Fresh	185.5 ± 21.61	33.5 ± 5.46	193.4 ± 6.99	227.4 ± 18.83	155.6 ± 2.69	123.05*
Dehydrated	201.6 ± 23.16	39.9 ± 5.12	178.9 ± 11.97	239.2 ± 11.25	146.2 ± 7.99	128.04
Insoluble Dietary Fiber (g/100 g)						
Fresh	3.87±0.02	1.86±0.06	5.08±0.00	3.13±0.01	2.99±0.44	2500.04*
Dehydrated	3.83±0.05	1.55±0.00	4.17±0.01	2.69±0.04	2.58±0.04	1985.75*
Soluble Dietary Fiber (g/100 g)						
Fresh	0.56±0.01	0.32±0.01	0.38±0.01	0.80±0.01	0.28±0.00	693.77*
Dehydrated	0.51±0.04	0.50±0.02	0.51±0.01	0.61±0.03	0.15±0.04	71.12

All values are reported on fresh weight basis, values are means of 4 replicates, *Significant at $P\leq0.001$

Table 2 Vitamin content of fresh and dehydrated green leafy vegetables* (mg/100 g)

Vitamins	*Amaranthus gangeticus*	*Chenopodium album*	*Centella asiatica*	*Amaranthus tricolor*	*Trigonella foenum graecum*	F-ratio
Ascorbic acid						
Fresh	38.2±2.60	78.1±4.42	13.8±1.69	41.0±1.45	99.7±1.87	679.04**
Dehydrated	1.7±0.00	0.5±0.00	1.9±0.00	1.5±0.00	8.2±0.50	769.26**
	(5)	(1)	(14)	(4)	(8)	
Thiamine						
Fresh	0.16±0.00	0.07±0.01	0.13±0.04	0.07±0.00	0.42±0.05	109.16**
Dehydrated	0.04±0.01	0.02±0.00	0.06±0.01	0.03±0.01	0.30±0.03	226.64**
	(22)	(31)	(43)	(48)	(71)	
Total carotene						
Fresh	23.85±0.21	19.74±0.73	38.13±2.00	33.11±2.02	32.06±3.14	59.89**
Dehydrated	16.23±1.59	10.77±0.49	27.78±1.42	21.00±0.75	15.70±4.12	36.92**
	(68)	(55)	(73)	(63)	(49)	
β-carotene						
Fresh	4.67±0.32	2.70±0.33	5.46±0.20	5.25±0.19	4.35±0.29	66.06**
Dehydrated	3.22±0.27	0.55±0.06	3.63±0.54	3.31±0.50	2.69±0.11	48.38**
	(69)	(20)	(66)	(63)	(62)	

*All values are reported on fresh weight basis, values are means of 4 replicates; **Significant at $P \leq 0.001$

#Figures in parenthesis indicate percent retention of vitamins

no significant differences were observed in the ash content on dehydration ($P=0.416^{ns}$).

The effect of dehydration on the retention of iron and calcium was studied. The results are presented in Table 1. Among the fresh GLV, *Amaranthus tricolor* had the maximum amount of iron, whereas *Chenopodium album* had the least. *Amaranthus gangeticus*, *Centella asiatica* and *Trigonella feonum graecum* had iron contents of 16.38, 12.46 and 4.05 mg/100 g respectively. Dehydration does not seem to have much effect on the iron content of the GLV. Although there were variations in the iron content of dehydrated GLV when compared to the fresh, no significant differences were seen on application of the *t*-test ($P=0.181^{ns}$). The calcium content of the fresh and dehydrated GLV was found to be similar. The slight variations that were observed were found to be statistically insignificant ($P=0.483^{ns}$). Not many studies have reported the effect of dehydration on mineral content of GLV although Kawashima and Valente Soares (2003) have reported that brief cooking did not cause appreciable losses of any of the minerals in leafy vegetables consumed in South Brazil.

When we consider the insoluble dietary fiber content of the fresh GLV, it was in the range of 1.86 g/100 g in *Chenopodium album* to 5.08 g/100 g in *Centella asiatica* (Table 1). In the other GLV, it was in the range of 2.99–3.87 g/100 g. In all the GLV, a decrease in the insoluble

Table 3 Antinutrient content of fresh and dehydrated green leafy vegetables (mg/100 g)

GLV/ Antinutrients	Amaranthus gangeticus	*Chenopodium album*	*Centella asiatica*	*Amaranthus tricolor*	*Trigonella foenum graecum*	F-ratio
Tannins[a]						
Fresh	170.9±4.88	115.8±6.28	122.5±7.16	304.6±13.30	163.1±11.42	274.92*
Dehydrated	125.2±6.11	94.8±7.61	146.9±7.17	162.1±4.63	175.8±8.46	85.07*
Total Oxalate						
Fresh	646.0±33.36	1139.8±44.88	78.3±5.31	1243.3±75.18	17.4±0.00	746.94**
Dehydrated	881.5±12.39	853.1±13.28	59.3±4.07	1216.9±13.75	18.2±0.00	10775.97**
Soluble oxalate						
Fresh	301.5±19.04	719.6±66.41	414.4±10.93	470.4±48.25	8.7±0.00	245.52**
Dehydrated	302.8±6.35	414.4±10.93	26.8±6.72	290.8±4.74	9.1±0.00	2875.96**

All values are reported on fresh weight basis, values are means of 4 replicates, a - expressed as catechin equivalents, *Significant at $P \leq 0.01$, **Significant at $P \leq 0.001$

Table 4 Dialyzable iron and calcium from fresh and dehydrated green leafy vegetables (mg/100 g)

GLV/Dialyzable minerals	*Amaranthus gangeticus*	*Chenopodium album*	*Centella asiatica*	*Amaranthus tricolor*	*Trigonella foenum graecum*	F-ratio
Dialyzable iron						
Fresh	0.53±0.08	0.64±0.02	3.50±0.12	5.57±0.24	0.21±0.00	24.42*
Dehydrated	0.39±0.00	0.15±0.06	0.50±0.04	1.78±0.08	0.05±0.00	66.87*
Dialyzable calcium						
Fresh	15.36±4.26	27.88±5.47	81.33±9.34	20.59±9.07	61.25±2.04	92.05*
Dehydrated	12.38±2.64	6.94±0.89	58.15±9.01	9.41±1.51	39.96±2.48	117.11*

All values are reported on fresh weight basis, values are means of 4 replicates.*Significant at $P \leq 0.001$

fiber content was seen on dehydration. These differences on the insoluble dietary fiber content in the fresh and dehydrated GLV were found to be statistically insignificant according to the student's *t*-test ($P=0.284^{ns}$).

A different trend was seen in the soluble dietary fiber content of the leafy vegetables. In the fresh samples the soluble fiber was found to be in the range of 0.32–0.80 g/100 g (fresh weight basis). On dehydration, a marginal increase was seen in *Chenopodium album* and *Centella asiatica*. In the rest of the samples, a marginal decrease in the soluble dietary fiber content was seen on dehydration. The statistical analysis revealed the differences to be insignificant ($P=0.462^{ns}$). There seems to be no trend of increase or decrease in the dietary fiber content of the GLV. These differences could only be attributed to the variety of samples that were used for the study. Punna and Rao (2004) have reported no significant effect of processing/cooking on insoluble and soluble dietary fiber contents of green leafy vegetables.

Ascorbic acid, thiamine, total and β-carotene were the vitamins that were analyzed in both fresh and dehydrated GLV. Ascorbic acid, the most water-soluble and heat labile vitamin was found to be lost in large quantities on dehydration. As can be seen in Table 2, the fresh GLV have good amounts of ascorbic acid ranging between 13.8–99.7 mg/100 g fresh vegetable. On dehydration, the ascorbic acid decreased to a range of 0.5–8.2 mg/100 g (fresh weight basis). Reduction in the ascorbic acid content on dehydration was found to be statistically significant ($P=0.005$*). Ascorbic acid is a vitamin that is lost very easily. When we consider the amount of ascorbic acid that was retained on dehydration, a considerable variation was seen. Almost all ascorbic acid was destroyed in *Chenopodium album* whereas *Centella asiatica* retained 14% of its initial ascorbic acid content. Among the other GLV, the retention of ascorbic acid was in the range of 4–8%. Conversely Kaur et al. (2008) have reported the retention of ascorbic acid in mustard, mint and spinach to be as high as 13–38%.

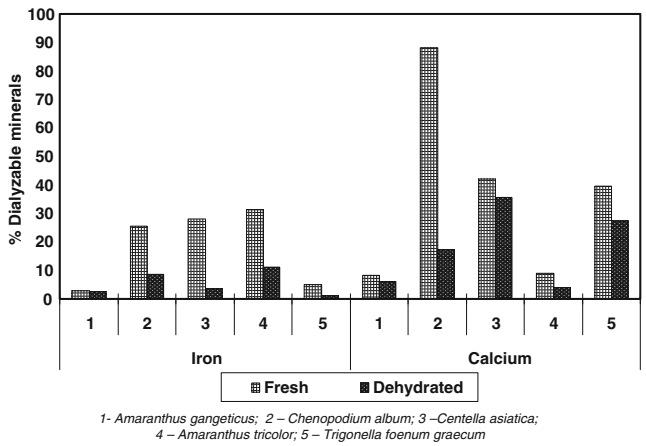

Fig. 1 Percent dialyzable iron and calcium from fresh and dehydrated green leafy vegetables

Fresh *Trigonella foenum graecum* was found to have the maximum amounts of thiamine, followed by *Amaranthus gangeticus* and *Centella asiatica*. Fresh *Chenopodium album* and *Amaranthus tricolor* had similar amounts of thiamine. Dehydrated *Trigonella foenum graecum* had 0.30 mg/100 g (fresh weight basis) followed by *Centella asiatica* and *Amaranthus gangeticus* (0.06, and 0.04 mg/100 g respectively). Dehydration did result in losses of thiamine. Statistical analysis showed no significant differences between the thiamine content of fresh and dehydrated GLV inspite of the losses on dehydration ($P=0.184^{ns}$). In comparison with ascorbic acid, thiamine was better retained on dehydration. Almost 71% retention was seen in *Trigonella foenum graecum*, followed by *Amaranthus tricolor* and *Centella asiatica*, which retained 48 and 43% of thiamine on dehydration. *Amaranthus gangeticus* and *Chenopodium album* retained 22 and 31% of their initial thiamine content after drying.

The total carotene content of the GLV was also affected by dehydration. Among the GLV selected for the study, *Centella asiatica* had the maximum amounts of total carotene in the fresh sample, which decreased by 27% on dehydration. The total carotene content decreased by 36.6% in *Amaranthus tricolor*, 52.9% in *Trigonella foenum graecum*, 31.9% in *Amaranthus gangeticus* and 45.4% in *Chenopodium album* on dehydration. Statistically signifi-

cant differences were observed in total carotene on dehydration (P=0.018*). β-carotene, which is a precursor of vitamin A was also analyzed. Among the GLV, the least amount of β-carotene was found in *Chenopodium album* that decreased by 79.6% on drying. The rest of the GLV had β-carotene in the range of 4.35–5.46 mg/100 g that reduced to 2.69–3.63 mg/100 g on dehydration. Dehydration losses were found to be statistically significant (P= 0.020*). These results are in agreement with Kaur et al. (2008) who have studied the retention of β-carotene in dehydrated mustard, mint and spinach greens. Uadal and Sagar (2008) have reported that dehydrated amaranth, fenugreek and spinach retained higher β-carotene and ascorbic acid when stored in high density polyethylene at low temperature. From the above results, it can be said that vitamins are more prone to destruction on dehydration, while there seems to be little effect on the other proximate constituents.

Tannins, total and soluble oxalates were analyzed in fresh and dehydrated GLV. In the fresh samples, the tannin content (expressed as catechin equivalents) was found to be the least in *Chenopodium album* and highest in *Amaranthus tricolor*. Among the other GLV, it ranged between 122.5–170.9 mg/100 g (Table 3). On dehydration, no trend was seen in the tannin content of the samples. This could be attributed to the sample itself. Differences in the tannin content of fresh and dehydrated GLV were found to be statistically insignificant (P=0.189^{ns}).

The total oxalate content of *Amaranthus gangeticus* and *Trigonella foenum graecum* was found to increase on dehydration, whilst in the other GLV the total oxalate content was found to decrease on dehydration. In the fresh and dehydrated samples, total oxalate ranged between 78.3–1243.3 and 18.2–1216.9 mg/100 g, respectively. No significant differences were seen in the total oxalate content as a result of dehydration (P=0.479^{ns}). A similar trend was seen in the soluble oxalate content of the dehydrated GLV. The soluble oxalate was seen to increase in *Amaranthus gangeticus* and *Trigonella foenum graecum* on dehydration, whilst in the other GLV dehydration seemed to have reduced the soluble oxalate content. The soluble oxalate was found to be in the range of 8.7–719.6 and 9.1–414.4 mg/100 g of fresh and dehydrated GLV, respectively. The differences between the soluble oxalate content of fresh and dehydrated GLV were found to be statistically insignificant (P=0.268^{ns}).

There are very few/limited studies on the effect of dehydration on the antinutrient content of the green leafy vegetables in the literature. However some literature studies have reported that cooking/conventional boiling method was effective in reducing the oxalic acid and tannin content of some GLV (Savage et al. 2000, Somsub et al. 2008). From the above observations, it can be concluded that dehydration seems to have little effect on the proximate, mineral and antinutrient contents of the GLV. However, statistically significant differences were seen only in the vitamin content of the GLV on dehydration.

Experiments were also carried out to analyze the effect of dehydration on dialyzable iron and calcium by *in vitro* technique. From Table 4, it can be seen that the dialyzable iron in the fresh GLV was found to be maximum in *Amaranthus tricolor* followed by *Centella asiatica*, which had 3.50 mg/100 g. In the rest of the fresh samples, the dialyzable iron was found to be in the range of 0.21–0.65 mg/100 g, respectively. When dehydrated GLV were considered, we found a sharp decline in the dialyzable iron of all the dried greens with the exception of *Amaranthus gangeticus*, which had higher dialyzable iron content in the dehydrated form than in the fresh form. The maximum amount of absolute dialyzable iron in the dried greens was seen in *Amaranthus tricolor*. In the remaining dehydrated greens the dialyzable iron was found to be in the range of 0.05 mg/100 g in *Trigonella foenum graecum* to 0.50 mg/100 g in *Centella asiatica*.

When we consider the percent dialyzable iron, in the fresh GLV it was in the range of 2.4–31.4%, while in the dehydrated greens it was found to be in the range of 2.7–11.1% (Fig. 1). Different workers have reported varying values for percent dialyzability from green leafy vegetables. Chawla et al. (1988) in one of the earliest studies determined the *in vitro* availability of iron and related constituents in six green leafy vegetables (amaranth, colocasia, drumstick, fenugreek, shepu and spinach) and found it to be between 2.8–4.6%. Lucarini et al. (2000) studied the dialyzable iron content from artichoke, asparagus, broccoli, cabbage, cauliflower, kale, carrot, tomato and potato. The *in vitro* dialyzable iron ranged between 10.7–23.1% with the exception of artichoke and asparagus. These findings have also been reported by Gillooly et al. (1983). The *in vitro* iron bioavailability in the uncommon GLV from the Uttaranchal region of India ranged between 4.62–6.20% (Raghuvanshi et al. 2001). These differences in the dialyzable iron content of the vegetables can be attributed to the variations in the organic acid content of vegetables and the presence of the antinutrients in these vegetables. To the best of our knowledge this could be the first report to show the effect of dehydration on the dialyzable iron content of GLV. The decrease in dialyzability on dehydration could be attributed to the fact that during the process of dehydration, iron could have been bound to other constituents of the vegetables thus reducing the solubility, which in turn influences the dialyzability of the mineral. Also, ascorbic acid that is a promoter of iron bioavailability is also destroyed during dehydration.

The absolute amount of dialyzable calcium was found to be highest in *Centella asiatica* and *Trigoenlla foenum graecum* in the fresh samples. In the other GLV, it ranged from 15.36–27.88 mg/100 g of fresh sample (Table 4).

When the dehydrated GLV were considered, we found a decline in their dialyzable calcium content with respect to the fresh greens. In *Chenopodium album* the dialyzable calcium reduced by more than half from 27.88 mg/100 g of fresh greens to 6.94 mg/100 g of dried greens. Similarly in *Centella asiatica* and *Trigonella foenum graecum* the dialyzable calcium content reduced from 81.33 to 58.15 and 61.25 to 39.96 mg/100 g, respectively, on dehydration.

Chenopodium album and *Centella asiatica* had the highest calcium dialyzability of 88.3 and 42.1% in the fresh GLV. On dehydration, the calcium dialyzability decreased to 17.4 and 35.5% respectively. In *Amaranthus gangeticus*, *Amaranthus tricolor* and *Trigonella foenum graecum*, the bioavailable calcium reduced from 8.3 to 6.1%, 9.1 to 3.9% and 39.4 to 27.3% (Fig. 1). Lucarini et al. (1999) evaluated the *in vitro* calcium availability from four varieties of *Brassica oleracea* L. (broccoli, cauliflower, green cabbage and kale). Twenty five percent of the total calcium was found to be dialyzable. Since *Brassica vegetables* are essentially phytate- and oxalate-free vegetables, dietary fiber components and organic acids could have influenced calcium availability. Raghuvanshi et al. (2001) reported that inspite of high oxalate content of uncommon GLV from Uttaranchal regions of India, the *in vitro* calcium bioavailability ranged between 7.30–63.48%. Conversely, Kamchan et al. (2004) reported high levels of dialyzable calcium (20–39%) in kale, celery, collard, pak-chee-lao (*Anethum graveolens*, L.), Chinese cabbage and soybean sprouts. Medium levels of dialyzable calcium (11–18%) were found in Indian mulberry and sesbania leaves. Pak-paw (*Polygonum odoratum,* L), amaranth and wild betel exhibited low calcium availability. The differences in the calcium bioavailability as reported by Raghuvanshi et al. (2001) and Kamchan et al. (2004) could be attributed to the different methods used for evaluation of *in vitro* available calcium.

A large variety of interactive food components were found to interfere in one or other form with the bioavailability of iron and calcium. The availability of iron and calcium in fresh GLV was found to be in the range of 2.4–31.4% and 8.3–88.3%, respectively, and that in the dehydrated GLV in the range of 2.7–11.1% and 3.9–40.0%, respectively. In our study, the inhibitors influenced the availability significantly and dehydration seems to have a negative influence on bioavailability of iron and calcium in GLV. Recently, some studies have reported that the disruption of the natural matrix or the microstructure created during processing may influence the release, transformation, and subsequent absorption of some nutrients in the digestive tract. Parada and Aguilera (2007) have reviewed recent scientific data that demonstrate that in the case of certain nutrients, the state of the matrix of natural foods or the microstructure of processed foods may favor or hinder their nutritional response *in vivo*.

Conclusion

The compositional changes that occurred on dehydration varied by the component. Proximate principles were least affected, total iron and calcium content decreased slightly, but dialysability of the minerals decreased significantly. Among the vitamins, ascorbic acid, total and β- carotene were lost significantly, while thiamine was retained moderately. Changes in the antinutritional factors was non-significant. The process of dehydrating GLV concentrates the nutrients and the dehydrated GLV are a rich source of dietary fiber which can find application in development of high fiber and micronutrient rich foods. Easy to preserve, feasibility, convenience and offseason availability are some of the advantages of incorporating dehydrated GLV in products. Dehydrated GLV can be incorporated into traditional products at the household level or can be utilized in the formulation of processed foods at the industrial level. Value addition of food products with dehydrated GLV can be advocated as a feasible food-based approach to combat micronutrient malnutrition.

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References

AOAC (1965) Official methods of analysis, 10th edn. Association of Official Analytical Chemists, Washington DC

AOAC (2000) Official Methods of Analysis, 17th edn, Methods 934.01, 920.39 and 942.05. Association of Official Analytical Chemists, Arlington

Asp NG, Johansson CG, Hallmer H, Siljestrom M (1983) Rapid enzymatic assay of insoluble and soluble dietary fiber. J Agric Food Chem 31:476–482

Badifu GIO, Akpapunam MA, Mgbemere VM (1995) The fate of β-carotene in processed leaves of fluted pumpkin (*Telfairia occidentalis*. Hook. F): a popular vegetable in Nigerian diet. Pl Food Hum Nutr 48:141–147

Chawla S, Saxena A, Seshadri S (1988) *In vitro* availability of iron in various green leafy vegetables. J Sci Food Agric 46:125–127

Gillooly M, Bothwell TH, Torrance JD, Macphail AP, Derman DP, Bezwoda WR, Mills W, Charlton RW (1983) The effect of organic acids, phytates and polyphenols on the absorption of iron from vegetables. Br J Nutr 49:331–342

Gupta S, Lakshmi JA, Manjunath MN, Prakash J (2005) Analysis of nutrient and antinutrient content of underutilized green leafy vegetables. LWT Food Sci Technol 38:339–345

Ibarz A, Barboda-Canovas GV (2000) Unit operations in food engineering. CRC, New York

Kadam DM, Samuel DVK, Chandra P, Sikarwar HS (2008) Impact of processing treatments and packaging material on some properties of stored dehydrated cauliflower. Int J Food Sci Technol 43:1–14

Kamchan A, Puwastein P, Sirichakwal PP, Kongkachuichai R (2004) *In vitro* calcium bioavailability of vegetables, legumes and seeds. J Food Comp Anal 17:311–320

Kaur A, Kaur D, Oberoi DPS, Gill BS, Sogi DS (2008) Effect of dehydration on physicochemical properties of mustard, mint and spinach. J Food Process Preservation 32:103–116

Kawashima LM, Valente Soares LM (2003) Mineral profile of raw and cooked leafy vegetables consumed in Southern Brazil. J Food Comp Anal 16:605–611

Lucarini M, Canali R, Cappelloni M, Di Lullo G, Lombardi-Boccia G (1999) *In vitro* calcium availability from *Brassica* vegetables (*Brassica oleracea* L.) and as consumed in composite dishes. Food Chem 64:519–523

Lucarini M, Di Lullo G, Cappelloni M, Lombardi-Boccia G (2000) *In vitro* estimation of iron and zinc dialyzability from vegetables and composite dishes commonly consumed in Italy: Effect of red wine. Food Chem 70:39–44

Luten J, Crews H, Flynn A, Van Deal P, Kastenmayer P, Hurrel R, Deelstra H, Shen L, Fairweather-Tait SJ, Hickson K, Farre R, Schlemmer U, Frohlich W (1996) Interlaboratory trial on the determination of the *in vitro* iron dialysability from food. J Sci Food Agric 72:415–424

Maharaj V, Sankat CK (1996) Quality changes in dehydrated dasheen leaves: effects of blanching pre-treatments and drying conditions. Food Res Int 29:563–568

Mulay SV, Pawar VN, Thorat SS, Ghatge UM, Ingle UM (1994) Effects of pretreatments on quality of dehydrated cabbage. Indian Food Packer 48:11–16

Negi PS, Roy SK (2000) Effect of blanching and drying methods on β-carotene, ascorbic acid and chlorophyll retention of leafy vegetables. Lebens Wiss Technol 33:295–298

Pande VK, Sonune AV, Philip SK (2000) Solar drying of coriander and methi leaves. J Food Sci Technol 23:639–641

Parada J, Aguilera JM (2007) Food microstructure affects bioavailability of several nutrients. J Food Sci 72:R21–R32

Patil VR, Kulkarni DN, Kulkarni K, Ingle UM (1978) Effect of blanching factors on quality and durability of sun dried and dehydrated fenugreek *(methi)*. Indian Food Packer 32:43–49

Premavalli KS, Majumdar TK, Madhura CV (2001) Processing effect on colour and vitamins of green leafy vegetables. J Food Sci Technol 38:79–81

Punna R, Rao UP (2004) Effect of maturity and processing on total, insoluble and soluble dietary fiber contents of Indian green leafy vegetables. Int J Food Sci Nutr 55:561–567

Rahman MS, Perera CO (1999) Drying and food preservation. In: Rahman SM (ed) Handbook of food preservation. Marcel Dekker Inc, NewYork, pp 173–216

Raghuramulu N, Nair MK, Kalyansundaram S (2003) A manual of laboratory techniques, National Institute of Nutrition, ICMR, Jamai-Osmania, Hyderabad, India

Raghuvanshi RS, Singh R, Singh R (2001) Nutritional composition of uncommon foods and their role in meeting micronutrient needs. Int J Food Sci Nutr 53:331–335

Ranganna S (1986) Handbook of analysis and quality control for fruit and vegetable products, 2nd edn. Tata McGraw-Hill, New Delhi

Savage GP, Vanhanen L, Mason SM, Ross AB (2000) Effect of cooking on the soluble and insoluble oxalate content of some New Zealand foods. J Food Comp Anal 13:201–206

Singh H, Bawa AS, Ahmed J (1997) Dehydration characteristics of some green leafy vegetables. Ind Food Packer 51:5–15

Somsub W, Kongkachuichai R, Sungpuag P, Charoensiri R (2008) Effects of three conventional cooking methods on vitamin C, tannin, myo-inositol phosphates contents in selected Thai vegetables. J Food Comp Anal 21:187–197

Uadal S, Sagar VR (2008) Influence of packaging and storage temperature on the quality of dehydrated selected leafy vegetables. J Food Sci Technol 45:450–453