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Influence of antioxidant spices on the retention of β-carotene in vegetables during domestic cooking processes

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Abstract

Considerable amounts of β-carotene were lost during the two domestic methods of cooking commonly used, namely, pressure cooking and open pan boiling, the loss ranging from 27 to 71% during pressure cooking and 16–67% during boiling for the four vegetables examined in this study. Pressure cooking of green leafy vegetables resulted in a greater retention of this provitamin. In the presence of red gram dhal, which is a common ingredient in the diet, there was an underestimation of β-carotene due to poor extractability. Inclusion of acidulants—tamarind and citric acid-along with these vegetables brought about some changes in the level of retention of β-carotene. The antioxidant spice turmeric generally improved the retention of β-carotene in all four vegetables studied. Onion also had a similar effect. The combinations of acidulants and antioxidant spices also improved the retention of β-carotene during cooking. This effect seemed to be additive in the case of processing of amaranth by boiling.

Keywords: β-Carotene retention in vegetables; Loss during domestic cooking; Acidulants; Antioxidant spices

1. Introduction

Malnutrition, particularly micronutrient deficiency, is one of the major public health problems in the developing countries, including India (Gopalan, Ramasastri, & Subramanian, 1999). The results of countrywide surveys have revealed that vitamin A deficiency is very common in India and many children below the age of 5 years become blind due to vitamin A deficiency (Thylefors, 1985). Vitamin A, in addition to preventing nutritional blindness, has been considered to promote growth and prevent morbidity and mortality in young children (Chandra & Au, 1981). Deficiency of vitamin A leads to impaired cellular functioning, since it has a role in numerous physiological processes in animals (Machlin, 1984). Carotenoids are the precursors of vitamin A and those commonly occurring in nature include α, β and γ-carotene, lycopene and cryptoxanthin. Among these precursors, a major proportion of vitamin A activity is accounted for by β-carotene which is widely distributed, in green leafy vegetables, yellow-orange fruits and some other vegetables (Goodwin, 1986). β-Carotene accounts for more than 90% of total carotenoids in vegetables. In human beings, β-carotene not only serves as valuable source of vitamin A, but also serves as a potent antioxidant, scavenging free radicals and quenching singlet oxygen. By this latter property, β-carotene is understood to reduce the risk of development of certain types of cancer (Bafidu, Akapapunam, & Mybemere, 1995).

Animal foods, such as eggs, milk and liver, which are good sources of preformed vitamin A, are expensive. The poorer segments of the population in India are therefore dependent on plant foods, which provide β-carotene to meet their requirements of vitamin A. Green leafy vegetables, in general are rich sources of β-carotene, in addition to ascorbic acid, calcium, iron and folic acid. These leafy vegetables are grown abundantly in India and are relatively inexpensive and easily and quickly cookable (Gopalan et al., 1999).

Compared with vitamin A, the provitamin carotenoids are more stable to light and oxidation. This may be due to the location of the carotenoids within the plant tissues. However, heat treatments, which disintegrate tissue if coupled with exposure to oxygen, light and acid, can result in the destruction of the provitamin

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A carotenoids. In addition, heat, acid and light have been reported to cause isomerization of vitamin A and carotenoids. These adverse factors can cause isomerization of the all-*trans* form to the *cis* form which is biologically less potent (Zechmeister, 1949).

In view of the above, information on the possible losses of β-carotene from vegetables, during preparation by traditional cooking methods, is of major importance. Several reports have documented the losses of β-carotene from vegetables during cooking procedures such as boiling, stewing, frying, blanching, and pressure cooking, etc. (Akapa-punam, 1984; Bafidu et al., 1995; Ogulensi & Lee, 1979; Onayemi & Bafidu, 1987; Padmavathi, Udipi, & Rao, 1992; Park, 1987; Sood & Bhat, 1974; Sweeney & Marsh, 1971; Yadav & Sehgal, 1995, 1997). It would, however, be interesting to see whether the presence of certain food components, such as antioxidant spices and acidulants, have a protective role against such losses. This study was therefore conducted to determine the extent of retention of β-carotene in representative vegetables, which are rich sources of the same during conventional cooking procedures. This study also examines the influence of commonly used acidulants and of spices known to have antioxidant properties on the extent of retention of β-carotene.

The objectives of the present study were to: (1) quantify the loss of β-carotene from vegetables—Carrot (*Dacus carota*), Pumpkin (*Cucurbita maxima*), Amaranth leaves (*Amaranthus gangeticus*) and Drumstick leaves (*Moringa oleifera*) during pressure cooking and boiling in water; (2) study the influence of acidulants—tamarind and citric acid, and antioxidant spices—turmeric and onion powder, as well as their combinations, on the retention of β-carotene during the two cooking procedures.

2. Materials and methods

2.1. Materials

The test materials studied here for monitoring β-carotene losses during cooking consisted of the following four vegetables: Amaranth (*Amaranthus gangeticus*) leaves, Drumstick (*Moringa oleifera*) leaves, Carrot (*Dacus carota*) and Pumpkin (*Cucurbita maxima*). These vegetables were procured fresh from the local market and cleaned and the edible portion was used for the study.

Other ingredients, which were included along with the test vegetables in the study, were red gram dhal (*Cajanum cajan*), turmeric (*Curcuma longa*) powder, onion (*Allium cepa*) powder, tamarind (*Tamarindus indica*) powder, citric acid and common salt. All these ingredients were procured from the local market. All chemicals used here were of analytical grade (Qualigens). Solvents were distilled before use. Pepsin (from porcine pancreas) and bile extract (porcine) were procured from Sigma Chemical Co., USA.

2.2. Food sample preparation

Carrot and pumpkin were diced to a uniform size of 5 mm thickness while, in the case of two green leafy vegetables, the edible portion was finely chopped. The test vegetable (10 g) was subjected to the cooking process in the following combinations: (1) test vegetable alone; (2) test vegetable + acidulant (tamarind powder/citric acid); (3) test vegetable + antioxidant spice (turmeric/onion powder); 4) test vegetable + acidulant + antioxidant spice. Accordingly, each test vegetable had the following variations:

(1) test vegetable alone (10 g)
(2) test vegetable (10 g) + tamarind powder (0.1 g)
(3) test vegetable (10 g) + citric acid (0.01 g)
(4) test vegetable (10 g) + turmeric powder (0.1 g)
(5) test vegetable (10 g) + onion powder (0.1 g)
(6) test vegetable (10 g) + tamarind powder (0.1 g) + turmeric powder (0.1 g)
(7) test vegetable (10 g) + tamarind powder (0.1 g) + onion powder (0.1 g)
(8) test vegetable (10 g) + citric acid (0.01 g) + turmeric powder (0.1 g)
(9) test vegetable (10 g) + citric acid (0.01 g) + onion powder (0.1 g)

0.1 g of common salt was added to all the variations. In a separate set, the earlier combinations were also cooked in the presence of red gram dhal (2.5 g). All the earlier 18 variations of food samples were processed in quadruplicate.

2.3. Heat processing

Two cooking variables namely, pressure cooking and open boiling were employed. In the case of pressure cooking, 15 ml water were added to the food sample which was pressure-cooked for 10 min at 15 p.s.i. using a domestic pressure cooker. In the case of boiling, food materials were boiled in an open vessel in the presence of water (80 ml initially) for 10 min, stirring at 2-min intervals. For the food samples which were subjected to cooking by boiling and where red gram dhal was an ingredient, previously pressure-cooked dhal was added. The pH of the cooked food materials was recorded.

2.4. β-Carotene analysis (Ranganna, 1977)

2.4.1. Extraction

All extractions were carried out under subdued light. All the glassware was wrapped with black carbon paper. The entire cooked food sample was mixed with acetone

(40–50 ml), blended in a Sorvall Omni mixer, using a stainless steel cup-blade assembly, and filtered over a sterile cotton pad. The residue was again blended with acetone. This process was continued until the residue was colourless. The extract was made up to 100 ml with acetone. Fifty millimetres of acetone extract were placed in a separatory funnel and agitated with petroleum ether (60–80 °C) and 5 ml water and left to stand. The top yellow-coloured petroleum ether layer was collected. Extraction was repeated with further portions of petroleum ether and water until no more yellow-coloured β-carotene was extractable. Petroleum ether extract was filtered over anhydrous sodium sulphate on a Whatman No. 1 filter paper. The extract was made up to a known volume.

2.4.2. Column chromatography

All chromatography was conducted under subdued light. Columns of size 150×20 mm were packed with neutral aluminium oxide to a length of 10 cm and topped with a 1 cm layer of anhydrous Na_2SO_4. The column was washed with petroleum ether (60–80 °C, 25 ml). Two millilitres of β-carotene extract (in petroleum ether) were gently loaded onto the column and the orange-coloured β-carotene band was eluted with petroleum ether (60–80 °C) containing 10% acetone. The eluent was collected and the volume noted.

2.4.3. Quantitation of β-carotene

The colour intensity of β-carotene eluent was measured at 450 nm in a Shimadzu UV/Visible spectrophotometer and compared with β-carotene reference standard.

2.5. Additional experiment involving simulated gastro-intestinal digestion

2.5.1. General

Since there was a general underestimation of β-carotene in food samples containing red gram dhal, an additional experiment was carried out to digest the red gram dhal by a simulated gastrointestinal digestion procedure before extracting the β-carotene (Miller, Schricker, Rasmussen, & Vancanpen, 1981).

2.5.2. Gastric digestion

The raw test vegetable (20 g), along with cooked red gram dhal (5 g) was homogenized and placed in a 250-ml Erlenmeyer flask and mixed with 80 ml water; pH was adjusted to 2.0 by adding 6M HCl. Fresh pepsin solution[1] (3ml) was added to the sample and volume was made up to 100 ml with water. The sample was then incubated at 37 °C for 2 h in an incubator shaker.

2.5.3. Intestinal digestion

Gastric digest aliquots (25 ml) were weighed into a 100-ml flask. pH was adjusted to 5.0 with 1M NaOH. The flask was kept aside for 15 min. Five millilitres of freshly prepared pancreatin–bile mixture[2] were added and volume was made up to 50 ml with water. It was then incubated in an incubator shaker for 3 h. Food samples, digested as earlier, were used for β-carotene estimation.

3. Results and discussion

Deficiency of vitamin A is one of the major public health problems in India and other developing countries. The most important contributory factor for this situation is inadequate intake of vitamin A or its precursor β-carotene. An increased intake of β-carotene-rich foods in the daily diet may be preferred to the massive synthetic vitamin A dosage approach and can be one of the strategies for improving nutritional status (Gopalan, 1972). Since β-carotene is susceptible to loss during heat treatment it is important to ensure maximum retention of this provitamin, either by adopting suitable cooking procedures, or by including specific ingredients which may minimize the loss.

In the absence of any studies in this direction, we have examined the influence of two common acidulants, namely tamarind and citric acid (to represent lime), which will bring about a reduction in pH up to about one unit at the concentration they are included in the diet. Such reduction in pH may alter the extent of loss of β-carotene during heat processing. Among the spices used in our diet a few have significant antioxidant properties. Such ingredients may influence the extent of loss of β-carotene during the cooking procedure. We have specifically examined, for this purpose, the inclusion of turmeric and onion, which are among the most commonly used spices in Indian cuisine.

Table 1 describes the extent retention of β-carotene in carrot during the two methods of cooking in the presence of acidulant and antioxidant spices. The loss of β-carotene from carrots was greater when the vegetable was pressure cooked for 10 min (27%), than in boiling in water for the same duration (16%). Among the two acidulants examined, tamarind improved the retention of β-carotene in carrot during pressure cooking, where the loss was brought down to 10%. The same was true in the case of the antioxidant spice turmeric; β-carotene retention was improved to 93% in pressure-cooked carrot. Onion, on the other hand, had a similar beneficial influence on carrots processed by boiling in water

[1] Pepsin digestion mixture was prepared by suspending 1.6 g pepsin (from porcine stomach mucosa) in 100 ml of 0.1 M HCl.

[2] Pancreatin–bile mixture was prepared by dissolving 4 g pancreatin (from porcine pancreas) and 25 g bile extract (porcine) in 1000-ml of 0.1 M $NaHCO_3$.

Table 1
Retention of β-carotene in carrots during domestic cooking

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Carrot–Fresh	8033	100	8040	100
Carrot–Cooked	5873	73	6750	84
Carrot + Tamarind	7250	90	7000	87
Carrot + Citric acid	5873	73	6650	83
Carrot + Turmeric	7468	93	7140	89
Carrot + Onion	6054	75	7825	97.5
Carrot + Tamarind + Turmeric	7323	91	7050	87.5
Carrot + Tamarind + Onion	7685	96	6950	86.5
Carrot + Citric acid + Turmeric	7468	93	7300	90.5
Carrot + Citric acid + Onion	71778	89	6450	80

Values (expressed per fresh weight) are averages of quadruplicate determinations.

(97.5% retention). Combination of tamarind and turmeric/onion did have a beneficial influence on the retention of β-carotene during pressure cooking (>90% retention), while combination of citric acid and onion exhibited this effect only during pressure cooking (89% retention).

Table 2 presents the β-carotene values in heat-processed pumpkin. The loss of β-carotene from pumpkin was greater than from carrot during heat treatment. While pressure-cooking reduced β-carotene by 71%; it was only 49% for boiling. Inclusion of acidulants—tamarind and citric acid—considerably improved the retention of β-carotene during pressure cooking (37 and 43%, respectively). Retention of β-carotene was higher in boiled pumpkin in the presence of turmeric, while it was marginally higher in pressure-cooked pumpkin in the presence of combinations of tamarind and onion/citric acid and turmeric. The combinations also showed a similar effect in boiled pumpkin.

Data on the influence of the two methods of cooking, and the presence of additives, on retention of β-carotene in the leafy vegetable amaranth are presented in Table 3. Boiling amaranth in water for 10 min resulted in a greater loss of β-carotene than pressure cooking. β-Carotene loss was as high as 67.5% from the boiled vegetable compared with 27% when pressure-cooked. This loss was minimized to a considerable extent by the presence of acidulants and antioxidants, both together, and the combination was more effective in minimizing the β-carotene loss than the respective individual additives. Presence of antioxidant spices somewhat increased the retention of β-carotene in amaranth during pressure-cooking.

Table 4 presents data on the loss of β-carotene in drumstick leaves during heat processing. As in the case of amaranth, boiling caused a higher loss of β-carotene from drumstick leaves than did pressure cooking (50% vs. 32%). Among the acidulants, tamarind produced a greater retention of β-carotene in boiled drumstick leaves (61%). The two antioxidant spices, however, produced this effect both individually and in combination with acidulants, except in the case of the combination of tamarind and turmeric. In the case of pressure cooking, only citric acid and turmeric caused a greater

Table 2
Retention of β-carotene in pumpkin during domestic cooking

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Pumpkin–Fresh	2272	100	2272	100
Pumpkin–Cooked	656	29	1165	51
Pumpkin + Tamarind	832	37	1000	44
Pumpkin + Citric acid	976	43	980	43
Pumpkin + Turmeric	720	32	1340	60
Pumpkin + Onion	635	28	820	36
Pumpkin + Tamarind + Turmeric	680	30	1280	56
Pumpkin + Tamarind + Onion	818	36	1228	54
Pumpkin + Citric acid + Turmeric	1040	46	1270	56
Pumpkin + Citric acid + Onion	768	34	1040	46

Values (expressed per fresh weight) are averages of quadruplicate determinations.

retention of β-carotene when added individually. All four combinations of acidulants and antioxidant spices marginally enhanced the retention of β-carotene during pressure cooking.

Red gram dhal is a common ingredient in the Indian diet. The vegetables used in the present study are often cooked with red gram dhal in preparations such as 'sambhar'. Hence we have also examined the extent of loss/retention of β-carotene from these vegetables cooked in the presence of red gram dhal. Data on this aspect are presented in Tables 5–8.

β-Carotene values for fresh vegetables were consistently lower when they were extracted and processed, for β-carotene assay, in the presence of cooked red gram dhal. The values were 7–21% lower in all four vegetables examined. Data on the influence of red gram dhal on the retention of β-carotene in carrots during the two heat processing methods are presented in Table 5. The loss of β-carotene from carrots was higher when they were pressure-cooked (70%) than when they were boiled (27%) in the presence of red gram dhal. Both the acidulants and the antioxidant spices caused greater retention of β-carotene in pressure cooking as well as in boiling. All four combinations of acidulant and antioxidant spices increased the retention of β-carotene when carrots were pressure cooked. However, only the combination of tamarind and turmeric exhibited this effect during boiling. Thus, the beneficial effect of all four additives studied, on the retention of β-carotene in carrot, seemed to be more pronounced in the presence of red gram dhal.

The presence of red gram dhal reduced the loss of β-carotene from pumpkin during pressure-cooking (30% vs. 71%) as seen in Table 6. The acidulants did not improve the retention of β-carotene in pressure-cooked pumpkin. Further, the antioxidant spices marginally enhanced the same, both alone and in the presence of citric acid. In the presence of red gram dhal, both acidulants and both antioxidant spices improved the retention of β-carotene significantly during boiling of pumpkin. This was true for their combinations also.

Table 7 shows the extent of retention of β-carotene in amaranth during the two methods of cooking in the presence of acidulant and antioxidant spices. The beneficial

Table 3
Retention of β-carotene in amaranth during domestic cooking

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Amaranth–Fresh	7360	100	7375	100
Amaranth–Cooked	5391	73	2400	32.5
Amaranth + Tamarind	5000	70	3563	48
Amaranth + Citric acid	5428	75	4068	55
Amaranth + Turmeric	6038	82	4357	59
Amaranth + Onion	5832	79	4945	67
Amaranth + Tamarind + Turmeric	4560	67	5187	70
Amaranth + Tamarind + Onion	5606	76	5500	74.5
Amaranth + Citric acid + Turmeric	5679	77	5375	73
Amaranth + Citric acid + Onion	5356	73	5937	80.5

Values (expressed per fresh weight) are averages of quadruplicate determinations.

Table 4
Retention of β-carotene in drumstick leaves during domestic cooking

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Drumstick leaves–Fresh	10720	100	10720	100
Drumstick leaves–Cooked	7286	68	5357	50
Drumstick leaves + Tamarind	7357	69	6572	61
Drumstick leaves + Citric acid	8438	79	5440	51
Drumstick leaves + Turmeric	8357	78	6107	57
Drumstick leaves + Onion	7430	69	6143	57
Drumstick leaves + Tamarind + Turmeric	7643	71	4484	42
Drumstick leaves + Tamarind + Onion	8143	76	7615	71
Drumstick leaves + Citric acid + Turmeric	7964	74	6214	58
Drumstick leaves + Citric acid + Onion	7928	74	8679	81

Values (expressed per fresh weight) are averages of quadruplicate determinations.

Table 5
Retention of β-carotene in carrots during domestic cooking in the presence of red gram dhal

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Carrot–Fresh	6920	100	6920	100
Carrot–Cooked	2076	30	5003	73
Carrot + Tamarind	5709	82.5	5490	80
Carrot + Citric acid	5709	82.5	5988	87.5
Carrot + Turmeric	7439	107.5	5492	80
Carrot + Onion	5605	81	5710	83
Carrot + Tamarind + Turmeric	6488	93.7	6134	89.5
Carrot + Tamarind + Onion	7612	110	4676	68
Carrot + Citric acid + Turmeric	5363	77.5	3669	53.5
Carrot + Citric acid + Onion	6142	88.5	3990	58.2

Values (expressed per fresh weight) are averages of quadruplicate determinations.

Table 6
Retention of β-carotene in pumpkin during domestic cooking in the presence of red gram dhal

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Pumpkin–Fresh	1884	100	1884	100
Pumpkin–Cooked	1328	70	824	44
Pumpkin + Tamarind	1172	62	1178	62.5
Pumpkin + Citric acid	1256	67	1320	70
Pumpkin + Turmeric	1420	75	1560	83
Pumpkin + Onion	1408	75	880	47
Pumpkin + Tamarind + Turmeric	850	45	1240	66
Pumpkin + Tamarind + Onion	760	40	1088	58
Pumpkin + Citric acid + Turmeric	1480	78.5	1040	55
Pumpkin + Citric acid + Onion	1380	73	1060	56

Values (expressed per fresh weight) are averages of quadruplicate determinations.

Table 7
Retention of β-carotene in amaranth during domestic cooking in the presence of red gram dhal

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Amaranth–Fresh	5760	100	5850	100
Amaranth–Cooked	4613	80	3862	66
Amaranth + Tamarind	6172	107	2625	45
Amaranth + Citric acid	5915	102	4062	69
Amaranth + Turmeric	6187	107	2857	49
Amaranth + Onion	5400	94	3519	60
Amaranth + Tamarind + Turmeric	5400	94	2750	47
Amaranth + Tamarind + Onion	6075	105	3938	67
Amaranth + Citric acid + Turmeric	5513	96	3750	64
Amaranth + Citric acid + Onion	5785	100	2688	46

Values (expressed per fresh weight) are averages of quadruplicate determinations.

Table 8
Retention of β-carotene in drumstick leaves during domestic cooking in the presence of red gram dhal

Ingredient	Pressure cooked for 10 min		Boiled in water for 10 min	
	β-Carotene (μg/100 g)	% Retention	β-Carotene (μg/100 g)	% Retention
Drumstick leaves–Fresh	10,000	100	10,000	100
Drumstick leaves–Cooked	2994	28	3357	31
Drumstick leaves + Tamarind	1751	17.5	3438	32
Drumstick leaves + Citric acid	4688	44	4286	40
Drumstick leaves + Turmeric	3425	32	3429	32
Drumstick leaves + Onion	1938	18	4857	45
Drumstick leaves + Tamarind + Turmeric	7187	67	4760	44
Drumstick leaves + Tamarind + Onion	6893	64	4000	37
Drumstick leaves + Citric acid + Turmeric	7773	72.5	5714	53
Drumstick leaves + Citric acid + Onion	6750	63	6643	62

Values (expressed per fresh weight) are averages of quadruplicate determinations.

influence of acidulant and antioxidant spices on the retention of β-carotene was significantly more pronounced when amaranth was pressure-cooked in the presence of red gram dhal. In many instances, loss of β-carotene due to pressure-cooking of this leafy vegetable was completely prevented. The trend, however, was not evident when the vegetable was processed by boiling.

Contrary to the higher retention of β-carotene when amaranth was heat-processed in the presence of red gram dhal, drumstick leaves incurred greater loss of this provitamin when cooked in the presence of red gram dhal. The loss was about 70% in either of the heat-processing methods (Table 8). The combinations of acidulant and antioxidants and spices produced a greater reversal of this loss than the individual additives.

Since there was a general under-estimation of β-carotene in the presence of red gram dhal, probably because of poor extractability of the carotenoids, an additional experiment was carried out involving digestion of red gram dhal prior to extraction. For this purpose the food sample was subjected to a simulated gastro-intestinal digestion procedure. Fig. 1 presents β-carotene values of these samples before and after such

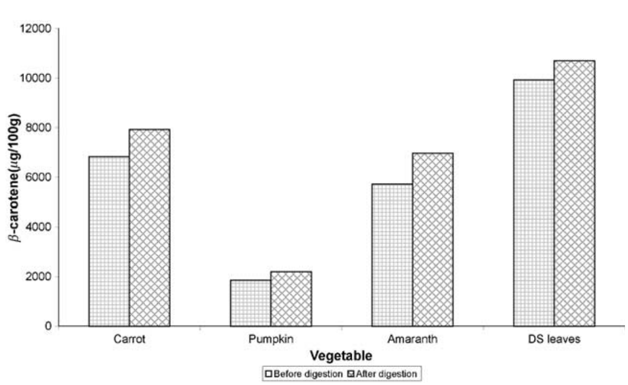

Fig. 1. Effect of simulated gastrointestinal digestion on β-carotene extraction from vegetables in the presence of red gram dhal.

digestion. β-carotene values of all these four fresh vegetables, in the presence of red gram dhal, considerably improved after simulated gastro-intestinal digestion. This proves that the under-estimation of β- carotene was due to poor extractability as a result of binding of this provitamin with the constituents of red gram dhal (proteins), which subsequently were released, consequent to gastro-intestinal digestion.

Among the β-carotene values of the four vegetables examined in this study, the value for amaranth was somewhat similar to the value reported by ICMR (Gopalan et al., 1999). However, the β-carotene value obtained for drumstick leaves was considerably lower while that for carrot and pumpkin was slightly higher than the reported values. These differences in β-carotene values could be due to varietal and seasonal differences in vegetables procured locally.

The high sensitivity of β-carotene to light and heat is well recognized and its loss is therefore expected during heat-processing. Among the two heat-processing methods employed in the current study, pressure-cooking reduced the β-carotene content of the two fleshy vegetables—carrot and pumpkin—to a greater extent than did boiling in water for a similar period. On the other hand, higher losses of β-carotene occurred during open pan boiling of leafy vegetables—amaranth and drumstick leaves—than on pressure cooking. Higher loss of β-carotene during open pan boiling of amaranth and drumstick leaves compared with pressure-cooking could be attributed to higher oxidative destruction in the open system occurring in the case of leafy vegetables.

The loss of β-carotene from the two leafy vegetables—amaranth and drumstick leaves—during pressure-cooking for 10 min in the present study ranged from 27 to 32% as compared with a loss of 50–60% during boiling in water for the same duration. Losses of β-carotene of 11–16% in pressure cooking and of 16–24% in traditional cooking (open pan boiling) from leafy vegetables have been reported by Sood and Bhat

(1974). These values are lower than that observed by us. This could be due to variation in the cooking time. Much lower losses of bathua and fenugreek leaves (1–4%) were reported by Yadav and Sehgal (1997) during pressure cooking (30 min) which has been attributed to the presence of hydrogenated fat fortified with vitamin A at the time of cooking.

Among the two fleshy vegetables examined, pumpkin incurred a higher loss of β-carotene than did carrot in either of the two cooking procedures. The retention of β-carotene in these vegetables was higher when they were boiled (16–49%) than pressure cooked (27–71%). Information on the loss of β-carotene from carrot and pumpkin by different methods of heat-processing is not available in the literature.

Since red gram dhal is a common ingredient in our diet, β-carotene retention during thermal processing was examined in the presence of red gram dhal. Red gram dhal seemed to minimize the loss of β-carotene from amaranth during both cooking procedures and this beneficial effect was also seen during pressure-cooking of pumpkin.

The stability of β-carotene has been believed to depend, to some extent on pH (Bafidu et al., 1995). The acidulants, tamarind and citric acid, added at 0.1 and 0.01%, respectively, to the test vegetables did not alter the pH to any significant level, except in the case of pumpkin where it was reduced by 0.6–0.8 units. Nevertheless, inclusion of these acidulants during cooking of the vegetables brought about some changes in the level of retention of β-carotene. Tamarind increased the retention in leafy vegetables by 11–16% during boiling. This beneficial increase was observed in carrot and pumpkin during pressure cooking (8–17%). Citric acid, on the other hand, increased the retention of β-carotene in pumpkin (14% increase) and drumstick leaves (11% increase) when they were pressure-cooked. Higher retention (23%) was promoted by citric acid included during boiling of amaranth. It it is noteworthy here that there is no direct relationship between pH value and acidity in a food system (Bafidu et al., 1995). This could explain the earlier changes in β-carotene retention brought about by acidulants, even in the absence of observable change in pH value. Most of the heat-labile nutrients are reported to be relatively stable under acidic conditions (Lund, 1988).

The antioxidant spice turmeric generally improved the retention of β-carotene in all four vegetables studied. This effect was seen in both methods of cooking of leafy vegetables while it was discernible only during pressure-cooking of carrot and boiling of pumpkin. Onion, on the other hand, improved the retention of β-carotene during boiling of carrot, amaranth and drumstick leaves and pressure-cooking of amaranth. The higher effectiveness of onion in improving the retention of β-carotene in open pan boiling compared to pressure-cooking is probably due to the higher destruction of the active ingredients of onion responsible for β-carotene retention during pressure cooking. It may be recalled here that boiling resulted in a greater loss of β-carotene from the leafy vegetables than did pressure-cooking. It should be noted that inclusion of either of the antioxidant spices also had the maximum beneficial effect with regard to β-carotene retention during boiling (27–35% higher retention by turmeric and onion).

The combinations of acidulants and antioxidant spices also proved to be beneficial with regard to retention of β-carotene during cooking. This effect was maximum in the case of amaranth during boiling and the magnitude was higher than that observed with the individual components (acidulants and antioxidants included separately). The combined effect of the acidulant and antioxidant seemed to be additive.

Thus, pressure cooking is preferable to processing by boiling with regard to β-carotene retention in green leafy vegetables. However, if open pan boiling is the chosen method of cooking, β-carotene losses can be minimized by the inclusion of acidulants and antioxidant spices.

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