Original Article

β-carotene losses due to handling and cooking in Kenyan leafy vegetables connote no comparative nutritional superiority over kales

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African leafy vegetables (ALVs) are known to be high in β-carotene content and are preferred over kales due to this nutritional superiority. Ten different vegetables were collected from farm and market locations and analyzed for β-carotene content. Cooked vegetables (in single or in combination) as well as solar dried samples were prepared by the community members in the study area in the usual way and without any instruction or conditions given. β-carotene content was analyzed using a High Performance Liquid Chromatography (HPLC). The results provided new representative β-carotene content of the fresh, marketed, cooked and dried vegetables without controlling or simulating the household handling or processing methods in a laboratory. While edible portions of kales are relatively inferior as a β-carotene source as compare to ALVs when in raw form, this is not the case at market place where kales exhibit comparable level of the β-carotene. As much as 280 µRE/100 g (a dietarily significant amount) can be lost through β-carotene oxidation before farm-fresh ALVs are sold in the market place with the losses severe in some ALVs and only subtle and relatively lower in kales. Post – cooking, kales had statistically comparable β-carotene content to ALVs save for when compared with purple amaranths and blacknight shade. Due to losses experienced in ALVs, kales are not comparatively inferior vegetables in terms of β-carotene content. Measures to prevent β-carotene losses in ALVs between the farm and market, during cooking and drying should be instituted in order to benefit from their high β-carotene content.

Key Words: kales, β-carotene losses, market, cooking, Brasica oleracea var acephala

INTRODUCTION

Vitamin A deficiency continues to be of public health significance especially among children under five years old, and pregnant and lactating women. In recent years, new physiological functions of vitamin A have been identified in addition to its role in vision. These include immune defense reducing morbidity of measles, of respiratory and possibly HIV infections; in gene regulation; and in cell differentiation and morphogenesis.[1] Worldwide, pre-formed vitamin A accounts for nearly 65% of total vitamin A intake, whereas carotenoids make up the rest.[2] This contribution of non pre-formed vitamin A sources is expected to be higher in sub-Sahara Africa where animal source foods are scarce compared to in the developed countries. The majority of African populations depend on plant sources (pro-vitamin vitamin A source) as conversion to 2 molecules of vitamin A in a physiologically their main supply of the vitamin. Pro-vitamin A carotenoids from foods of plant origin are more affordable than pre-formed vitamin A from animal sources, and many resource-poor households rely on yellow/orange-fleshed vegetables and fruits and dark-green leafy vegetables as their main source of vitamin.[3] The role of β-carotene in fulfilling the recommended intake for vitamin A is apparent from a variety of studies.[4]

The contribution of African leafy vegetables (ALVs) to vitamin A intake in the diets of the growing communities, relative to other plant source is of appreciable significance. ALVs contributed 65.7% of vitamin A from plant sources and 32.7 % of total household vitamin A intake in Western Kenya (the study area), for instance.[5] In ALVs, the most important pro-vitamin is the β-carotene which is relatively high in content compared to other carotenes. The uniqueness of β-carotene is that compared with other carotenoids, it has a β-ionone structure as the terminal ring system on each end of the polyene chain, and its con version to 2 molecules of vitamin A in a physiologically

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regulated manner. The oxidative cleavage of β-carotene, the major carotenoid of human diets, is achieved by beta-carotene 15,15'-monooxygenase 1 (BCMO1), which cleaves b-carotene into 2 molecules of all-*trans*-retinal (retinal-aldehyde).[4] β-carotene is lost during processing at varying amounts for different vegetables through isomerization and oxidation.[6-8] This loss is important in estimating the amount of vitamin A effectively consumed by the population.

Over few recent years, there may have been over emphasis on the consumption of ALVs due to their higher vitamin A and minerals content compared to kale, a vegetable more recently introduced into Kenya and other African countries. Kale (an 'African exotic vegetable) is much easier to produce compared to other vegetables, and requires fewer chemical inputs and less labor. Another key advantage is that when kale is sufficiently nourished with compost manure and well watered, it produces huge volumes of leaves, which can be harvested repeatedly (several times a week from the same plant).[9] This study utilized green leafy vegetables sample analysis for two related studies - one to study the marketing of ALVs and the other to study the contribution of ALVs to dietary vitamin A intake in a rural community; it seeks to evaluate this recommendation.[5,10] This was done through comparing β-carotene contents of farm fresh, market and cooked ALVs to one another and to kales. Kale is the most consumed green vegetable in both urban and rural areas of East Africa.[9] Kale, however have been reported to be inferior in β-carotene content to most ALVs.[5,9] With the traditional practice of cooking vegetables in combinations, this study also aimed at providing indications of any benefits of this practice to β-carotene content of ALVs.

Most of the β-carotene or retinal equivalent values for ALVs provided in food composition tables reflect values for simulated preparations/conditioning in laboratory or in controlled set ups. These may not represent the true values due to the variety of preparation methods used by different households and communities. In addition, most food composition values lack values of cooked and market ALVs samples. Thus secondarily, this present paper thus secondarily also offer some empirical values of ALVs marketed and cooked in rural households of western Kenya.

METHODS

In total, 10 types of vegetables were collected from farmers as raw and fresh. They were then cooked and dried in Butere-Mumias District and transported to Nairobi (~400 km away) for β-carotene analysis. Butere-Mumias District is divided into four divisions but the study focused on the two where the ALVs are most extensively grown – Butere-Mumias district (Figure 1). The district has since been divided into two - Butere and Mumias districts. The vegetables considered were kales, cowpea leaves blacknight shade (African nightshade), pumpkin leaves, jute mallow, spider plant, sun hemp (slender leaf), purple amaranths, white amaranths and Ethiopian kales. The botanical names of the vegetables are shown in Table 1.

Sample collection and preparation

Among the farmers interviewed in a vitamin A survey those growing the ALVs were randomly selected using random tables. The same was repeated for the vegetables cooked in combinations; the different vegetable combinations considered are shown in Figure 1. Observations on the ingredients used and the process of preparation (cooking) were recorded by trained enumerators. For each raw and cooked vegetable type, 4 different farmers were considered – 2 from a Butere division and 2 from Mumias division. Each selected farmer was then instructed to prepare (cook) the edible portions in the usual way known to them without any standard instructions given. From each of the division in the study areas, 2 of each vegetable samples were collected from the market. Four randomly selected farmers growing vegetables commonly dried in the study area were asked to sun-dry the vegetables in the 'normal' way again without being given specific instructions. Triplicate samples were collected. Observations on the process of preparation and drying were recorded.

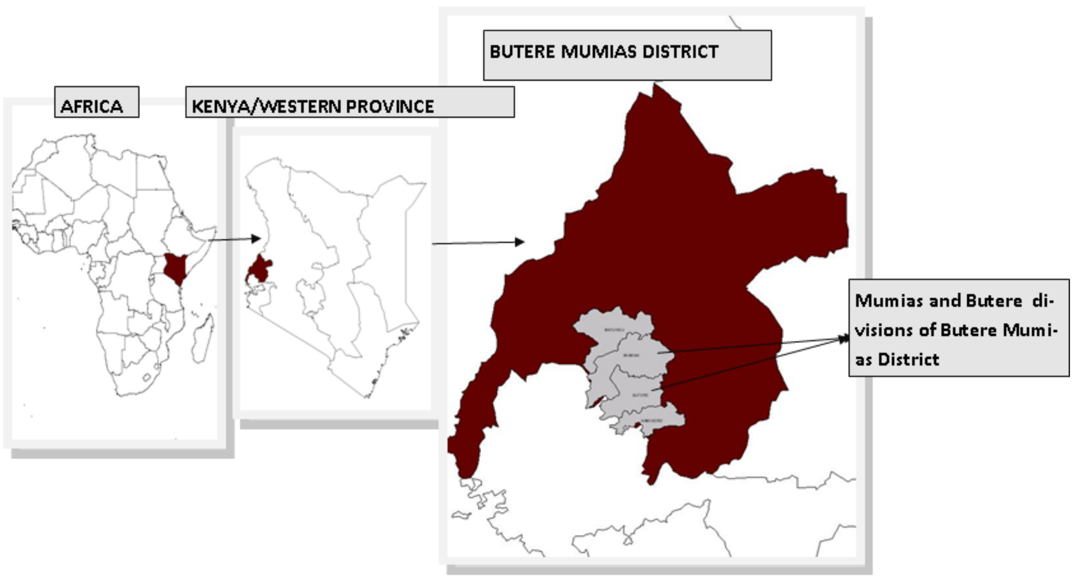


Figure 1. Study location

Sample transportation and β-carotene analysis

All the collected samples were placed in cool boxes (packed with ice-cubes) immediately after collection and transported to the Nairobi University Food Laboratories overnight. The cool boxes temperatures were maintained at below 4^{o}C during the ~6-8 hour trip. β-carotene content was analyzed using a High Performance Liquid Chromatography (HPLC). For each sample, the analysis was done in triplicate. The β-carotene content of the 4 separate samples were averaged to give the mean β-carotene content of respective vegetables.

Data analysis

The mean of triplicate samples considered were averaged to give the β-carotene level of a particular vegetable form (raw, marketed, cooked single, cooked combined and dried). Significant differences between raw and marketed samples were found by comparing confidence intervals (CI) (at α=0.05 level of significance) of the means. Absolute and percent changes as a result of processing were used to compare the β-carotene losses among the vegetables. To arrive at the mean β-carotene content of the vegetables cooked separately and then mixed, an assumption of equal composition of the vegetables in the mixture by weight was made.

Study ethical considerations

The study was approval by the College of Agriculture and Veterinary Sciences, University of Nairobi and all those who participated consented prior involvement in the research.

Limitations of the study

This study did not control for the methods of preparation and ingredients used as has been done in other studies where confounding factors are taken care of. The study was also not able to account for the agronomic variables including soil type and farming practices that my influence the nutrient content in the studied vegetables.

RESULTS

β-carotene content of raw African leafy vegetables

Farm-fresh ALVs had varied level of β-carotene content ranging from 1.04 mg/100 g in white amaranths to 7.62 mg/100 g edible portion in blacknight shade (Table 1). Save for the white amaranths, the ALVs exhibited significantly higher levels of β-carotene as compared to the kales when in raw forms. Based on the CIs, the β-carotene levels in raw samples were not significantly different among the ALVs. Comparing the farm and the market samples, the β-carotene content in cowpea leaves, pumpkin and sun hemp were significantly different thus depicting them as the most vulnerable to vitamin a losses in between the farm and the market. Although majority of the vegetables had significantly higher β-carotene content than the kales when in raw form, the situation was observed to be different at the market place where only purple amaranths and the pumpkin leaves exhibited significantly higher β-carotene content than the kales. The difference between farm and market samples was found highest in sun hemp and blacknight shade (3.36 and 3.26 g/100 g edible portion respectively) and lowest in kales (0.65 g/100 g) and jute mallow (0.87 g/100 g).

Effect of cooking on β-carotene content

Table 2 shows that cooking at household level lead to loss of β-carotene in the vegetables with jute mallow depicting the highest reduction of the carotene. Kales and purple amaranths remained much more stable during cooking, not depicting any loss of β-carotene. After cooking, the β-carotene content of kales was not statistically different (considering the CIs) to the content in ALVs, and this was *vice versa* for the β-carotene content in the raw vegetables. The ratio of the β-carotene content in ALVs to the content in kales was also computed for both raw and cooked samples (Table 2) to further compare the levels. While all the vegetables were superior to kales (in terms of β-carotene content) when raw (farm fresh), only two – the blacknight shade and purple amaranths were superior to kales after cooking (ratio >1.0). Cowpea leaves and jute mallow were found to be inferior to kales after cooking (ration <1.0) whereas other vegetables which depicted the ratio ~1.0 indicated comparability with kales.

As shown in the Table 3, the ingredients used for preparing kales are not profoundly different from those used in the preparation of the ALVs. Those that can influence vitamin A content such as fats and oils (which are mostly fortified with vitamin A), tomatoes and milk are used

Table 1. β-carotene content of raw farm vegetables and market samples

Vegetable	Botanic name	β-carotene content in mg/100 g edible portion (CI)	
		From farm (fresh)	From market
White amaranths (White pigweed)	*Amaranthus albus*	1.04 (-0.17-2.24)	ND
Kales (not an ALV)[‡]	*Brasica oleracea var acephala*	3.33 (2.54-3.52)	2.68 (2.13-3.23)
Purple amaranths	*Amaruthus lividus*	4.92 (3.39-6.45)	5.97 (3.84-8.09)
Cowpea leaves	*Vigna unguiculata*	5.24 (3.61-6.87)	2.62 (2.53-2.71)
Ethiopian kales	*Brassica carinata*	5.26 (2.01-8.51)	ND
Jute mallow	*Corchorus olitorius*	6.38 (5.29-7.47)	5.51 (2.37-8.65)
Pumpkin leaves[†]	*Cucurbita maxima*	6.53 (5.56-7.50)	4.16 (4.08-4.24)
Sun hemp (slender leaf)[†]	*Crotalarias ochroleuca*	7.46 (6.21-8.71)	4.10 (2.73-5.46)
Spider plant	*Cleome gynadra*	7.57 (6.64-8.50)	4.94 (1.93-7.94)
Blacknight shade (African nightshade)	*Solanum spp*	7.62 (5.24-10.0)	4.26 (2.03-6.48)

ND: Not done. This was because the samples were not available in the markets at the time of the study.
[†]Significant difference between farm and market samples.
[‡]Although kales in not an ALV, it is the most commonly consumed vegetable in Kenya and one of the most consumed vegetable in the study area.[5]

across all the vegetables. Decanted salt which is used to soften the vegetables is also used in most preparations. Ingredients that were common across all the vegetables (not shown in the Table 3) were water, salt and onions. All the processing methods used on the vegetables were used on the kales – with variabilities observed in the ALVs. For jute mallow, which exhibited the highest reduction (% reduction) in the β-carotene content, only two processes were used – shredding and boiling. Further for sun hemp which was the second in the loss, they were only boiled.

Figure 2 depicts the comparison of the mean β-carotene content of vegetables when cooked separately (and then mixed) and the content when cooked in combination. Out of the 5 common combinations analyzed, 3 had higher β-carotene levels compared to the mean of the individual vegetables when cooked separately (Figure 2). Further, combinations C2 and C3 were statistically higher β-carotene levels as compared to when cooked separately and mixed. Only one combination (C1) exhibited sigficantly lower β-carotene content as compared to samples that were cooked separately.

β-carotene content of some sun dried ALVs were also analyzed. Sun drying reduced the β-carotene content in edible portions of all the vegetables by between 43-74% (Table 4). Out of the four analyzed vegetables, the highest reduction was observed in sun hemp and the lowest in jute mallow. Sun hemp and jute mallow also manifested highest and lowest drop in absolute values of β-carotene-40.1 and 16.0 mg/100 g dry weight edible portion respectively. The drying time ranged between 2 days (for cowpea leaves) and 4 days (for sun hemp).

DISCUSSIONS

The results have brought to the fore, new values of β-carotene content to be used for estimating vitamin A intake from ALVs in Kenya and perhaps in Africa. The values presented herein are more pragmatic in the sense that they represent the actual content as processed at the household level or found in the markets. This is not the case for currently used values in Kenya as reported by Sehmi et al and Maundu et al.[13,14] In these commonly referred to publications, the values presented are either values of raw or cooked samples; moreover, and for the few cooked items, the cooking processes are simulated at the laboratory level. This means that the values may not be a true reflection of the actual values for the vegetables found in the rural households and markets.

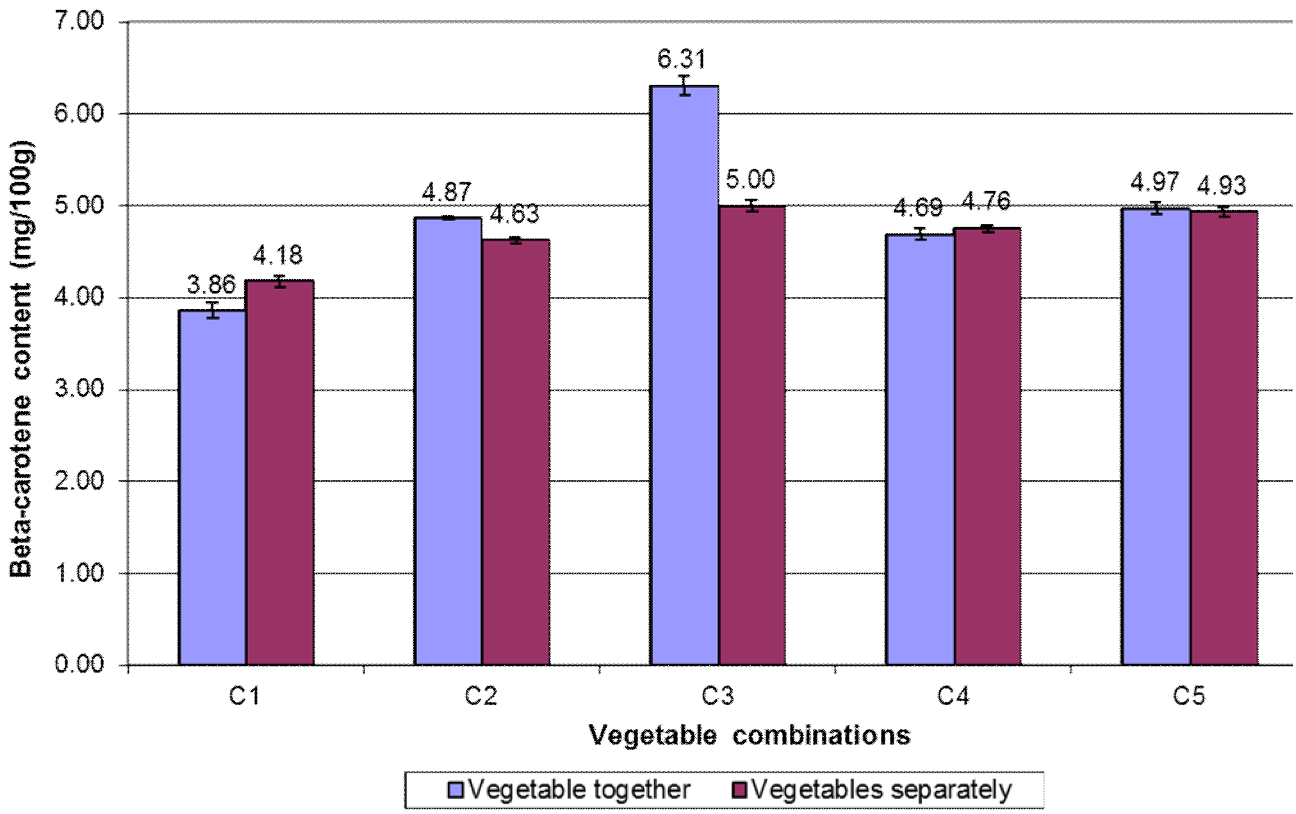
There are losses in β-carotene content as farm-fresh vegetables are moved to the market and the level of change in the content is vegetable specific; therefore and the loss factors can be used to estimate for the market

Table 2. Change in β-carotene content of vegetables as result of cooking

Vegetables	β-carotene content in mg per 100 g edible portion (CI)			Ratio of β-carotene content to that of kales	
	Raw	Cooked	% Change	Raw	Cooked
Kales	3.33 (2.54-3.52)	4.47 (2.13-3.23)	47.4	1.0	1.0
Cowpea leaves	5.24 (3.61-6.87)	3.72 (2.53-2.71)	-29.1	1.7	0.8
Blacknight shade	7.62 (5.24-10.0)	5.71 (2.03-6.48)	-25.1	2.5	1.3
Pumkin leaves	6.53 (5.56-7.50)	4.15 (4.08-4.24)	-36.5	2.2	0.9
Jute mallow	6.38 (5.29-7.47)	2.23 (2.37-8.65)	-65.1	2.1	0.5
Spider plant	7.57 (6.64-8.50)	4.74 (1.93-7.94)	-37.4	2.5	1.1
Sunhemp	7.46 (6.21-8.71)	4.46 (2.73-5.46)	-40.2	2.5	1.0
Purple amaranthus	4.92 (3.39-6.45)	6.22 (3.84-8.09)	26.4	1.6	1.4

Table 3. Ingredient and processes used in cooking of the vegetables

Vegetables	Ingredient used					Processes utilized				
	Fats/ oils	G. nut paste	Tomatoes	Milk	Decanted salts	Shredding	Squeezing	Boiling	Frying	Mashing
Kales	✓	✓	✓	×	×	✓	✓	✓	✓	✓
White amaranths	✓	×	✓	✓	×	×	×	✓	✓	×
Purple amaranths	✓	×	✓	✓	×	×	×	✓	✓	×
Cowpea leaves	✓	✓	✓	×	×		×	×	✓	×
Ethiopian kales	✓	×	✓	✓	×	✓	×	✓	✓	×
Jute mallow	×	×	×	✓	✓	✓	×	✓	×	×
Pumpkin leaves	✓	×	✓	✓	✓	×		✓	✓	✓
Sun hemp	✓	✓	✓	✓	✓	×	×	✓	×	×
Spider plant	×	✓	✓	×	✓	×	×	✓	✓	×
Blacknight shade	✓	×	✓	✓	×	×		✓	✓	✓



Key: Vegetable combinations.
C1=Sun hemp, Jute mallow, Cowpea leaves and Purple amaranths.
C2=Cowpea and purple amaranths.
C3=Spider plant, Blacknight shade, Purple amaranths and Ethiopian kales.
C4=Pumpkin leaves and Purple amaranths.
C5=Pumpkin leaves and Purple amaranths and Sun hemp.

Figure 2. β-carotene content of vegetables cooked in combination and separately

Table 4. β-carotene content of raw and sun dried vegetables

Vegetable	Days of drying	β-carotene content (mg/100 g dry weight edible portion)		% Change
		Raw	Sun dried	
Jute mallow	3	37.4 (32.2-42.5)	21.4 (21.1-21.6)	-42.8
Cowpea leaves	2	38.1 (17.7-58.6)	10.4 (10.1-10.6)	-72.8
Sun hemp	4	54.0 (41.8-66.2)	13.9 (13.8-14.0)	-74.2
Purple amaranths	3	54.1 (40.7-67.5)	26.3 (26.1-26.5)	-51.4

values if the content on-farm is known. Relatively higher losses are observed for cowpea leaves, pumpkin leaves, and sun hemp – depicting them as most vulnerable to vitamin A losses between the farm and the market. This is particularly important given that most ALVs consumers are not growers, but purchase them from the markets. In general the losses are potentially due to the storage methods used and the extended time taken before they reach the market. It has been found that storing the vegetables for longer time at room temperature gradually decreases β-carotene content of vegetables.[11] While kales do not generally compare in terms of β-carotene level with ALVs when raw and fresh, it favorably compares at market place. Further, kales are the most stable in terms of β-carotene change between the farm and the market. This finding means that the perceived superiority of the ALVs over the 'common vegetable' (kales) does not necessarily hold unless measures are put in place to prevent β-carotene losses in ALVs between harvesting and market place. Significant losses in pumpkin leaves and sun hemp and only subtle changes in kales and jute mallow is an indication of inherent or external factors (or a combination of these factors) in contributing to the variations in β-carotene losses. These factors need to be understood. Nevertheless, β-carotene loss during storage is mainly due to oxidation which may not be enzymatic and is directly related to available water (water activity), oxygen and heat and certain metals.[8] Preservation processes that reduce water activity, oxygen and heat can reduce β-carotene losses in fresh vegetables before reaching the market place. The losses have a dietary significance. When translated to retinal equivalents (RE) using the conversion factor of 12:1, as high as 280 μgRE/100 g in ALVs (between the farm and market) is lost, an amount equivalent to daily recommended intake of vitamin A for toddlers in Kenya.[12,13]

During cooking β-carotene losses occur through β-carotene oxidation and sterioisomerisation and the differences vary from vegetables to vegetables, some depicting relatively more stability. It is imperative to note that the vegetables were analyzed post-cooking together with all the ingredients used and that the methods of preparation were not dictated or specified to those who prepared them. The recorded ingredients used however did not indicate any possible influence on β-carotene content by the ingredients added. The methods of preparations were not controlled for as was done by Farber et al. Farber et al found a significant difference in the total and trans β-carotene content when amaranths were boiled and fried. [15] Further the household methods employed for most vegetables during cooking employed both boiling and frying. The observation that kales are much stable and comparable to ALVs post-cooking opens up a number of possibilities including: the inherent community knowledge on the relative nutritional values (β-carotene content) which prompt them to compensate (during cooking) for vegetables whose content is low when raw. The compensatory practice may take the form of the preparation method such as length of cooking. Observations have shown that all the possible processes for the vegetables were used on kales, and thus variations in the β-carotene content in kales and ALVs cannot be explained by the choice of the preparation method. There is also an observation that ALVs with comparatively higher β-carotene lose more of the carotenes than otherwise; and the difference in occurrence of β-carotene and structural formation may explain the differences in looses. In terms of the dietary implication, these findings points to the fact that ALVs may not be superior vegetables in the form which they are consumed (cooked). It is known that the potential contribution of plant foods to vitamin A status depends on the retention of pro-vitamin A carotenoids after storage, preparation and processing.[3]

There are indications that the traditional practice of combining vegetables during cooking may have imperative dietary implication of potentially heightening the β-carotene levels when compared to vegetables cooked separately. Factors that may contribute to the benefit of combining the vegetables may include cocking time and relative ALVs constitution (by weight) of the various combinations. There is need for further research and affirmation of the observations and the elucidation of the possible reasons for the changes in vitamin A content as a result of ALVs combinations.

β-carotene content of ALVs reduces significantly when sun-dried, with as high as 74% reduction observed mainly due to direct solar heat which accelerates oxidation and sterioisomerisation of β-carotenes. This is indicative that while sun drying may be a simple method of preservation in rural set-ups where the vegetables are grown and in abundant, it leads to substantial reduction in the nutritional value in terms of vitamin A content.

Conclusions

Kales are not inferior vegetables as it regards to β-carotene content compared to ALVs at the point of sale in the market and post-cooking. The benefits of higher β-carotene content of ALVs (*Vis a Vis kales*) can only be fully harnessed if measures to prevent losses between the farm and market and during cooking. There are indications that traditional practice of cooking vegetables in combinations has benefits beyond the organoleptic qualities, contributing to higher β-carotene content in cooked ALVs, albeit the explanations not well known. Sun drying leads to substantial loses in the β-carotene content of ALVs.

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AUTHOR DISCLOSURES

The authors declare that there was no conflict of interest before, during and after conducting the research.

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Original Article

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肯尼亚叶菜处理和烹饪过程中 β-胡萝卜素的损失意味着羽衣甘蓝没有营养比较优越

非洲的叶菜类蔬菜（ALVs）因富含 β-胡萝卜素而著称，由于其营养优势，羽衣甘蓝被作为首选。在不同农场和市场选择 10 种不同的蔬菜，分析 β-胡萝卜素的含量。研究区域的社区成员采用常规方式，而不是指示或给定的条件制备煮熟的蔬菜（单一或组合），以及太阳晒干样品，使用高效液相色谱法 (HPLC) 分析 β-胡萝卜素含量。在实验室不控制或模拟家庭处理或加工方法的条件下，研究结果提供了新的具有代表性的、新鲜、市场销售、熟食和干燥蔬菜中 β-胡萝卜素含量。作为 β-胡萝卜素的来源，与生的 ALVs 相比，羽衣甘蓝可食用部分 β-胡萝卜素含量相对较低。这是在没有市场的地方，羽衣甘蓝的水平相当 β-胡萝卜素。在市场出售农场新鲜 ALVs 前，差不多 280 μRE／100 g（饮食上有意义的数量）可以通过 β-胡萝卜素的氧化过程丢失。这种丢失情况在一些 ALVs 或者微小且含量低的羽衣甘蓝中更严重。加工后的羽衣甘蓝 β-胡萝卜素含量与紫苋菜和深色的蔬菜相当。由于 ALVs 加工过程中的损失，就 β-胡萝卜素含量而言，为了从高的 β-胡萝卜素含量中受益，应在 ALVs 农场和销售环节采取措施，阻止烹饪和干燥过程中 β-胡萝卜素含量的损失。

关键词：羽衣甘蓝、β-胡萝卜素损失、销售、烹饪、巴西利亚变种羽衣甘蓝