Effect of thermal processing on carotenoids compared among organic and conventional vegetables

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Abstract
The nutritional requirements are fulfilled by the vegetables through their daily consumption. Carotenoids are vital components of the vegetables which provide various health benefits apart from providing pigmentation to the plant crops. During cooking processes, various nutrients are either degraded or increased depending upon the type of cooking method employed. The aim of the present study was to evaluate the effect of different cooking methods on the carotenoids composition among organic and conventional vegetable crops. The samples in the present study included six vegetables divided into three groups depending on the nature of vegetables as green leafy vegetables, tubers and traditional vegetables. Moringa and amaranth were green leafy vegetables, carrot and sweet potato were tubers and tomato and bitter gourd were traditional vegetables. The cooking methods employed in the study included microwave, steaming, boiling with lid and boiling without lid processes.

The results observed in the study showed the presence of lutein and β-carotene in all the analyzed samples whereas β-cryptoxanthin, α-carotene and γ-carotene were not found in any of the samples with exception of carrot for the presence of α-carotene. The different cooking processes had varying effects on the carotenoids composition with almost all cooking processes showing the reducing trend in comparison to the uncooked samples. The highest total carotenoids were found in Moringa samples (19413-34930 µg/100g) whereas the least total carotenoids were found in bitter gourd samples (493-675 µg/100g). The present study will provide a detailed insight about the required information.

Keywords: Organic, Conventional, Vegetables, Cooking, Carotenoids.

Introduction
The increasing consumer demand for organic vegetables has prompted significant research into their nutritional profiles and health benefits. Among the various phytochemicals present in these vegetables, carotenoids have emerged as a focal point of study due to their potent antioxidant properties and their role in human health. Carotenoids, a class of pigments responsible for the vibrant colors of many fruits and vegetables, are not only critical for plant health but also contribute to essential biological functions in humans. These compounds are known to play a protective role against chronic diseases including certain cancers and cardiovascular conditions, by mitigating oxidative stress and enhancing immune function[18].

The growing consumer interest in organic vegetables has sparked extensive research into their nutritional profiles and associated health benefits[19]. Among the myriad of phytochemicals found in these vegetables, carotenoids have garnered particular attention due to their remarkable antioxidant capabilities and their significant contributions to human health. Carotenoids are a diverse class of pigments that impart the rich, vibrant colors seen in many fruits and vegetables, serving not only vital functions in plant growth and development but also playing crucial roles in various biological processes within the human body. These compounds are recognized for their protective effects against a range of chronic diseases including specific types of cancer and cardiovascular disorders. They achieve this by combating oxidative stress, a condition characterized by an imbalance between free radicals and antioxidants in the body, which can lead to cellular damage[14, 17].

Carotenoids are a diverse group of naturally occurring pigments found abundantly in various vegetables, playing a crucial role not only in plant health but also in human nutrition[10]. These pigments are responsible for the vibrant red, orange and yellow hues that characterize many fruits and vegetables. Among the most well-known carotenoids are β-carotene, lutein, zeaxanthin and lycopene, each contributing unique health benefits. β-Carotene, for instance, is a precursor to vitamin A, which is essential for maintaining healthy vision, supporting immune function and promoting skin health. This carotenoid is commonly found in carrots, sweet potatoes and butternut squash, making these vegetables vital for a balanced diet. Lutein and zeaxanthin, on the other hand, are particularly concentrated in green leafy vegetables. Lycopene, primarily found in tomatoes, watermelon and pink grapefruit, is another powerful carotenoid that has garnered attention for its potential role in reducing the risk of certain cancers, particularly prostate cancer. Its strong antioxidant capacity helps to neutralize free radicals, thus safeguarding cells from damage[11].

In addition to their individual health benefits, carotenoids also work synergistically with other nutrients found in vegetables, enhancing their overall nutritional profile. Consuming a diet rich in carotenoid-containing vegetables not only supports individual health but also promotes a vibrant, diverse diet that can lead to long-term wellness. Research has increasingly highlighted the significance of carotenoids as potent antioxidants, contributing to the prevention of chronic diseases and promoting overall health. With a growing body of evidence linking carotenoid intake to reduced risks of conditions such as cardiovascular disease and certain types of cancer, understanding the distribution, bioavailability and metabolic pathways of these compounds in vegetables is imperative[20].

The impact of various cooking methods on carotenoids is vital due to the health benefits associated with these pigments[12]. The type of cooking method can substantially influence the bioavailability and stability of these vital compounds. Different cooking techniques such as boiling, steaming and frying can lead to varying degrees of carotenoid retention and transformation. Understanding how these methods impact carotenoid stability and bioavailability is essential for optimizing dietary practices and maximizing the nutritional benefits of carotenoid-rich foods. As such, incorporating a variety of cooking techniques while being mindful of time and temperature can help to preserve these important nutrients in our diets.

The method of cooking can significantly influence the bioavailability and retention of carotenoids in vegetables, altering their health benefits[3,13]. For instance, while raw consumption of certain vegetables may preserve their carotenoid content, cooking techniques such as steaming can enhance absorption by breaking down cell walls, thus making these nutrients more accessible to the body. Research indicates that lycopene levels, for example, increase when tomatoes are cooked, which could potentially amplify its protective effects against cancer. Conversely, excessive heat or prolonged cooking times may lead to degradation of sensitive carotenoids like lutein and zeaxanthin, underscoring the importance of optimal cooking practices in maximizing nutrient intake.

Therefore, understanding how different cooking methods affect carotenoid stability not only informs dietary choices but also supports public health initiatives aimed at promoting vegetable consumption for improved nutritional outcomes. The variation observed for the carotenoids components among organic vs conventional Indian fruits and vegetables has been reported earlier[15]. Vegetables form an important part of the food through which the carotenoids are provided in the diet.

However, vegetables are normally cooked by various methods before consumption and the effect of various cooking methods on the retention of carotenoids is scarce. The commonly consumed vegetables in India are being grouped into green leafy vegetables, traditional vegetables and tubers. The present study aimed to analyze and to compare the carotenoids in the organic and conventional cultivated vegetables. The retention of carotenoids in the green leafy vegetables, traditional vegetables and tuber vegetables was analyzed in the study.

Material and Methods

Sample collection: The samples were grouped into green leafy vegetables, traditional vegetables and tubers. Among each group, two different types of samples were selected for study which included; Moringa leaves (*Moringa oleifera*) and green amaranthus (*Amaranthus viridis*) in green leafy vegetables, tomato (*Solanum lycopersicum*) and bitter gourd (*Momordica charantia*) in traditional vegetables and sweet potato (*Ipomoea batatas*) and carrot (*Daucus carota subsp. sativus*) in tubers group.

Both the organic and conventional vegetable samples were harvested from two different locations of Arivu organics, Karnataka, India and PPR farms, Telangana, India. To ensure the uniformity and comparative analysis, the organic and conventional farms' proximity were separated by 5 kilometre distance which provides a robust approach to evaluate the nutritional values among the analysed samples including the farming practice approaches.

Sample processing and preparation: Once the samples were brought to the laboratory, they were thoroughly washed under tap water for removing any extraneous matter. The excess water was removed from the sample surface by air drying on the blotting paper. The samples were further processed for different cooking methods. The air-dried uncooked samples were homogenized using a steel mixer grinder and directly used for analysis. For microwave cooking, the samples were microwaved in a standard home microwave unit, homogenized in a steel mixer grinder and subsequently analyzed. In the case of cooking with a lid, the samples were boiled in a closed vessel to minimize air exposure, then ground using a mixer grinder before being subjected to analysis.

Conversely, in the cooking without a lid method, the samples were boiled in an open vessel, allowing maximum air exposure and then homogenized using a steel mixer grinder for further analysis. To ensure consistency and to allow for additional testing, homogenized samples from all methods, both uncooked and cooked, were stored in PET airtight containers at -20°C and preserved for future analysis if needed.

Chemicals: All the chemicals used were of analytical grade procured from Merck KGaA (Darmstadt, Germany). Reference standards chemicals were obtained from Sigma Aldrich (St. Louis, Missouri, USA). Ultra-pure water was used for the analysis purpose (MilliQ®, Merck KGaA, Darmstadt, Germany).

Total carotenoids: Caroteniods were analyzed according to the previously reported method[9]. In brief, sample was extracted using 10 mL of 12% methanolic KOH under dark condition, vortexed for 2 min and incubated at room temperature for 30 min. Further, petroleum ether was added to the solution until it appears to be colorless. Now vortex and pool the upper layer into round bottom flask. The obtained solution was concentrated using rotary evaporator and the obtained residue was reconstituted using 3 mL of chloroform.

The absorbance of the re-constituted solution was observed at 450 nm (UV-Vis spectrophotometer, Analytikjena U-2800 Specord S.600, Germany). Total carotenoid content was calculated using the equation:

$$\text{Total carotenoid content } = \frac{\text{A x volume x } 10^4}{\text{AE x sample weight}} \text{ x } 100$$

where A = absorbance of sample, volume = total volume of extract and AE = absorption co-efficient of β-carotene in petroleum ether.

Carotenoids profile: Carotenoids profile was evaluated using the HPLC method[2]. HPLC system consisted of Dionex Ultimate 3000 RSLC system. The column used for the analysis was C18 column (Spherisorb waters® 150 x 4.6mm, 5µm) maintained at 25˚C. Elution was isocratic using the mobile phase acetonitrile : dichloromethane : methanol in the ratio of 7:2:1 (v/v/v). The injection volume was 2 µL and the flow rate was 0.8 mL/min. The photodiode array detector was used for quantification at wavelength of 300-600 nm. The results were reported as microgram per 100g (µg/100g) of sample.

Statistical analysis: The analysis for One-way Analysis of Variance (ANOVA) was subjected for significant variation ($p<0.05$) evaluation by the SPSS software (IBM SPSS Statistics, Version 24.0., IBM Corp., Armonk, USA). The results for the obtained values are represented as standard deviation (±SD) of the mean of replication results (n=3).

Results and Discussion

Green leafy vegetables: The carotenoids profile among the analysed green leafy vegetables samples is recorded in table 1 ($p<0.05$). In Moringa, the highest concentrations of total carotenoids (TC) were observed in the UNC sample (34930±57.93 µg/100g), suggesting that eschewing thermal processing preserves the highest levels of carotenoids. Among the cooking methods, steaming (STE) and microwave (MIC) process for organic conditions demonstrated comparatively minimal nutrient degradation, showcasing higher retention of carotenoids. This pattern is also reflected in the lutein and β-carotene measurements where the least thermally invasive methods preserved these nutrients effectively. Green amaranthus sample exhibited analogous trends, with organic UNC sample containing the highest TC value (21185±76.73 µg/100g).

This consistency across both crops underscores that organic cultivation, combined with minimal processing, optimally retains the carotenoids. The data also indicated that cooking methods like steaming and microwaving preserve more nutrients compared to boiling, whether performed with or without a lid. Similarly, Chinese cooking methods were employed among various green vegetables to assess the carotenoids retention and the similar results were recorded in accordance to the present study[7].

The data illuminates the profound impact of culinary methods on the carotenoid content of Moringa and Green amaranthus, delineating a clear preference for uncooked preparations in maximizing nutrient preservation. Among cooking methods, those imposing less thermal stress such as steaming and microwaving were more conducive to the retention of carotenoids, particularly under organic farming conditions. These conditions may enhance the plants' intrinsic carotenoid concentrations, thus offering a superior nutrient profile. The statistically significant differences denoted by the annotations confirm that these variations in nutrient content are not attributable to random fluctuations but are robust, scientifically validated outcomes. Such insights are indispensable for nutritional planning and advisement, particularly in contexts where the dietary intake of carotenoids is prioritized for their health benefits.

Moreover, the non-detection of carotenoids such as β-cryptoxanthin, γ-carotene, α-carotene and all-trans carotenoids among the analysed samples might be due to the lesser limit of detection or below detectable limits among the samples. These findings have pivotal implications for agricultural methodologies, advocating for organic farming coupled with specific cooking practices to optimize the health benefits derived from carotenoids. Such evidence-based research outcomes will provide the consumers for their choices and information to public for healthy recommendations, promoting optimal dietary strategies for the consumption of leafy vegetables.

Traditional vegetables: The significant variation was observed for the carotenoids profile among the analysed traditional vegetables of tomato and bittergourd samples (Table 2, $p<0.05$). In conventional tomatoes, microwaving had reduced the TC content (3055±23.46 µg/100g) significantly ($p<0.05$) in comparison to their raw counterparts (3583±94.27 µg/100g). Similar observation was found in the organic tomato where microwave cooking recorded lower TC levels (3725±36.77 µg/100g) in comparison to the uncooked sample (4049±52.18 µg/100g). Both steaming and boiling irrespective of lid usage sustained higher TC content, although boiling without a lid (3101±74.48 µg/100g in conventional; 3622±93.81 µg/100g in organic) exhibited a marginal reduction when compared against other employed cooking methods.

Table 1
Effect of cooking processes on the micronutrient composition compared between organic and conventional green leafy vegetables (GLVs)

Moringa	**Conventional (µg/100g)**					**Organic (µg/100g)**				
	UNC	**MIC**	**STE**	**BWL**	**BOL**	**UNC**	**MIC**	**STE**	**BWL**	**BOL**
TC	34492±55.90^{e}	19413±55.46^{a}	25658±95.11^{c}	28560±86.73^{d}	24797±67.63^{b}	34216±81.03^{d}	19535±94.39^{a}	34930±57.93^{e}	29637±85.77^{c}	25554±67.19^{b}
Lutein	14294±64.46^{e}	10296±48.87^{a}	12271±44.10^{c}	13226±6.82^{d}	11143±27.68^{b}	14310±51.52^{d}	11289±24.63^{a}	13195±60.19^{b}	14066±37.90^{c}	13281±86.43^{b}
β-Crypt	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
γ-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
β-Carotene	16199±79.68^{e}	10224±69.69^{a}	15873±88.86^{d}	15146±21.03^{c}	13518±73.92^{b}	17282±62.09^{e}	15419±70.79^{b}	16632±40.05^{d}	16193±59.94^{c}	15070±94.06^{a}
All-Trans	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Green amaranthus	**Conventional (µg/100g)**					**Organic (µg/100g)**				
	UNC	**MIC**	**STE**	**BWL**	**BOL**	**UNC**	**MIC**	**STE**	**BWL**	**BOL**
TC	19745±79.91^{e}	16745±68.97^{c}	18329±76.06^{d}	14902±86.66^{b}	14078±79.34^{a}	21185±76.73^{e}	18841±70.04^{b}	20314±61.83^{c}	20496±65.35^{d}	17074±41.33^{a}
Lutein	8670±70.44^{a}	7911±49.81^{b}	8524±66.77^{d}	8280±61.78^{c}	7452±51.79^{a}	8608±63.05^{d}	8057±13.11^{b}	8209±60.36^{c}	8236±16.65^{c}	7327±81.77^{a}
β-Crypt	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
γ-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
β-Carotene	8268±58.55^{d}	6094±51.90^{b}	7222±44.21^{c}	8153±96.38^{d}	5091±70.17^{a}	8505±64.82^{e}	6293±61.02^{a}	7200±67.84^{c}	8146±14.38^{d}	6527±22.92^{b}
All-Trans	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

TC-total carotenoids, β-Crypt- β-Cryptoxanthin, UNC-uncooked, MIC-microwave, STE-steaming, BWL-boiling with lid, BOL-boiling without lid, Superscript in the rows for different cooking process compared with uncooked sample within the group organic or conventional for particular parameter is statistically significant ($p<0.05$)

Lutein content in tomato was notably consistent across cooking methods and between the conventional and organic categories, with observed minor variations suggesting the heat stability of lutein (conventional steamed 1040±22.23 µg/100g and organic steamed 1175±10 µg/100g). Another study observed variation among carotenoid composition with different cooking methods of steaming, boiling and microwaving in tomato sample[16].

The β-carotene content in conventional tomato displayed substantial variability, attaining peak levels in the uncooked (842.39±14.22 µg/100g) and steamed (829.06±6.2 µg/100g) conditions. Conversely, organic tomatoes exhibited the highest β-Carotene concentrations in their natural state (828.17±88.46 µg/100g), with notable decreases post-microwaving (618.76±6.54 µg/100g). The influence of cooking on TC content in bitter gourd was comparatively subdued, although conventional bitter gourd samples which were processed by microwave showed lesser TC content (493.37 µg/100g) compared to other cooking processes which ranged between 597.9 – 660.53 µg/100g. Organically grown samples did not demonstrate significant TC fluctuations across different cooking methods. Lutein content in conventional bitter gourd was significantly augmented in the uncooked (316.00±5.56 µg/100g) or lid-boiled scenarios (311.66±3.21 µg/100g). Organic variants typically manifested higher lutein concentrations across all culinary processes when compared to their conventional counterparts, with the apex levels observed in steamed conditions (342.33±7.50 µg/100g). β-Carotene demonstrated remarkable stability across culinary methods in both conventional and organic bitter gourd, suggesting its relative insensitivity to thermal processes in this vegetable as opposed to tomatoes. Effect of thermal stability on β-carotene and other compounds has been explained in the study[6].

The data underscores that culinary methods distinctly influence the micronutrient compositions of vegetables, particularly impacting carotenoid levels. Microwaving is generally associated with more substantial nutrient depletion whereas techniques like steaming and boiling prove more favorable for nutrient conservation.

https://doi.org/10.25303/295rjce027035

Table 2
Effect of cooking processes on the micronutrient composition compared between organic and conventional traditional vegetables

Tomato	**Conventional (µg/100g)**					**Organic (µg/100g)**				
	UNC	**MIC**	**STE**	**BWL**	**BOL**	**UNC**	**MIC**	**STE**	**BWL**	**BOL**
TC	3583 ±94.27^{c}	3055 ±23.46^{a}	3519 ±27.97^{c}	3217 ±78.61^{b}	3101 ±74.48^{ab}	4049 ±52.18^{a}	3725 ±36.77^{a}	3903 ±47.78^{b}	3668 ±39.26^{a}	3622± 93.81^{a}
Lutein	1042 ±31.50^{a}	1028 ±11.59^{a}	1040 ±22.23^{a}	1033 ±19.07^{a}	1009 ±6.24^{a}	1204 ±9.53^{a}	1133 ±23.57^{a}	1175 ±10.00^{a}	1149 ±99.76^{a}	1128± 47.75^{a}
β-Cryp	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
γ-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
β-Carotene	842.39± 14.22	751.66 ±6.23^{a}	829.06 ±6.20^{b}	830.34 ±34.31^{b}	769.62 ±10.33^{a}	828.17 ±88.46^{c}	618.76 ±6.54^{a}	657.4 ±23.25^{ab}	724.93 ±11.81^{b}	679.86± 6.64^{ab}
All-Trans	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bitter gourd	**Conventional (µg/100g)**					**Organic (µg/100g)**				
	UNC	**MIC**	**STE**	**BWL**	**BOL**	**UNC**	**MIC**	**STE**	**BWL**	**BOL**
TC	675.64± 57.15^{b}	493.37 ±81.67^{a}	660.53 ±11.97^{b}	656.08 ±26.39^{b}	597.9 ±25.40^{b}	671.02 ±43.68^{b}	632.43 ±57.82^{ab}	656.62 ±13.34^{ab}	639.51 ±16.41^{ab}	595.15± 22.39^{a}
Lutein	316± 5.56^{b}	223 ±16.09^{a}	230.33 ±22.50^{a}	311.66 ±3.21^{b}	301.66 ±3.05^{b}	367.66 ±23.07^{c}	314.33 ±9.45^{ab}	342.33 ±7.50^{bc}	359 ±22.00^{c}	310.33± 7.63^{a}
β-Cryp	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
γ-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
β-Carotene	126.33± 11.01^{a}	102.06 ±3.68^{a}	121 ±3.60^{bc}	113.33 ±8.02^{abc}	110 ±7.00^{ab}	135.33 ±11.59^{a}	125.63 ±2.05^{a}	131.63 ±3.10^{a}	129.5 ±5.52^{a}	124.66± 2.43^{a}
All-Trans	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

TC-total carotenoids, β-Crypt- β-Cryptoxanthin, UNC-uncooked, MIC-microwave, STE-steaming, BWL-boiling with lid, BOL-boiling without lid, Superscript in the rows for different cooking process compared with uncooked sample within the group organic or conventional for particular parameter is statistically significant ($p<0.05$)

Notably, organic vegetables typically commence with higher nutrient levels, which are nonetheless susceptible to reduction via certain cooking methods. These findings are pivotal for nutritional advice and underscore the significance of culinary methods in dietary management.

Tubers vegetables: Carotenoids profile among the organic and conventional samples of tuber vegetables is reported in table 3 ($p<0.05$). In carrots, significant differences were observed in the total carotenoid (TC) content between cooking methods and cultivation types. Uncooked organic and conventional carrots showed highest TC content of 7408 and 7017 µg/100g respectively. Among the cooking methods, the highest reduction of TC content was observed in microwave processing in organic and conventional carrots with 3407 and 5273 µg/100g respectively. The retention of TC in steamed carrots was higher in organic (6717±93.70 µg/100g) as well as in conventional (6924±69.69 µg/100g) samples. Boiling with and without lids showed a decrease in TC, with organic carrots boiled without a lid displaying a significant drop to 3404±41.74 µg/100g.

For α-carotene and β-carotene, both types showed reductions in content with most cooking methods, but the organic carrots maintained higher concentrations. Specifically, organic carrots exhibited an α-carotene content of 2523±78.49 µg/100g when uncooked, which decreased to 2221±71.89 µg/100g upon boiling without a lid. Conventional carrots showed a significant decrease from 1224±38.85 µg/100g (uncooked) to 1027±24.55 µg/100g when boiled without a lid. The β-carotene in organic carrots also followed this pattern with the highest content in uncooked samples (4898±68.70 µg/100g) and a considerable reduction in microwave samples (3565±75.14 µg/100g).

Sweet potatoes revealed a different pattern. The TC content was highest in organic uncooked samples at 7799 µg/100g and was significantly reduced in boiled samples without a lid to 6656 µg/100g. Conventional sweet potatoes showed the highest TC in uncooked samples (7929±86.12 µg/100g) but experienced a substantial decrease when boiled without a lid (5264±81.47 µg/100g). Lutein content in organic sweet potatoes was highest in the uncooked sample with 272.33±7.63 µg/100g which showed decreasing trend with various cooking methods.

However, the conventional sweet potato sample exhibited the lowest lutein content in microwave (177.33 µg/100g) and boiling with lid (179.00 µg/100g) processes. The variation in β-carotene was similar to that of TC, with organic sweet potatoes maintaining higher levels in most cooking conditions, notably 5198±75.50 µg/100g uncooked, which was significantly higher than the corresponding conventional samples (4141±31.81 µg/100g).

Cooking method such as microwave can lead to significant carotenoid losses irrespective of cultivation method among vegetables. The present study results reveal that the cooking method and vegetable type play an important role in retention of carotenoids in the samples.

Effect of various cooking methods on the distribution of carotenoids among different vegetables has been reported by a study[8]. Each cooking method influences the nutrient availability differently and this must be considered in dietary planning and food preparation to maximize nutrient intake. This study highlights the need for tailored cooking recommendations for different vegetable types to preserve their nutritional value, particularly in terms of carotenoids.

Bioaccessibility of carotenoids: Figure 1 presents a comprehensive comparative evaluation of the bioaccessibility of total carotenoids (TC) contents among analysed samples of conventional and organic carrot, sweet potato, amaranth, moringa, tomato and bitter gourd. The cooking methods employed were boiling with lid, boiling without lid, steaming and microwave which were compared with the raw (uncooked sample) and different farming system. Bioaccessibility of carotenoids among various food groups and their processing effects has been earlier reviewed in a study[4,5].

The results reveal notable variations in the bioaccessibility of TC, contingent upon both the cultivation method and the cooking process employed. For instance, carrots exhibited a marginal reduction in TC under conventional farming compared to their organic counterparts, with uncooked carrots displaying values of 63.81% (conventional) and 60.76% (organic) samples. Cooking processes, such as boiling and steaming, generally resulted in decreased bioaccessibility of TC in carrots, particularly in the organic variant, where significant reductions were observed, especially in the boiling and steaming methods.

The microwave preparation, however, demonstrated relatively stable bioaccessibility of TC. Similarly, effect of various cooking methods on the bioaccessibility of carotenoids in carrot has been reported by a study[1].

Table 3
Effect of cooking processes on the micronutrient composition compared between organic and conventional tuber vegetables

Carrot	**Conventional (µg/100g)**					**Organic (µg/100g)**				
	UNC	**MIC**	**STE**	**BWL**	**BOL**	**UNC**	**MIC**	**STE**	**BWL**	**BOL**
TC	7017 ±41.54^{d}	5273 ±34.90^{a}	6924 ±69.69^{d}	6757 ±43.52^{c}	6533 ±87.66^{b}	7408 ±63.01^{d}	3407 ±81.52^{a}	6717 ±93.7^{b}	7057 ±82.62^{c}	3404 ±41.74^{a}
Lutein	200.86 ±16.41	175.96 ±2.55^{a}	181.53 ±6.70^{ab}	192.00 ±2.55^{bc}	185.00 ±2.32^{ab}	262.33 ±9.86^{b}	212.66 ±6.50^{a}	221.00 ±4.00^{a}	256.00 ±15.62^{b}	214.00 ±2.64^{a}
β-Crypt	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
γ-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Carotene	1224 ±38.85^{c}	1150 ±74.00^{bc}	1134 ±15.09^{b}	1195 ±46.45^{bc}	1027 ±24.55^{a}	2523 ±78.49^{c}	2173 ±36.51^{a}	2474 ±58.12^{bc}	2370 ±95.03^{b}	2221 ±71.89^{a}
β-Carotene	4584 ±69.03^{e}	3140 ±22.60^{a}	3806 ±88.48^{c}	4160 ±83.34^{d}	3273 ±58.10^{b}	4898 ±68.70^{d}	3565 ±75.14^{a}	4725 ±11.06^{c}	4821 ±10.01^{d}	3666 ±49.21^{b}
All-Trans	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sweet potato	**Conventional (µg/100g)**					**Organic (µg/100g)**				
	UNC	**MIC**	**STE**	**BWL**	**BOL**	**UNC**	**MIC**	**STE**	**BWL**	**BOL**
TC	7929 ±86.12^{a}	6725 ±91.53^{b}	7516 ±72.40^{c}	7619 ±73.75^{c}	5264 ±81.47^{a}	7799± 75.27^{a}	7085± 77.08^{b}	7332 ±19.54^{c}	7633 ±62.60^{d}	6656 ±82.93^{a}
Lutein	212.67 ±10.26^{c}	177.33 ±3.21^{a}	185.00 ±1.73^{ab}	190.66 ±6.65^{b}	179.00 ±6.24^{ab}	272.33± 7.63^{d}	253.66± 9.86^{bc}	262.00 ±1^{cd}	250.33 ±4.04^{b}	233.33 ±3.21^{a}
β-Crypt	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
γ-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
β-Carotene	4141 ±31.81^{e}	3146 ±31.64^{a}	3300 ±76.68^{b}	4024 ±3.60^{d}	3653 ±40.27^{c}	5198± 75.50^{e}	3230± 27.07^{b}	4196±39.92^{c}	4979 ±47.37^{d}	3062 ±43.86^{a}
All-Trans	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

TC-total carotenoids, β-Crypt- β-Cryptoxanthin, UNC-uncooked, MIC-microwave, STE-steaming, BWL-boiling with lid, BOL-boiling without lid, Superscript in the rows for different cooking process compared with uncooked sample within the group organic or conventional for particular parameter is statistically significant ($p<0.05$)

https://doi.org/10.25303/295rjce027035

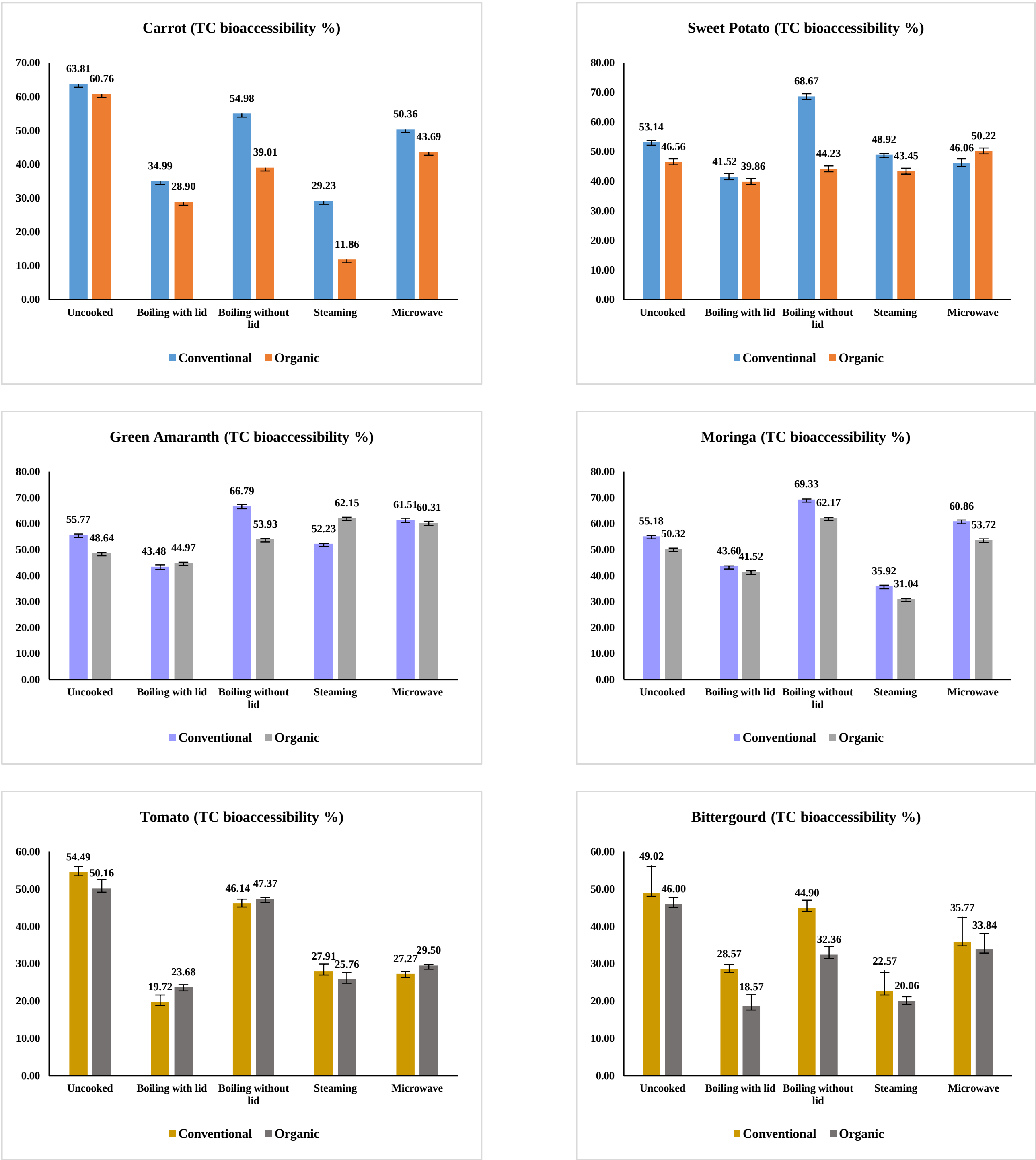

Fig. 1: Comparison of total carotenoids (TC) bioaccessibility (%) among the conventional and organic vegetables of carrot, sweet potato, green amaranth, moringa, tomato and bitter gourd

Similarly, sweet potatoes showed variations with conventional cultivation yielding marginally higher bioaccessibility of TC in the uncooked sample. Contrarily, organic sweet potatoes exhibited slightly enhanced bioaccessibility of TC (50.22%) when processed with microwave cooking in comparison to conventional sample (46.06%). Both boiling and steaming led to reductions in bioaccessibility of TC, with notable losses in the conventional samples. Green amaranth, exhibited higher bioaccessibility of TC with cooking methods of steaming, boiling without lid and microwave. However, bioaccessibility increased among steaming and boiling with lid processes among organic samples when compared to the conventional sample. Moringa, similarly showed increased bioaccessibility after cooking methods of boiling without lid and microwave processing. Whereas, boiling with lid and steaming reduced the bioaccessibility in comparison to the uncooked samples. Among the tomatoes, reducing trend was observed in the bioaccessibility of TC with highest reduction observed in boiling with lid process (19.72 and 23.68%).

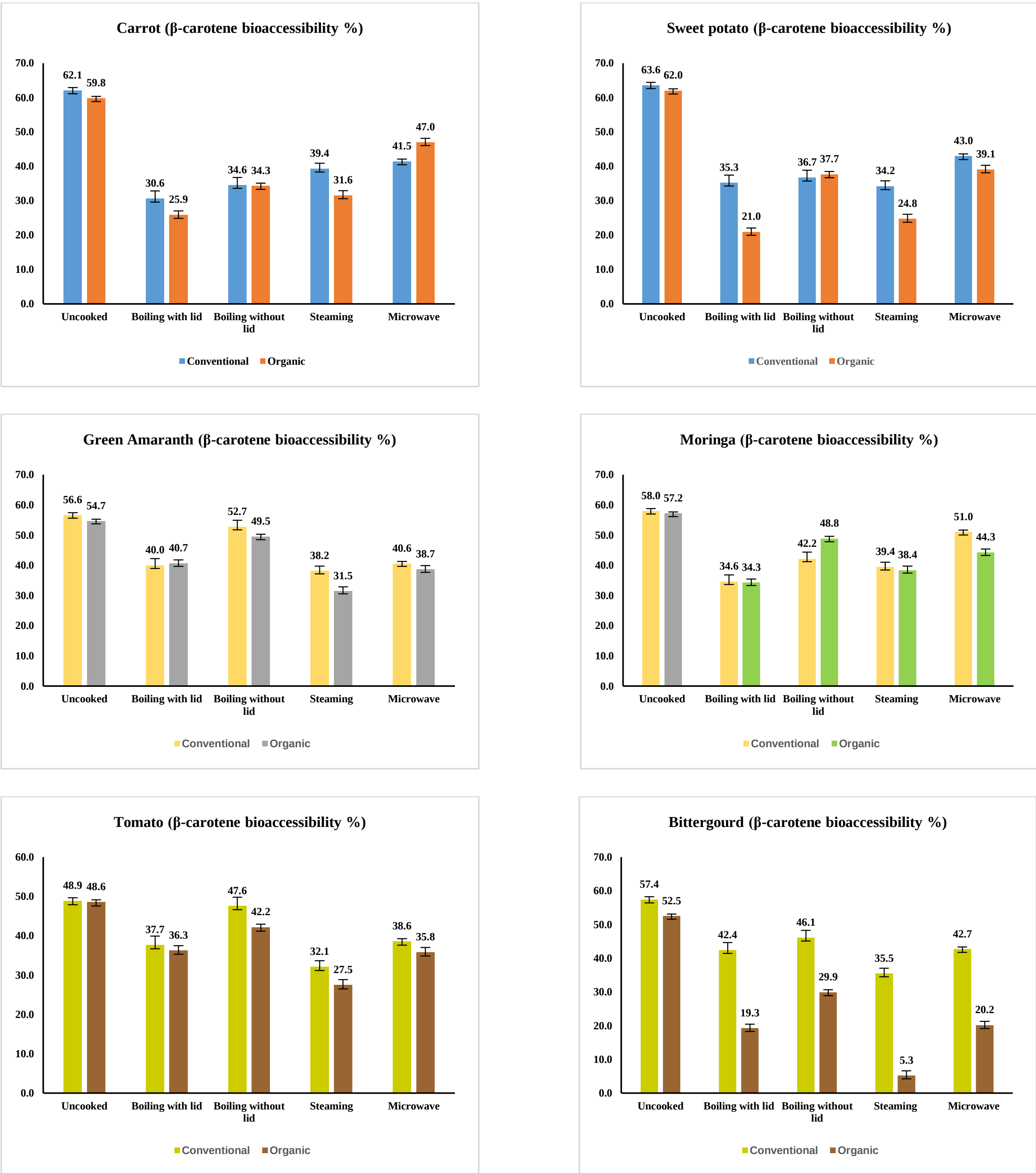

Fig. 2: Comparison of β-carotene bioaccessibility (%) among the conventional and organic vegetables of carrot, sweet potato, green amaranth, moringa, tomato and bitter gourd

Similarly, bittergourd samples also showed reducing trend for TC bioaccessibility with highest reduction observed after boiling with lid and steaming cooking processes.

Bioaccessibility of β-carotene among the analyzed samples is represented in figure 2. The carrot samples showed highest bioaccessibility in the microwave cooking process in comparison to other cooking methods, however the uncooked samples showed β-carotene bioaccessibility (%) ranging between 59.8 – 62.1%. Similarly, sweet potato sample also recorded highest β-carotene bioaccessibility (%) in microwave process compared to other cooking methods.

Green amaranth sample showed β-carotene bioaccessibility of 56.6 and 54.7% in conventional and organic uncooked samples respectively. However, cooking methods showed reduced bioaccessibility of β-carotene with varying percentages and boiling without lid had highest bioaccessibility in comparison to other cooking methods. Similar trend was observed in the moringa samples. Tomato sample showed β-carotene bioaccessibility of 48.9 and 48.6% in conventional and organic uncooked samples respectively. Boiling without lid showed higher bioaccessibility of β-carotene when compared among other cooking methods. However, in bittergourd samples, the cooking methods significantly reduced the bioaccessibility of β-carotene.

Conclusion

Effects of various cooking methods on the carotenoids composition among organic and conventionally cultivated vegetables were evaluated. The results revealed that most of the cooking methods decreased the carotenoids on cooking irrespective of cultivation method. The highest percent reduction in total carotenoids was observed in carrot and moringa up on microwave cooking whereas sweet potato observed highest reduction in total carotenoids on boiling without lid.

Overall steaming process showed less reduction for carotenoids among all the samples in comparison to other cooking processes. Since there is very limited information about the cooking effect on the carotenoids composition compared among organic and conventional vegetables, the outcome of the study will provide important information about cooking effects on carotenoids in vegetables.

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(Received 30th January 2025, accepted 25th February 2025)