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Review Article

Effects of Traditional and Novel Cooking Processes on the Nutritional and Bioactive Profile of *Brassica oleracea* (Kale)

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The present study investigates the impact of traditional and novel cooking techniques on the nutritional and bioactive profile of *Brassica oleracea*, commonly known as kale. As a member of the *Brassica* family, kale is well known for its high nutritional value and possible health benefits. However, it is crucial to remember that the cooking techniques can significantly impact the nutritional profile of kale. Various cooking methods were applied to kale samples through controlled experiments. Traditional techniques like boiling and steaming were compared with innovative approaches such as microwave cooking and vacuum cooking. Soluble solids, which include sugars and other compounds, were used as indicators of nutritional change. Additionally, the levels of vital bioactive components, such as vitamins, antioxidants, and phytochemicals, were analyzed to assess the overall impact of cooking methods. Preliminary findings suggest that the choice of cooking method plays a pivotal role in determining the extent of nutritional and bioactive alterations in kale. Traditional methods, such as boiling, exhibited substantial losses of soluble solids and certain heat-sensitive nutrients. In contrast, novel methods like vacuum cooking displayed better preservation of soluble solids and bioactive compounds. The study sheds light on the complex relationship between cooking techniques and the nutritional integrity of kale. By exploring various methods, this review paper contributes to understanding how culinary practices can be optimized to enhance the retention of vital nutrients and beneficial bioactive components in kale. These findings hold practical implications for individuals seeking to maximize the health benefits of kale consumption while enjoying its culinary versatility.

1. Introduction

The present status of the research domain indicates that when considering cost-effectiveness, vegetables are renowned for providing substantial quantities of nutrients, as well as nonnutritive components (water, roughage, flavors, colors, pesticide, and residues), thereby bestowing significant health advantages [1, 2]. Kale is a vegetable frequently appearing on lists of the healthiest foods, being the first evergreen leafy vegetable from Eastern Turkey. It arrived in Europe throughout the first millennium and made a talk of every household and several cultures. The consumption of kale did not gain popularity among the American population until the first decade of the 1980s. A change in dietary habits and tastes was one of the leading causes. Kale had been overshadowed in previous decades by other plants that were more extensively consumed and accessible. A greater understanding of the nutritional advantages of particular foods and a growing interest in better eating emerged in the 1980s. This rise in health consciousness led to a revaluation of kale's nutritional value. Kale acquired recognition as a superfood and a nutrient-dense choice for a balanced diet as researchers and nutritionists emphasized its high levels of antioxidants, vitamins, and minerals [3].

Since then, the production of *Brassica oleracea* in the agricultural sector has proved to be a good possibility for the economic and cultural factors in agriculture due to its high tolerance to severe weather conditions and low cost of production. Kale is a crop for the colder months because it thrives in cooler areas. It thrives in conditions that range in temperature from 40°F to 75°F (4.4°C to 23.9°C). Exposure to low temperatures can improve kale leaves' flavor and sweetness. Kale can withstand brief periods of light cold and may benefit from them. On the other hand, sweltering heat can make the leaves tough and bitter [4].

Kale pertains to the *Brassicaceae* family and comprises Brussels sprouts, cauliflower, broccoli, and arugula. The kale resembles a cross between Swiss chard and lettuce in appearance and has a sweet, somewhat bitter flavor. Numerous kale types can be distinguished primarily by leaf size, type, and color shades [5]. Several plant varieties comprise collard, thousand-headed kale, marrow kale, and tree kale. The Siberian and Scotch kales are the most frequently grown [6]. Moreover, the significant nutritional claim is that 100 grams of raw kale only contains 1.49 g of fat, 2.9 g of protein, 4.4 g of carbs, and 4.1 g of fiber [7].

The composition depends on the type of kale and numerous environmental and crop factors, i.e., water content, sunlight, rainfall, temperature, fertilization, and harvesting stages, emphasizing the species *Brassica oleracea*, which is widely renowned for having an excellent source of antioxidants like vitamin C, polyphenols, glucosinolates, lutein, and carotenoids [6]. In addition, kale is also widely farmed all over the world [2, 8]. Most of kale's total antioxidant activity is credited to phenolic chemicals (flavonoids, kaempferol, quercetin, chlorogenic acid, and caffeic acid), particularly flavonoids, which offer free radical protection. Other functional ingredients, vitamins and minerals, also have positive effects due to their antioxidant properties [3, 9].

Brassica oleracea contains many organic acids and minerals, many of which, like calcium and magnesium, are necessary for human nutrition. Prominent minerals are calcium, iron, potassium, zinc, and phosphorus are some of these minerals. Since organic acids are in charge of the sensory qualities of foods and may also affect the shelf life of vegetables, it becomes imperative for organic acids to be analyzed and believed to be of utmost importance in food processing and determining quality. The alteration in amounts of organic acids during heating is an efficient indicator of the degree of cooking/processing [10–12].

Additionally, it provides three to four times as much folic acid of 241 μg/100 g as eggs, twice as much vitamin C of 93.4 mg/100 g as oranges, and more iron of 1.6 mg/100 g [13]. Many factors, including the harvest season, growth stage, postharvest handling, climate, and variety, can modify the levels of primary and secondary metabolites [14]. Moreover, it is possible to manage the concentrations of desired molecules and enhance plant quality by manipulating these metabolites. For example, it has been demonstrated that applying abiotic stress can raise the content of phytonutrients in other plants, such as broccoli and carrots [15].

For most foods, cooking techniques such as steaming, boiling, frying, and microwaving are typically utilized. It is widely known that cooking induces noticeable changes in chemical composition, changing the number of bioactive chemicals and their bioavailability in vegetables [6]. Zhang and Hamauzu [16] discovered that after the cooking process, broccoli florets and stems retained approximately 34.1-34.4 percent of their ascorbic acid content and 29.1-29.5 percent of phenolic compounds. The effects of cooking on antioxidant capacity and bioactive components in Brassica plants, such as kale, have been intensively studied. Furthermore, the most effective approach for demonstrating the antioxidant potential of a specific food remains a subject of ongoing debate. Each food matrix tends to align with a particular antioxidant capacity assessment method and its corresponding extraction technique. Nevertheless, it can be deduced that a stronger correlation exists between polyphenol content and methods used to measure antioxidant capacity [17]. Raw kale has many medicinal uses which are presented in Figure 1.

To prevent the loss of nutrients (vitamins and minerals) during cooking, novel processing techniques are being created. A process known as "sous vide" involves vacuum-sealing items in plastic bags and cooking them at a temperature of about 100°C. "Sous vide" cooking appears to lessen the loss of bioactive substances, antioxidant potential, and organoleptic parameters as compared to conventional cooking methods [18]. Additionally, "sous vide" meals that are ready to eat and can be refrigerated for many days may be convenient for modern consumers who do not have much time to prepare meals. However, using the "sous vide" method to cook some vegetables (i.e., root vegetables, leafy greens, cruciferous vegetables, and asparagus) can result in sensory quality loss.

Vegetable vacuum packaged without water and then heated to a high temperature may not show the same palatability characteristics [19]. In addition, according to Armesto et al. [3], kale nutrient losses after vacuum cooking and boiling ranged from 87 to 95 percent. Also, according to Akdaş and Bakkalbaş [4], the amounts of ascorbic acid lost during steaming, stir-frying, microwaving, and boiling were 54.9, 2.9, 10.6, and 53.1%, respectively. This research sought to determine how different processing treatments, with an emphasis on cooking methods and times (including microwave, steaming, boiling, and vacuum cooking) affected the number of flavonoids, antioxidant capacity, minerals, and organic acids in *Brassica oleracea* L. var. acephala.

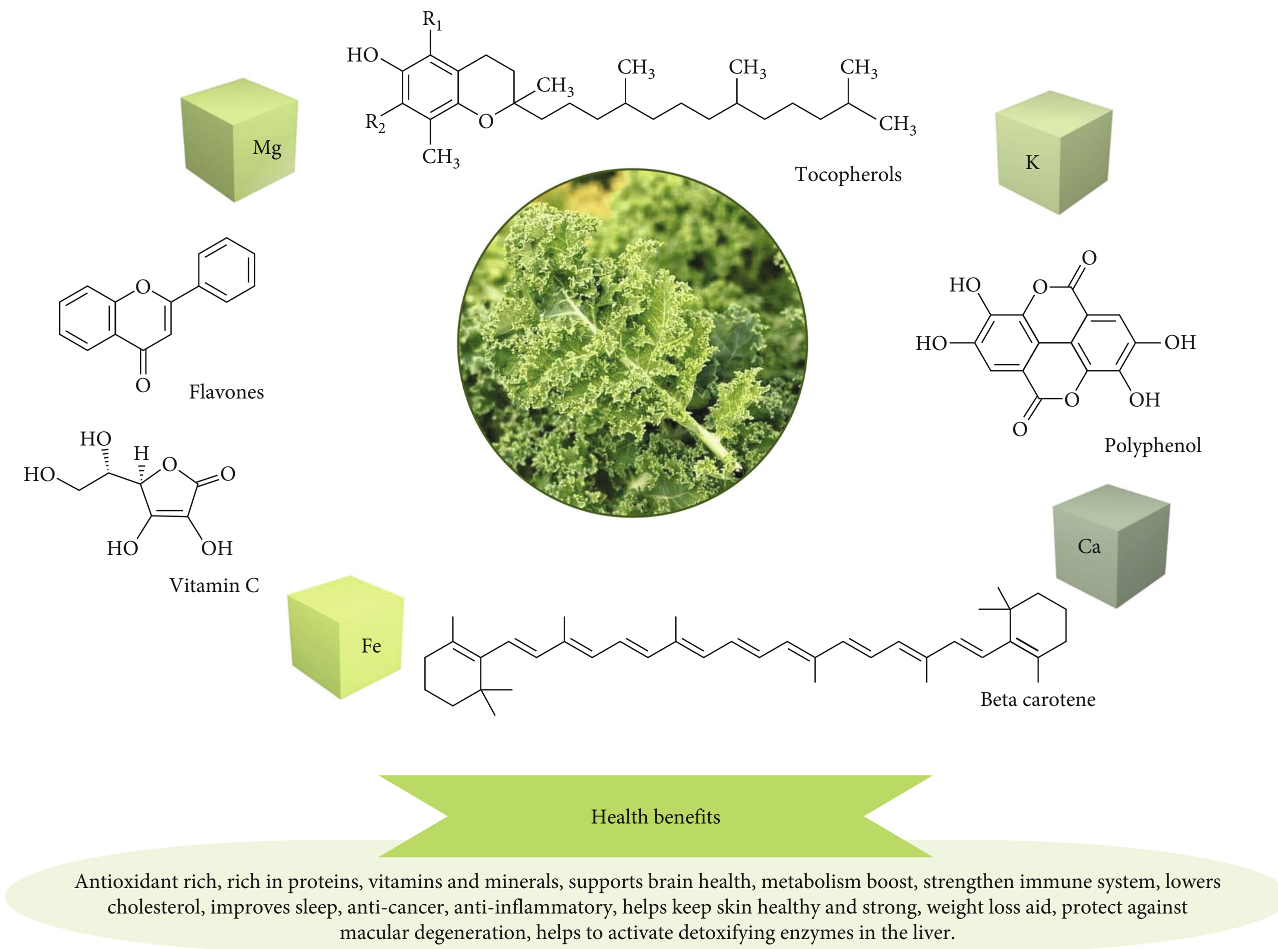

Figure 1: Chemical composition and nutritional benefits of kale plant.

2. Processing and Its Effect on Nutritional Profile of Kale

Kale is beneficial due to its high water, fiber, carbohydrate, vitamin, and mineral concentrations. The composition of *Brassica* spp. changes as a result of various preparation, treatment, and storage procedures. Phenolic compounds, ascorbic acid, soluble sugars, chlorophyll, etc., are highly water-soluble substances whose losses are primarily caused by leaching into processing water [20, 21]. Other elements, such as ascorbic acid, phenolic, and carotenoid components, are heat-sensitive and can be destroyed during cooking and afterward storage. *Brassica* spp. composition and quality after processing and storage are influenced by various factors, including time and temperature [22]. Furthermore, these effects may vary based on the product considered for the same processing conditions. The nutritional profile of raw kale is presented in Figure 2.

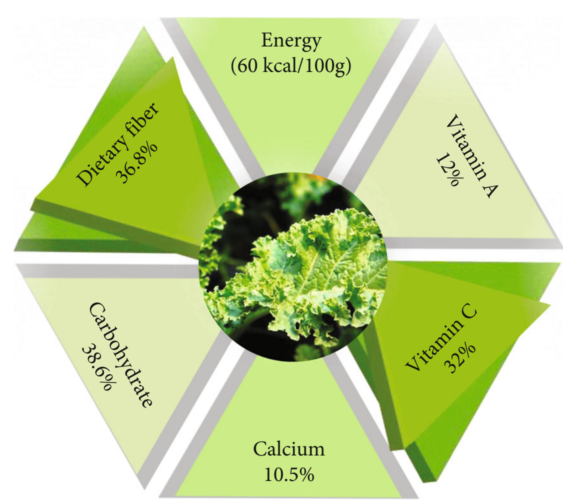

Figure 2: The nutritional profile of raw kale leaves (dry basis) [23].

The sensory characteristics and attributes of *Brassica* spp. are impacted by blanching, heating, and canning. These effects could be caused by the reduction in vegetable content per unit weight caused by the thermal component breakdown and water absorption during heat treatment. Kapusta-Duch et al. [2] reported blanched Brussels sprouts to contain higher water content. An increase in the moisture content of Brassica spp. has been observed [24, 25], highlighting various techniques. As vegetables are cooked, cellular changes occur in plant tissues, gradually increasing moisture content due to water absorption. For instance, boiling and vacuum cooking led to an elevation in the moisture content of Galega kale.

Alternatively, greater temperatures in boiling and canning procedures may cause tissues to shrink, losing water while increasing the amount of dry matter and concentrations of particular substances (such as starch, glucosinolates, and carotenoids). The intricate interactions between these chemically different chemicals create a wide range of heat effects [26]. Physical characteristics like the thickness or size of plant tissues and components can also explain these variations. The soluble compounds leached out, primarily sugars, proteins, and minor quantities of vitamins, organic acids, free amino acids, glucosides, and essential oils, can occur when plants are heated in water [27].

These elements, also referred to as soluble solids, have an impact on flavor and taste. Their loss during blanching, boiling, or canning may harm food's nutritional value and sensory attributes. Due to their effect on taste, these elements are used to assess quality characteristics. As a result of processing circumstances (amount of water added, temperature, and treatment time), certain vegetable cuts lose 2–3% of their soluble solids, or antioxidants. These cuts are processed using the heat treatment method [28].

According to Xu et al. [23], soluble and reducing sugars are significantly lost during boiling and stir-frying. Armesto et al. [3] observed the degradation of soluble solids in kale when subjected to different cooking techniques, including boiling, steaming, microwaving, and blanching. Martínez et al. [27] found significant degradation of soluble solids while canning turnips using pressure cooking, steaming, boiling, and microwaving. The extent of leaching is influenced by both the amount of water used and the cooking duration and might result through leaching or thermal breakdown into the cooking medium. Variations in the amino acid profile come with varied species, degree of ripeness, treatment type, variety, useable sections, contact surfaces, and storage conditions under the same circumstances [29].

The number of amino acids in kale was found to be reduced by blanching, according to Korus et al. [30], but other nutrients (minerals, ash, fatty acids, protein, etc.) can also be changed by heat treatment. The nutritional value of cauliflower was greatly diminished by boiling it, according to Ali [31], and large losses in the amount of protein, minerals, and phytochemicals were also produced. Additionally, this author discovered that the cooking techniques with the fewest losses were steaming, frying, and microwaving. This might be brought on by the microwave's quicker cooking durations or the decreased surface area of the vegetables' interaction with the water compared to other cooking techniques, such as frying.

Temperature vs. time combination and mechanism of heat transfer during processing impact the nutritious and bioactive chemical contents of *Brassica* spp. Boiling and steaming are two standard cooking techniques that use conduction and convection to move heat from the food's surface to its interior.

According to Hwang [28], cooking reduces the antioxidant power of Brussels sprouts. Additionally, these researchers found that microwaved samples had stronger antioxidant activity than steamed or boiled samples. Also, according to Murador et al. [32], steaming kale and red cabbage significantly increased the antioxidant activity. Complementarily, to Florkiewicz et al. [33], boiling reduces antioxidant activity.

3. Cooking Methods for Kale

Kale is typically prepared according to flavor and practicality. Suitable cooking techniques should be used to increase these vegetables' palatability and edibility. According to several studies, cooking affects food's physical parameters, composition, sensory properties, and nutrient bioavailability [2, 3, 25]. Depending on the type and quality of the raw vegetables as well as the type and circumstances of the cooking technique, the changes might either increase or degrade the quality of the cooked vegetables. The most popular methods for preparing vegetables are boiling, steaming, frying, pressure cooking, and microwaving [4, 34, 35].

Vegetables vacuum packaged without water and heated may not taste very good [3]. To prevent nutrient loss and degradation, it is crucial to understand the changes that occur both during cooking and afterward. There is a lack of knowledge regarding the nutritional and sensory attributes of vacuum cooking. Little is known about how vacuum cooking with water and various cooking temperatures and times affect kale [36]. Most of the knowledge now available on the flavonoid, organic acid, and mineral contents of kale was acquired through an analysis of the raw vegetables, and very little is known about the losses brought on by cooking. Understanding how different cooking techniques affect nutrients and bioactive chemicals in vegetables is essential to cook food that retains the most nutrients and provides the most benefits for customers [3] (Figure 3).

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In addition, conventional cooking methods for vegetables like kale include boiling, steaming, and blanching. The vegetable weight-to-water volume ratio (1:5) was used for boiling. It is a typical cooking method which involves boiling time. Samples were steamed by laying them in a single layer on a tray at 97.2°C for three different cooking times (conventional cooking by boiling for 1, 2, and 3 minutes, respectively) [37].

3.1. Effect of Cooking Methods on the Nutritional and Bioactive Status of Kale. This section presents how nutrients and bioactive components are affected by various cooking methods in kale regarding conditions and apparatus of processing. A summary of the species and different parameters examined in the numerous studies described in the scientific literature is shown in Table 1 highlighting the variety of such conditions.

Moreover, food and vegetable nutrition are influenced by how they are prepared and what and how much is consumed. But the preparation and cooking processes alter the

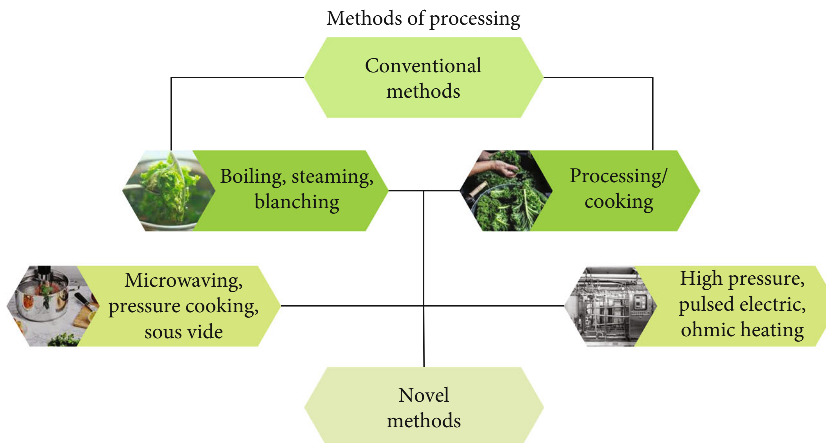

Figure 3: Methods of processing/cooking kale.

Table 1: Cooking methods of kale considering various conditions of processing and apparatus.

Kale type	Major findings					Reference
	Cooking	Processing	Conditions	Apparatus	Finding	
Brassica alboglabra	Novel	Microwave cooking	Time: 1-3 min Power: 900 W	Microwave	During boiling, the phytochemical decrease can decrease due to oxidative degradation or altercation.	[37, 38]
Brassica alboglabra	Conventional cooking	Boiling and steaming	Time: 1-3 min Temperature: 97 ± 2°C	Induction cooker and steaming bowl	The finding showed that microwave steaming can be recommended for use in the food service industry and domestic cooking because it maximizes the nutritional values of vegetables and convenience.	[37]
Brassica oleracea var. *acephala*	Conventional and novel	Boiling, stir-frying, microwaving, and steaming	Boiling, stir-frying, and steaming: 5 min Microwave: 600 W for 5 min	Induction cooker, steaming bowl, and microwave	The finding found that steaming can be considered the best cooking method to preserve the bioactive compounds and antioxidant activity.	[4]
Kale (*B. oleracea* L. var. acephala) (*leaves*)	Domestic cooking	Boiling, blanching, and microwaving	Boiling: 10 min Steaming: 20 min Microwave: 7 min at 900 W	Stainless steel vessel, steam basket, and microwave oven	The current study showed that the steaming treatment can be best to retain the antioxidant compounds in the fresh and frozen kale.	[34]
Brassica oleracea var. *acephala* cv. *Galega*	Conventional and novel	Boiling and vacuum cooking	Boiling: 100 ± 1 °C for 20 Vacuum: 90 min at 85 ± 2 °C	Stainless steel pan and water bath	The results found that vacuum cooking could be used as an alternative to conventional methods of cooking kale.	[3]
Kale (*Brassica oleracea* var. *acephala*)	Conventional and novel	Boiling, microwaving, pressure cooking, and steaming	Boiling: 10 min Microwave: 1,000 W for 5 min Pressure cooker: pressure of 2 MPa at 121°C for 5 min Steaming: 10 min	Pan, microwave oven, and pressure cooker	The finding suggested that steaming is the best cooking method for increasing the concentration of polyphenols and antioxidants.	[35]
Brassica oleracea var. *acephala*	Domestic cooking	Electric stove top	Time: 15 min	Stainless steel pot	The results showed that fresh and cooked kale had similar antioxidative potential.	[2]

nutrients' availability and composition in plants like kale. Cooking methods depend on two variables: cooking temperature and cooking time. Due to their mineral and vitamin content, vegetables like kale are essential in the diet. Most cooking methods do not dramatically lower the minerals in vegetables like kale, though they may leach in small amounts [3, 35]. At higher temperatures, carbohydrates break down and leak into cooked vegetables. With heat and prolonged cooking time, complex proteins will denature, alter their structure, and may break down into simpler pieces. Compared to their fat-soluble vitamin counterparts, water-soluble vitamins (B and C) will leak into the cooking water and are less heat stable (A, D, E, and K). The nutrients in food decay more quickly the longer they are cooked. Extremes in pH and temperature will cause proteins to break down, although individual amino acids should still be present and easier to digest than complex proteins [39–41]. Conventional processes, novel processes, and how it affects the nutritional and bioactive profile of *Brassica oleracea* are shown in Figure 4.

4. Effect on Bioactive Compounds

4.1. Vitamin C Content. Bioactive substances, like vitamin C, are susceptible to heating up and storing. Cooking, canning, freezing, and blanching all have the potential to destroy vitamin C. Water-soluble vitamin C is primarily lost through processes called leaching. Therefore, blanching using steam, hot air, or other heating techniques that do not entail submersion in water reduces vitamin C loss. The heating technique, the degree of grinding, and the surface area exposed to water, light, oxygen, and pH all affect how much vitamin C is lost.

Vegetables generally lose more vitamin C when heated over more extended periods or at higher temperatures [2, 4, 42–44]. Studies have revealed that various blanching and cooking techniques result in Vitamin C loss in kale. According to Kapusta-Duch et al. [2], blanching Brussels sprouts lowered their vitamin C content by 7%. Also, in another study, stir-frying and boiling were shown to have the lowest vitamin C concentration after cooking. In contrast, microwave cooking and steaming had the lowest vitamin C loss rates (0.2%) [23].

In addition, according to Bureau et al. [45], stir-frying and boiling were shown to have the lowest vitamin C concentration after cooking, whereas microwave cooking and steaming had the lowest vitamin C loss rates. According to Armesto et al. [3], boiling and vacuum cooking lowered kale's vitamin C content by 87% to 95%. Also, according to Akdaş and Bakkalbaş [4], kale loses vitamin C when it is stir-fried, boiled, microwaved, or steamed. Then, Florkiewicz et al. [40] stated that heating significantly reduced the vitamin C content of various Brassica species. The greatest losses of this chemical occurred when boiling in water, whereas the minor losses occurred when cooking sous vide.

4.2. Carotenoid Content. Kale plants are a good source of carotenoids. Carotenoids are more heat-resistant than other bioactive components, although heat reduces their content; the quantity of loss depends on the type of vegetable, the method of treatment, if oxygen is present, the temperature, and the period of heating [4, 45, 46]. With minimal heat treatment, such as blanching, carotenoids are often lost in negligible amounts; however, in other cases, the compounds released from cell matrices may potentially cause the bioavailability to increase [2, 16]. In consonance with Murador et al. [32], boiling, steaming, and stir-frying kale decreased its total carotenoid content (boiling (35.47 μg/g), steaming (43.38 μg/g), and stir-frying (69.17 μg/g)).

Zeaxanthin and beta-carotene concentrations decreased with each cooking technique. In contrast to steaming, boiling, and microwaving, which had no discernible effects, stir-frying drastically reduced carotenoid content in kale [4]. Carotenoids are soluble in fat; thus, the fact that fried kale has less of them is likely due to the easy solubilization of these substances in the oil during stir-frying.

Carotenoids can also be found as carotenoid proteins, which connect to the cells of the matrix. The breakdown of carotene-protein complexes during heat processing increases extractability, which raises the carotenoid content [47]. However, processing with high heat might cause carotenoids to oxidatively degrade. Carotenoids can be lost during processes like canning because of techniques like oxidation and isomerization. However, light, air, and pH-related deterioration can also be reduced with canning [44].

4.3. Chlorophyll Content. Kale and other plants are green because of the pigment chlorophyll, which also contains defensive qualities like antioxidant and antimutagenic actions [44]. Heat normally destroys chlorophyll; however, processing at high temperatures for brief periods allows more chlorophyll to be retained than processing at low temperatures for extended periods.

The type of plant, area, temperature and time of the thermal treatment, and pH all affect how much chlorophyll is lost following thermal treatment [4]. Enzyme thermal inactivation can stop the breakdown of chlorophylls [48]. According to Armesto et al. [3], cooking reduced the chlorophyll in kale, albeit the alterations varied depending on the cooking method. Thus, it was observed that steamed kale had the lowest chlorophyll loss and microwaved kale had the greatest.

In cooked kale, in this instance, kale cooked by sous vide method in an autoclave lost less chlorophyll than the one in a water bath or when it was boiled. According to another research developed by Akdaş and Bakkalbaş, processing techniques such as steaming, microwaving, and stir-frying reduce its total chlorophyll concentration by 18.7, 21.5, and 55.3%, respectively [4]. In general, variables in the cooking techniques, such as temperature, time, and medium, as well as the types of kale utilized, may be to blame for the observed variations.

4.4. Phenolic Compound Content. Green vegetables like kale are categorized into groups containing high concentrations of phenolic compounds. Plant secondary metabolites known as phenolic compounds have an aromatic ring with one or

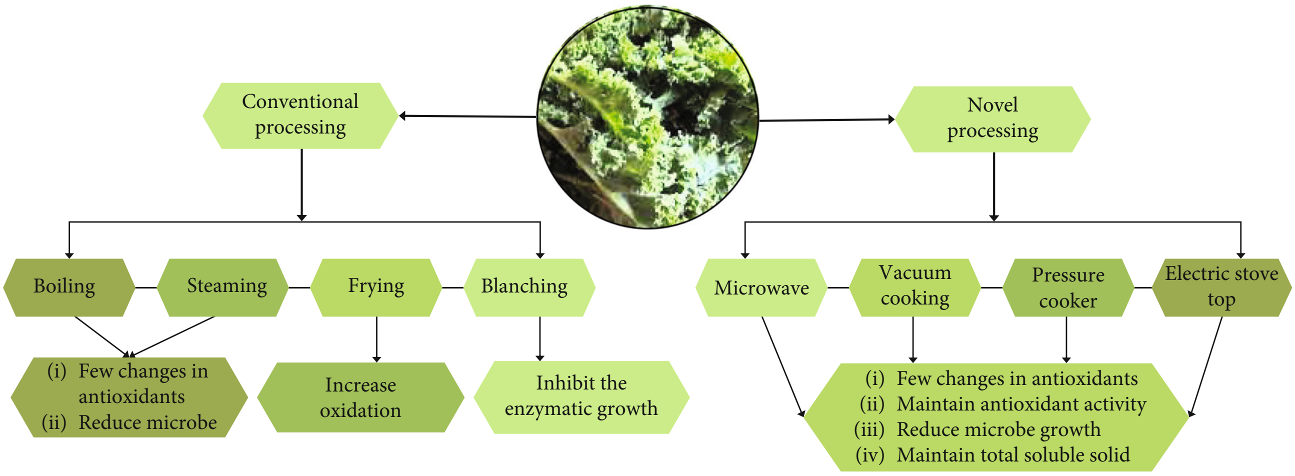

Figure 4: Traditional and novel cooking techniques and how it affects the nutritional and bioactive profile of *Brassica oleracea*.

more hydroxyl substituents [37, 49]. Phenolic compounds significantly influence the biological characteristics of food plants. Some flavonoids and phenolic compounds are fairly heat-resistant. Vegetables' phenolic content, however, might show variations depending on the method of storage and handling. The vegetable matrix, cooking settings, and heating time influence kale's phenolic compounds' stability. Leaching, chemical interactions with other compounds, or oxidation is frequently responsible for decreased quantities of these substances.

According to Palermo et al. [50], chemical structure has a considerable impact on predicting flavonoid losses after cooking. Şengül et al. [51] discovered that compared to kale or white cabbage, turnip, red radish, red cabbage, and broccoli had reduced total phenolic levels after boiling, steaming, microwaving, and stir-frying. On the other hand, the total amount of kale and white cabbage polyphenols increased after blanching in boiling water. Murador et al. [34] reported that total phenolic compounds significantly decreased in cooking kale, whereas these significantly increased in steamed and stir-fried kale. Armesto et al. [3] found that total phenolics in broccoli and kale were degraded in conventional and vacuum cooking. Also, Zhan et al. [52] found that stir-frying, followed by boiling and steaming, increased the total phenolic content of broccoli.

Additionally, Florkiewicz et al. [40] showed that sous vide cooking increased the nutritional content compared to raw vegetables, whereas boiling and steaming reduced the total phenolic content of various *Brassica* spp. Wu et al. [53] observed that steaming and microwaving produced negligible destruction and even apparent gains of the majority of complex flavonoids compared to boiling, which caused the loss of various flavonoids. The various cooking techniques and characteristics, the various vegetable components employed, the various food matrices, and the numerous types of quantitative analysis are all to blame for the highly variable findings published in the pertinent scientific publication. The magnitude of the exposed surface area and the amount of water used may be primary reasons for observed variations in the findings [35, 37, 54].

4.5. Glucosinolate Content. In the human diet, kale is the principal source of glucosinolates. Due to thermal breakdown, leaching into the heating medium, and diminished activity of the enzyme myrosinase, which hydrolyzes glucosinolates, heating significantly reduces the glucosinolate concentration [6, 40, 44, 55]. Short-term retention of some glucosinolates occurs with heat treatment. On the other hand, significant differences in the stable nature of the same glucosinolates in several *Brassica* spp., including kale, have also been found.

Different study findings have been obtained from earlier investigations on the impact of heat treatment on the glucosinolate content of *Brassica* spp. Baenas et al. [55] found that after cooking, total glucosinolate concentration in broccolini and kale varied depending on the method utilized, with boiling being the least effective (>85% loss in both kinds) at degrading these beneficial substances. With the glucosinolate loss around 50% less than the uncooked samples, there were no discernible changes between the stir-frying and steaming techniques for broccolini samples. However, the stir-frying procedure retained 50% of the total amount of glucosinolates in the kale samples compared to steaming.

According to Hwang and Thi [56], glucosinolate and S-methyl methionine levels were retained by steaming or microwaving but decreased by blanching. Also, a study performed by Florkiewicz et al. [40] observed that steaming broccoli and romanesco greatly increased their glucosinolate concentrations, whereas boiling them significantly decreased them. Similar to certain studies, the number of vegetables and cooking water utilized is inversely related to the amount of glucosinolate leaching when boiling vegetables [30, 44, 57].

4.6. Effect on Antioxidant Activity. High quantities of antioxidant compounds such as vitamin C, β-carotene, phenolic compounds, tocopherols, and glucosinolates are present in Brassica species, including kale [44]. According to Chin et al. [37], heating could soften cell walls, denature proteins, and liberate bioactive chemicals. The action of scavenging free radicals would intensify; also, longer boiling and

Table 2: Different cooking methods and their impact on nutritional status and changes in the bioactive compounds.

Kale type	Processing methods	Nutritional status	Major findings Types of bioactive compounds (BCs)	Major finding	Reference
Brassica oleracea var. *acephala* cv. Galega	Boiling and vacuum cooking	Vitamin and minerals	Phenolic compounds, ascorbic acid, total chlorophyll, and antioxidants	The outcome suggested that the vacuum cooking method can be used as an alternative to traditional cooking methods.	[3]
Brassica alboglabra	Microwave cooking, boiling, and steaming	Fiber and ash	Total phenolic content and antioxidants	Microwave steaming can be recommended for cooking greenish vegetables due to the health benefit (increased antioxidant activity) convenience and similar cooked food properties (color and texture).	[37]
Brassica spp.	Cooking, blanching, freezing, and canning	Fiber	Ascorbic acid, β-carotene, and phenolic compounds	Results showed that some bioactive compounds (ascorbic acid) are lost due to these treatments whereas other compounds are less affected or may even increase in concentration.	[44]
Brassica oleracea var. *acephala* cv. Galega	Boiling, steaming, microwaving, pressure cooking, and vacuum cooking	Minerals (potassium and calcium)	Antioxidants, total flavonoids and organic acids	The current outcomes showed that the different cooking methods have different effects on the bioactive compounds in kale. However, it can be important the optimization of such methods in order to minimize losses of the nutritional properties.	[61]
Kale	Boiling, microwaving, pressure cooking, and steaming	—	Antioxidants and soluble and hydrolysable polyphenolic content	The finding investigated that steaming is the best cooking method for increasing the concentration of polyphenols and antioxidants whereas microwaving is the least recommended method.	[35]
Kale (fresh and frozen)	Boiling, microwaving, and steaming	—	Total phenolic content and antioxidants	Outcomes showed that frozen uncooked samples contained a higher antioxidant capacity than the fresh. However, the freezing process may be enhanced the antioxidant capacity of the kale.	[34]
Kale	Boiling, stir-frying, microwaving, and steaming	Vitamin C	Total carotenoids, total chlorophylls, total flavonoids, and total phenolic contents	The finding verified that water-soluble phytochemicals are significantly decreased by boiling. However, stir-frying gave the highest degradation ratio for all phytochemicals, and steaming gave the lowest degradation ratio.	[4]
Brassica oleracea var. *acephala*	Electric stove top	Vitamin C	β-Carotene, total polyphenols, antioxidant, indole-3-carbinol, indole-3-acetonitrile, total indoles, and total isothiocyanate	The results noted that fresh and cooked kale had similar antioxidative potential.	[2]

steaming times could greatly boost Chinese kale's ability to scavenge DPPH and ABTS under both traditional and microwave cooking conditions. As stated by Armesto et al. [3], kale's antioxidant activity decreased while it was being cooked, confirming the potential modifications during the processing of kale.

The significant antioxidant content of cooked kale was preserved in the autoclave treatment due to the brief cooking times at a high temperature and the low oxygen environment in the packing. However, the losses varied depending on the cooking times. The capability of the antioxidants was most negatively impacted by cooking times that were the longest. Ilyasoğlu and Burnaz [34] demonstrated that steaming is the best treatment to retain the antioxidant compounds of fresh and frozen kale. The amount of antioxidant activity in cooked vegetables is substantially influenced by the cooking time and temperature. The compositional changes in cooked vegetables brought on by the Maillard reaction may increase or decrease the food's antioxidant activity. This is due to the possibility that the interaction will result in the oxidation of cell structures, the production of new compounds with pro-oxidant or antioxidant capabilities, or an increase in some antioxidant molecules [58].

Various components, some of which can have conflicting effects, appear to be involved in the changes in an antioxidant capacity that occur throughout processing. Cooking alters the cellular structure and structural integrity of vegetables like kale, which impacts the antioxidant components and, also, the antioxidant capacity (Table 2) [44, 59, 60].

5. Future Perspectives

Future research should identify cooking methods that preserve kale's nutritional and bioactive content while enhancing its digestibility and flavor. Combining various cooking techniques could provide a balanced approach. Investigating how cooking processes affect kale's functional properties, such as antioxidant activity and anti-inflammatory potential, can provide insights into its health-promoting effects. Exploring novel cooking methods, such as sous vide, fermentation, and minimal processing, could unlock new ways to prepare kale that retain its nutritional value and appeal to modern culinary preferences.

6. Current Challenges and Limitations

The effects of cooking processes on kale nutritional and bioactive profile can vary significantly due to differences in cooking times, temperatures, and methods. This makes it challenging to establish consistent guidelines for maximizing nutrient retention. Traditional cooking methods like boiling can result in the leaching of water-soluble vitamins and minerals from kale into the cooking water, leading to nutrient loss. Cooking can alter the bioavailability of certain nutrients, affecting how well the body absorbs them. Balancing the preservation of nutrients with enhanced bioavailability is a complex challenge.

The absence of consistent cooking techniques in studies makes it challenging to compare the outcomes of various study projects. Establishing common cooking conditions would enhance the reliability of findings. Different kale varieties may respond differently to cooking methods. Research should consider a range of kale cultivars to provide a comprehensive understanding of cooking effects. Some bioactive compounds in kale are sensitive to heat and can degrade during cooking. Studying the impact of cooking on specific compounds like glucosinolates and phenolic compounds is essential. People's nutrient requirements and response to cooking methods can vary due to genetics and health conditions. Studying these individual differences could lead to personalized cooking recommendations. The effects of traditional and novel cooking processes on the nutritional and bioactive profile of Brassica oleracea (kale) are a multidimensional challenge. Addressing these challenges while considering future perspectives can provide valuable insights for promoting kale's health benefits through culinary practices.

7. Conclusions

In conclusion, the effects of both traditional and novel cooking processes on the nutritional and bioactive profile of Brassica oleracea, commonly known as kale, have been extensively investigated. The cooking methods applied to kale significantly influence its nutrient content and bioactive compounds. Traditional methods like boiling can result in the loss of water-soluble nutrients due to leaching into cooking water. On the other hand, novel techniques such as microwaving and vacuum cooking have shown promise in preserving more of the original nutrient content, owing to shorter cooking times and reduced water exposure. Several studies have shed light on these effects. Research demonstrated that steaming kale retains a higher vitamin and antioxidant content than boiling.

Similarly, another study showed that microwave cooking better preserves the bioactive compounds in kale than conventional boiling. Additionally, the potential of pressure cooking is needed to maintain the nutritional profile of kale through shorter cooking durations. However, the choice of cooking method should consider the desired outcomes, including taste preferences and nutrient retention. While some methods may better preserve certain bioactive compounds, others might enhance the release of certain beneficial substances through the breakdown of cell walls. The culinary treatment of kale can significantly impact its nutritional value and health-promoting properties, and future research should delve into optimizing cooking methods to balance flavor, texture, and nutrient retention in this wholesome vegetable.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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