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Exploring the health benefits and utility of carrots and carrot pomace: a systematic review

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ABSTRACT

The carrot is a root vegetable well-known for its high nutritional content and health advantages. It is well known for its strong antioxidant content, particularly carotenoids, which have been linked to cancer-fighting effects. Carotenoids, polyphenols, and vitamins in carrots have been demonstrated to have anticarcinogenic, antioxidant, and immune-boosting qualities, lending credence to the long-held concept that carrots are good for eye health. Numerous in-vivo and in-vitro research have revealed carrots' numerous health benefits, including cholesterol-lowering, anti-diabetic, antihypertensive, renoprotective, hepatoprotective, and facilitate the excretion of fats and bile by the liver. Carrot seed extracts have also been shown to have antibacterial, antifungal, anti-inflammatory, cardioprotective, and hepatoprotective effects. Carrot pomace, which contains about 50% -carotene, has been recognized as a valuable byproduct that can be economically helpful for boosting culinary products such as biscuits, bread, and cakes, as well as preparing various functional goods. Carrot pomace powder is used to create bread and extruded items, demonstrating this waste's variety and prospective applications. This comprehensive review focuses on the nutritional composition, phytonutrients, functional properties, product development, and utilization of carrots and their byproducts. This review aims to provide valuable insights into the diverse uses and advantages of incorporating carrots into various food and health products by highlighting the potential health benefits and applications of carrots and their derivatives.

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Introduction

Carrots are a widely consumed crop in the Apiaceae family that is produced annually worldwide for food purposes. The cultivation of the crop was favored in tropical and subtropical regions between September and November, while the temperate circumstances offer an extensive choice of cultivation all over the year. A lower temperature is necessary for growing carrot seeds. Carotenoids and flavonoids are pigments found in roots that give carrots their color and antioxidant properties.[1] The family of carrots is known by the inflorescence, which grows biannually, while the root crop is grown annually as a food source. The root output largely depends on the cortex core proportion, which declines with ripeness. The secondary change to the inner and outer sides produces the roots' xylem vascular system and phloem. The bioactive constituents are concentrated primarily on the

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external side of the root (cortex), and the occurrence of vitamins, bioactive components, and trace elements has caused it to rank as one of the top ten vegetables and fruits on a nutritional basis.[2,3] The carrot roots are distinctive carotenoid-rich roots with the addition of polyacetylenes and terpenoids. The dominant terpenes are monoterpenoids and sesquiterpenoids, and falcarinol complexes are polyacetylenes. The harsh carotid taste is reduced to acceptable levels by delaying sugar production in the root while it grows. The foundation of orange, red, yellow, violet, light, and dark roots is formed by the color differences.[4] The pigments found in different roots have extensive medicinal use for human health. The yellow carrot lutein produces macular colors necessary for normal eye function.[5,6] Lycopene found in the tomatoes, and red carrot assortments is strongly oxygen-free and has high levels of plasma in the body fluid to reduce the possibility of various cancers.[7] Carrots are colored black and purple by an antioxidant known as anthocyanin.[6]

Other carotenes have studied their role in pro-vitamin A extensively, and it is still true that vitamin A deficiency is the foremost source of early demise in children.[8] Carrots are a rich source of vitamin A as they contain β-carotene, which is easily converted into vitamin A by the human body. Considering the dietary and health benefits, the marketing and developing of various products are essential in satisfying people's nutrient requirements, particularly as a low-priced source of vitamin A.[9] The existing literature lacks a comprehensive synthesis of research on the health benefits and practical applications of carrots and carrot pomace. This study aims to comprehensively assess and synthesize existing research on carrots and carrot pomace's health benefits and practical applications. It provides valuable insights into their nutritional value and potential contributions to human well-being.

Morphology of carrot plant

The carrot leaves have two or three compound pinnate leaves; children are lancet leaves (lines). The plant leaves have a compact and firm texture with a smooth base, while the leaf edges exhibit a loose and thin appearance. Every plant has a size of 5–7 small ones. Carrot plant twigs are thin; those corpulent rods with firm and small diameters (about 1–1.5 cm) are barely visible. Greenish-yellow stems usually. Plant carrots have such a tough root and riding system. In taproot development, the size and structure of the feeding volume will change. The root border is a more expansive and rounded structure until it reaches a distance of up to 6 centimeters and a width of up to 30 cm, depending on the variety.[6] Taproot with modified frames and power is regularly named or recognized as "Carrot Root." Carrot plants grow flowers toward the crop finish: double parachute-shaped, white, or light pink. Roses have thick and thin stalks. Bloom petals remain in a parallel plane where carrot flower insemination has occurred, producing tiny and fluffy soil products. Carrots are a seasonal tuber crop with a molded bush that can reliably develop in temperature and rainfall. Yellowish-orange round globules with a rich hue indicate high levels of carotene. Carrot bulbs are a valuable source of water-soluble vitamins B complex, C, and minerals. The storage compartment has short and durable roots with rounded and extended capacity.[3,8]

Classification of carrot

Carrots, scientifically classified as *Daucus carota L.*, belong to the Kingdom Plantae, placing them among the diverse realm of plants. They are part of the Division Magnoliophyta, indicating their status as flowering plants, and further categorized as Class Magnoliopsida, signifying their dicotyledonous nature.[2] Within the order of Apiales, carrots find their place, aligning them with other species with similar characteristics. Carrots belong to the Apiaceae family, also known as the carrot family, encompassing various aromatic plants. Specifically, they fall under the genus Daucus L., which includes wild carrot varieties, and their particular species is Daucus carota L., colloquially referred to as Queen Anne's lace. This systematic classification provides insight into the botanical relationships and characteristics that define *carrots* as a distinct and valuable component of the plant kingdom.[5,6]

Table 1. Nutritional composition of carrot. [22–24]

Nutrient	Amount per 100 g	% Daily Value*
Calories	41 kcal	–
Water	88.29 g	–
Protein	.93 g	1.86%
Carbohydrates	9.58 g	3.19%
Dietary Fiber	2.8 g	11.2%
Sugars	4.74 g	–
Fat	.24 g	0.37%
Saturated Fat	.04 g	0.20%
Monounsaturated Fat	.01 g	–
Polyunsaturated Fat	.12 g	–
Cholesterol	0 mg	0%
Vitamins		
Vitamin A	835 µg (from beta-carotene)	92.78%
Vitamin C	5.9 mg	6.56%
Vitamin K	13.2 µg	11%
Vitamin E	.66 mg	4.40%
Vitamin B6	.14 mg	8.24%
Minerals		
Potassium	320 mg	6.81%
Calcium	33 mg	3.30%
Iron	.30 mg	1.67%
Magnesium	12 mg	2.86%
Phosphorus	35 mg	5%
Sodium	69 mg	–
Zinc	.24 mg	2.18%
Manganese	.14 mg	6.09%

*Percent Daily Values are based on a 2000-calorie diet.

Nutritional profile

Table 1 displays the nutritional profile of carrots. Carrots are a rich source of vitamin C and Vitamin A, primarily in the form of carotene. Carrots have protein, moisture, fat, sugars, carbohydrates, as well as fiber in the levels of 0.6 to 2.0%, 84 to 95%, 0.2 to 0.7, 5.4 to 7.5%, 9.58 to 10.6% plus 0.6% to 2.9%, respectively.[10] The carrots have total ash, which is 15.32%, total lipids are 4.75%, and complete protein is 18.23% as monounsaturated acids (MUFA), polyunsaturated acids (PUFA), and (SFA) saturated fatty acids with the ranges of 160.0 921.7, and 693.4 mg respectively. Carrot leaves' primary saturated fatty acids (SFA) are stearic, palmitic, myristic, lignoceric, and behenic. The primary monounsaturated fatty acids (MUFA) are oleic and palmitoleic, while linoleic acid (LA) and alpha-linolenic acid (ALA) constitute the primary polyunsaturated fatty acids (PUFA).[11,12] Carrots comprise carbohydrates, 9.58 g/100 g, and protein, 0.93 g/100 g. Fiber 2.80 g/100 g, total sugars are 4.74 g/100 g of which 3.59 g/100 g sucrose, 0.59 g/100 g glucose and 0.55 g/100 g fructose, vitamin C (5.9 g/100 g), B1 (0.07 g/100 g), B2 (0.06 g/100 g), B3 (0.93 g/100 g), B6 (0.138 g/100 g), β-carotene (8285micro-g/100 g), α- carotene (3477 µg/100 g) and Vitamin E (0.66 mg/100 g). The soluble dietary fiber is 1.65%, and the insoluble dietary fiber is 4.1% in fresh carrots.[13] The arrangement of β- carotene protein, total dietary fiber, fat, and carbohydrates content in fresh carrot peels is 20.45 mg/100 g, 9.7 g/100 g, 45.45 g/100 g, 1.54 g/100 g, 32.98 g/100 g, respectively. In comparison, its equivalent values upon dryness at 60°C changed to 8.81 mg/100 g, 9.75 g/100 g, 49.23 g/100 g, 1.53 g/100 g, 29.05 g/100 g for unblanched trials. The carrot powder comprises crude Fiber 24.66%, protein 6.16%, moisture 8.78%, and fat 2.43%.[14]

Carrot juice increased its solid soluble content from 2.22 to 4.96%, whilst pomace decreased its solid soluble content from 4.53 to 1.79% when subjected to higher force.[15] According to a Chun et al.,[16] the tocopherol content of frozen carrots was 0.71 mg/100 g, compared to 0.87 mg/100 g in raw blanched carrots. The yellow and orange varieties of the carrot contain carotenoids in the range of 0.47–0.56 mg/100 gm and 5.99 to 12.52 mg/100 gm, whereas dark orange contains carotenoids in the range of 26.55 mg/100 gm, respectively. Lutein of various carotene varieties in purple, orange, yellow,

and dark are present in the range of 176–224, 61–180, 138–232, and 103 mg/100 g. Violet carrots contain 93–168 mg/100 g of ferulic and coumaric acylated cyanide as the chief forms of pigments.[17,18]

The white cultivars were entirely free of coloring pigments. The red carrot variety contains more lycopene (10 mg/100 g) than tomatoes, with almost no α-carotene.[19,20] The study across five European countries revealed that 60–90% of human ß-carotene was ingested into the diet.[8] The phenolic aggregate in the diverse carotene cultivars extended between 10.5 mg/100 g and 267.1 mg/100 g, where the violet-colored roots exhibited the highest amounts of phenols.[21] Carrots are rich in chlorogenic acid, a phenolic compound with significantly more antioxidants than other colored roots.[3]

Chemical properties of carrot

A carrot's root is a remarkable and delightful vegetable with high nutritional value. The chip/slice of carrot exhibits varying levels of total soluble solids, typically around 12°Brix.[22] Orange carrots, rich in carotene, serve as a precursor of vitamin A. Carrots possess a robust nutritional profile, with a 100 g fresh sample containing approximately 42 kcal of energy, 1.1 g of protein, 1100 IU of vitamin A, 8 mg of ascorbic acid (vitamin C), 0.06 mg of thiamine (vitamin B1), 37 mg of calcium (Ca), 36 mg of phosphorus (P), and 0.7 mg of iron. Carrots serve as a beneficial source of minerals and carbohydrates, including phosphorus (P), calcium (Ca), magnesium (Mg) and iron (Fe). According to a study by Sharma et al.,[23] the chemical composition of carrots with a humidity of 86% includes approximately 0.9% protein, 0.2% fats, 10.6% carbohydrates, 1.2% fiber, and 1.1% total ash. Additionally, carrots contain about 80 mg of calcium (Ca) per 100 g, 2.2 mg of iron (Fe) per 100 g, and 53 mg of phosphorus (P) per 100 g. In four carrot cultivars, the edible portion of carrots comprises approximately 10% carbohydrates, with soluble carbohydrates ranging from 6.6 to 7.7 g per 100 g. The protein content in the edible part of these carrot cultivars ranges from 0.8 to 1.1 g per 100 g. A study found that six carrot cultivars had a 1.67–3.35% reduction in sugar, 1.02–1.18% non-reducing sugar, and 2.71–4.53% reduction in total sugar. Sucrose, glucose, xylose, and fructose are free sugars known. Carrot root crude fibers comprise 71.7%, 13.0%, and 15.2% of hemicellulose, cellulose, and lignin. Carrots taste mainly due to glutamic acid and free amino acid buffering. Carrots have low levels of riboflavin, thiamine, folic acid, niacin, and vitamin C.[1]

Phytonutrients

Scientists, food manufacturers, and consumers are particularly interested in nationwide constituents as the future trends toward functional foods with well-defined health benefits. Carrots play a significant role in promoting health and protecting against heart disease and cancer. Plant components are called *phytonutrients*, generally optional metabolites with health-promoting properties. In vitro, carotenoids and phenolics will take on a substantial portion of phytonutrients. Vitamins safeguard natural frameworks from the detrimental effects of oxidative stress, thus contributing to overall health and well-being.[24] Carrots represents an important phytonutrient source, containing phenolics, polyacetylenes, and carotenoids. A carrot is considered a vegetable and fruit, rich in ascorbic acid, tocopherol, and β-carotene, essential vitamins. Carrots are considered a realistic food choice due to their wide variety of mixes and remarkable health benefits.[25]

Carotenoids

Carotenoids are naturally occurring compounds in various fruits and vegetables responsible for their vibrant yellow, orange, and red colors. Among these carotenoids, β-carotene adds visual appeal to food and offers numerous health benefits. With its potent antioxidant properties, β-carotene contributes to a range of advantages, such as reducing the likelihood of specific diseases and cancers and fortifying the immune system while safeguarding counter to age-related deterioration of the eyes.[26] The

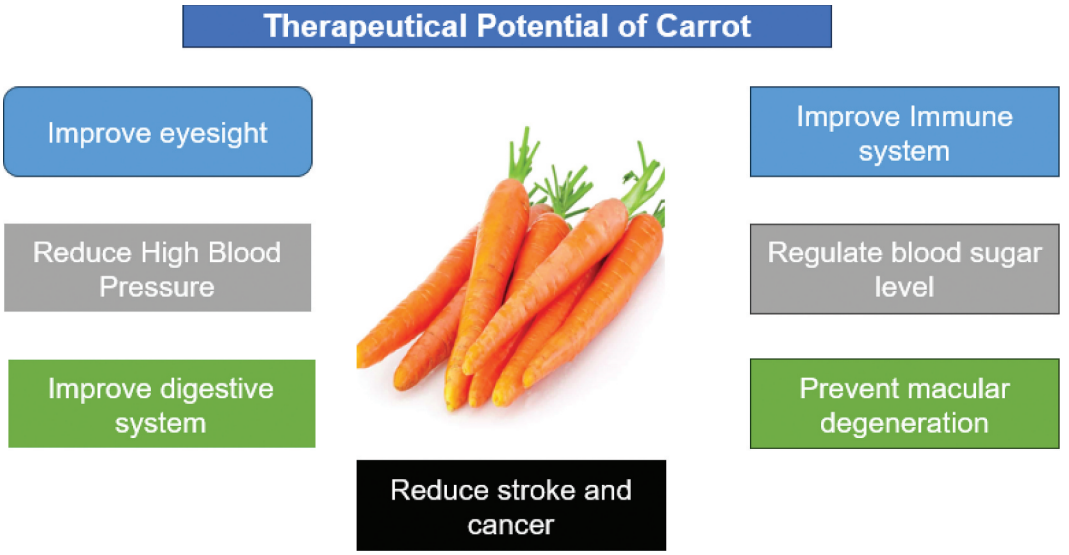

Figure 1. Therapeutical Potential of carrots Anjani, et al.,[26].

relevance of carotenoids in sustenance goes beyond an increasing recognition of the natural pigments, carotenoids, and their biological functions and activities. The yellow-orange discoloration of the skin characterizes Carotenosis due to the excessive intake of carotenoids, typically through a diet rich in foods like carrots and sweet potatoes. This discoloration is harmless and reversible when dietary habits are adjusted.[12] The biological effects of carotenoids are not solely dependent on their pro-vitamin activity but also attributed to their antioxidant properties, which involve the deactivation of free radicals and the quenching of singlet oxygen. Carotenoids in foods are typically categorized as carotenes and xanthophylls, contributing to the food's appealing red or yellow color. Structurally, carotenoids can be acyclic or contain five or six carbon rings on one end of the molecule, as described by Leite et al.[11] Figure 1 presents the additional therapeutic potential of carrots.

Due to their physiological function, phenolics or polyphenols have received substantial attention, including antioxidant, antimutagenic, and anti-tumor activities. Though phenolic compounds have no known nutritive role, their antioxidant potency could be important for human health.[12] They are potential fighters against free radicals that harm our bodies and food systems.

Dietary fiber

Dietary Fiber is an undigested complex carbohydrate derived from a plant structural arrangement. Carotenoids do not provide any caloric value as the human body cannot metabolize them. However, a fiber-rich diet offers numerous health benefits, such as curing constipation, regulating blood sugar levels, promoting heart health, reducing cholesterol levels, and aiding in cancer prevention. The carrot cell wall has been reported by Singh et al.,[1] by Linebox to contain the following various types of dietary fiber, including pectin, cellulose, and lignin. Pectin comprises rhamnogalacturonans, galacturonic acid, galactans, arabinans, and arabinogalactans-1. Cellulose is a type of fiber known as ß-4, D-glucan.

Conversely, lignin consists of components like trans-coni-coniferyl alcohol, trans-sinapyl alcohol, and trans-p-coumaryl alcohol. Carrots have rich dietary fibers, and dietary fibers play a crucial role in promoting human health. Consuming a diet rich in these fibers is related to preventing, mitigating, and treating certain diseases. For instance, a high-fiber diet can help prevent and manage conditions like diverticular disease and cardiovascular diseases.[22]

Table 2. Therapeutic Potential of Carrot and Carrot Pomace.

Therapeutic Potential	Carrot	Carrot Pomace	References
Antioxidant Benefits	Rich in beta-carotene and vitamin C	Contains polyphenols and antioxidants	[27]
Heart Health	High fiber content supports heart health	May help lower cholesterol levels	[21,24]
Eye Health	High in beta-carotene for vision support	Potential benefits for eye health	[22]
Anti-Inflammatory	Contains anti-inflammatory compounds	May exhibit anti-inflammatory effects	[13]
Digestive Health	Dietary fiber promotes healthy digestion	Fiber content may aid digestive system	[24]
Blood Pressure	Potassium content supports blood pressure	Potential positive impact on blood pressure	[13]
Skin Health	Nutrients contribute to skin health	Antioxidants might benefit skin health	[3]

Medicinal benefits of carrot

The anti-cancer property that guides potential movements toward functional and therapeutic foods with unique health effects has drawn significant interest from researchers and food producers. Carrots are a versatile vegetable with many health benefits, as presented in Table 2. They can help purify the digestive system, act as a diuretic, and provide various vitamins and minerals. The substance contains alkaline elements that purify and revitalize the blood. It contains essential antioxidant components for health maintenance and coronary heart disease defense. Carrots is a crucial source of phytonutrients like phenolics, carotenoids, and polyacetylenes. Carrot has abundant ascorbic acid, vitamin food, and β-carotene, tocopherol.[20]

Carrots are a functional food with important health promotion properties because of their enormous amounts of different compounds.[25] Carrots serve as a vital source of nutrient fuel with many beneficial effects on human health. Primarily, they contribute to increased immunity, a quality particularly advantageous for older individuals, enhancing the body's defense mechanisms. The presence of beta carotene in carrots acts as a shield against photosensitivity, safeguarding the skin from the harmful effects of sun exposure. Furthermore, carrots play a role in alleviating HIV symptoms and easing the challenges of alcohol withdrawal. They also aid in treating minor injuries and disabilities, facilitating healing. Incorporating carrots into one's diet reduces cardiovascular risk while simultaneously elevating the risk of hypertension.[22]

Moreover, carrots actively contribute to liver purification, supporting the daily excretion of fats and bile from this vital organ. With its rich vitamin content, particularly vitamin A, carrots play a pivotal role in combating bronchitis and fighting infections by preserving the integrity of cell membranes and shielding them from disease-causing microorganisms.[1] This nutrient profile also enhances the protection and health of muscles, flesh, and skin. Additionally, carrots effectively address anemia and eliminate acne, promoting more transparent skin. Lastly, their consumption significantly improves eye health, offering enhanced protection for vision. In sum, carrots emerge as a versatile and potent dietary component, offering various health benefits spanning immune support to skin protection.[13]

Carrot byproduct processing

A byproduct of its carrot juice abstraction method, Carrot pomace, is shaped in a thousand tons of environmentally-friendly industries, and novel technologies have to be created for reliable byproduct use that reduces the ecological burden to decrease the problem.[28] The carrot pomace consists of a good quantity of entire vitamins, minerals, and dietary fibers. Although carrots have potential for commercial production in developing countries, the proper use of carrot pomace after juice extraction remains unsolved. The dehydrated carrot fractions (whole and pomace) can produce drinks by altering particle size, and the potentially pre-biotic biomaterial is coarser particles.[4] Carrot pomace and vitamin and mineral products are added to defatted soy meal biscuits to increase their insoluble fiber content. In carrot pomace, the insoluble rich fiber fraction, consisting mainly of pectic polysaccharides, hemicelluloses, and cellulose is used as a fiber-rich cooking product and rice-based extrusion process product.[29] Carrot pomace was a dietary fiber and vitamin source to develop

grain flour-based cookies.[30] The cookie recipe had an addition of up to 6% concentration. In a study by Kohajdova et al.[27] The improved hydration qualities of carrot pomace powder increased the dough's stability and shortened the production time.

Furthermore, it contributed to a favorable change in the development of wheat rolls, reducing loaf length by approximately 3%. According to a study by Upadhyay et al.[31] the levels of β-carotene and ascorbic acid in dried carrot pomace range from 13.53 to 22.95 mg/100 g and from 9.87 to 11.57 mg/100 g, respectively. Use carrot pomace in hot boiling water, rehydrating the pomace and then cooking and adding condensed milk/khoa for 15 minutes. Carrot pulp was highly antioxidant, as was recorded in beetroot waste.[32]

Carrot pomace

The vegetable and fruit industries have expanded worldwide in response to postharvest losses and revenue generation. However, the food processing industry has accounted for 25% of losses and waste in organic leftovers like peel, base, heart, seeds, and pomace. The byproducts on or after fruit production plants provide the untapped capacity to produce natural low-cost bio-components for food uses.[30]

Table 3 provides a comprehensive overview of the characteristics of carrot pomace. Therefore, it is crucial to utilize the annual generation of pomace to address environmental issues and establish additional sources of income. The use of pomace in nutritional claims is significant as they have large amounts of tocopherols, phytic acid, carotenoids, and antioxidant activity. Approximately 76% of fruits and vegetables are consumed fresh, with 20–22% going to waste, according to Department of Food Industry statistics. Processing represents just 2% of total production for vegetables and 4% for fruit.[27] The processing industry of fruits and vegetables accounted for 25% of discarded waste after processing fruit and vegetables, including 10% during utilization and 7% during usage. This results in processing large amounts of waste byproducts in a specific area. Carrot pomace can be effectively managed and utilized through various methods such as deposition, land spreading, or sale as feed. These approaches help control waste and make productive use of carrot pomace. .[42]

Table 3. Description of Carrot Pomace.

Component	Description	References
Composition	Carrot pomace refers to the residual material left after processing carrots, typically following carrot juice extraction or other processing methods. It is composed of various elements, including carrot pulp, skins, seeds, and other remnants. The exact composition may vary depending on processing techniques and carrot varieties.	[33]
Nutritional Content	Carrot pomace is a nutritionally rich byproduct. Its nutritional content includes dietary fiber, vitamins, minerals, and antioxidants. However, the precise nutrient profile can vary based on carrot type and processing conditions.	[34]
Fiber Content	Carrot pomace is an excellent source of dietary fiber, consisting of both soluble and insoluble fibers. Its high fiber content contributes to improved digestive health and satiety.	[35]
Vitamins	Carrot pomace contains a range of vitamins, with a focus on vitamin A (in the form of beta-carotene) , vitamin K, vitamin C, and various B vitamins, including folate. These vitamins support overall health, immune function, and vision.	[36]
Minerals	Essential minerals present in carrot pomace include potassium, calcium, magnesium, with trace amounts of iron, zinc, and others. These minerals play vital roles in various physiological functions.	[37]
Antioxidants	Carrot pomace is rich in antioxidants like beta-carotene, lutein, and zeaxanthin. These antioxidants combat oxidative stress, support eye health, and provide protection against chronic diseases.	[38,39]
Color and Flavor	Carrot pomace retains the characteristic orange color and a mildly sweet flavor of carrots, making it a valuable ingredient for enhancing both color and taste in various food products.	[39,40]
Texture	The texture of carrot pomace is typically coarse and fibrous. This texture is advantageous for certain food applications, such as incorporating it as a natural thickening agent in soups, stews, and sauces.	[41]
Applications	Carrot pomace can be utilized as a natural food coloring, flavor enhancer, or ingredient in baked goods, smoothies, soups, and baby food.	[40]

The production of dietary fiber jam using byproducts of fruits and vegetables is possible. The critical organic waste includes peel, stem, heart, seeds, and pomace. The appropriate technology and raw materials can transform leftover materials into versatile food ingredients. These may also be used in industrial materials or for manufacturing new goods. Such byproducts can also be a valuable source of biofood additives, an effective alternative to food safety problems.[28] These may also produce commercially viable food additives and supplements with high nutritional quality. The findings indicate that utilizing byproducts such as carotene peel, apple pomace, banana peel, and mandarin skins presents a promising opportunity for creating affordable, functional foods. These byproducts are abundant in dietary fiber, vitamin C, improved minerals, and flavonoids and exhibit antioxidant activity. Incorporating these byproducts into food production can help develop nutritious products with added health benefits, all while minimizing waste and maximizing their value. This alteration of these byproducts into high-value commodities helps food producers cut costs and reap profits, thus enhancing their productivity. In this setting, the key reason for this analysis is to increase the possibility of food waste, particularly for pomace treatment. Pomace is well-defined as a class residue of fruits and vegetables after squeezing for juice or oil.[29]

Usage of carrot pomace

During carrot juice processing, up to 50% of the materials are discarded as waste or used as animal feed. This pomace, however, includes significant quantities of valuable substances such as uronic acids, dietary fibers, carotenoids, and neutral sugars.[38] Pomace has sometimes caused ecological problems. New advanced technologies are needed to solve this issue. Food manufacturing units in congested, spacious, and waterproof areas need help handling solid waste with high BODs. This waste causes gradual disposal, severe possible pollution problems, and loss of valuable biofuels and nutrients. When processing commercial carrot juice, approximately 30–50% of the vegetable is converted into pomace, reducing carotene content by up to 50%.[35] Based on manufacturing conditions, the carotene content in pomace can reach as high as 2 g/kg in dry weight.[43] Carrot pomace derived from new, unblanched, and white carrots typically contains approximately 17% of total α-carotene and β-carotene. Additionally, the pomace can have a higher range of 31–35% for the combined content of α-carotene and β-carotene. The dried pomace consists of Na (3.2 mg/g), K (18.6 mg/g), P (1.8 mg/g), Ca (3.0 mg/g), Mg (1.1 mg/g), Cu (4.0 mg/g), Mn (10.8 mg/g), Fe (30.5 mg/g), and Zn (29.4 mg/g). The composition of dietary pomace fiber constituents (on a dry weight basis) as lignin (32.1%), hemicellulose (12.3%), pectin (3.88%), and cellulose (51.6%).[29] Carrot pomace, the byproduct of carrot juice extraction, holds the potential as a source of bioactive compounds for developing food ingredients and nutritional supplements and other uses, as highlighted in Table 4.

The added value of the waste helps reduce the significant component's price, thus directly benefiting producers and customers of bioethanol.[46] Dehydrating carrot shreds in the primary growing season, both with and without deriving juice, could be an alternative to having carrots available year-round. Carrot pomace has been used to prepare high-fiber cookies and pasta and functional drinking for pasta, fortified wheat bread, pickles, cake, and dressings. Acceptance of such products by consumers remains particularly sensory, which is highly affected.[45]

Carrot pomace comprises approximately 4–5% protein, 8–9% sugar, 5–6% minerals, and 37–48% total dietary fiber, so carrot product is a rich source of dietary fiber. Carrot pomace powder was analyzed to produce delightful and salty fiber biscuits for its proximal composition and total dietary fibers and incorporated at 10, 20, and 30% in wheat flour. Since the powder has a fair amount of ash and dietary fiber, the quality of minerals and fibers has increased. The dry-weight carrot pomace contains 2.5 ± 0,15% humidity, 5.5 ± 0,10% ash, 1.3 ± 0,01% fat, 0,7 ± 0,04% protein, 20,9 ± 0,15% crude fiber, 55,8 ± 1,67% food fiber, 71,6 ± 0,23% total carbohydrate as well as 301 ± 0,09 kcal/100 g of energy.[22] The carrot pomace, which contains more soluble solids, total sugar and reduction, non-reduction sugar, acidity, and ascorbic acid, can prepare good-quality toffees. When examining wheat bread with additions

Table 4. Uses of Carrot pomace.

S/N	Usage	Description	References
1.	Pectin production	Both a value-added product and environmental concerns may benefit from the use of Carrot pomace in the production of pectin, using citric acid.	[44]
2.	Pasta	High-quality pasta that not only adds a variety of phytochemicals to the pasta but also allows for its substitution with finger millet, pearl millet, and carrot pomace powder could be created.	[45]
3	Corn starch extrudates	As a source of dietary fiber and other bioactive substances, dry pomace can be incorporated into a variety of food products. Like corn starch extruduates	[43]
4.	Feedstock for bioethanol production	Carrot pomaces as a feedstock for bioethanol production by using Saccharomyces cerevisiae.	[46]
5.	Enzymatic production of soluble-fiber hydrolyzate	As a byproduct of the manufacture of carrot juice, edible snail enzymes have been employed to create soluble dietary fiber from carrot pomace.	[47]

of 5%, 7%, 5%, and 10% carrot pomace, it became evident that the dried carrot pomace contributed carotenoids, fiber, and minerals to the bread. In its dried form, Carrot pomace contains approximately 5.5% of mineral compounds, including iron, zinc, potassium, and manganese. These minerals can significantly augment the mineral composition of wheat bread, particularly considering that wheat is inherently a low source of microelements, offering just 1.4 mg of iron per 100 g.[32]

Carrot pomace valorization

The global population is projected to reach 9.7 billion by 2050, accompanied by a 70% increase in annual waste production over the next four decades.[] This underscores the urgent need to address the paradox of 820 million people facing hunger and malnutrition while simultaneously witnessing excessive food consumption and waste.[48]

Within the agri-food industry, there is untapped potential in the pomace produced from plant material during juice manufacturing. This residual material contains valuable bioactive molecules that can be purified and utilized by the food, cosmetics, and pharmaceutical sectors. Despite its potential, a significant challenge arises during juice extraction, as a substantial portion of these bioactive compounds becomes trapped in the liquid, resulting in pomace with diminished nutraceutical content. Therefore, there is a growing interest in developing technologies to enhance the bioactive compound content in plant-based food waste.

This is where controlled abiotic stresses come into play, such as wounding stress, ultraviolet (UV) light exposure, and modified atmospheres. Applying stressors to plant tissue triggers the production of secondary metabolites with health-enhancing properties.[49] Carrot pomace, in particular, undergoes significant wounding stress during juice extraction due to mechanical processes. Hence, proper storage practices may promote the accumulation of secondary metabolites in this pomace. Previous research has shown that subjecting carrots to wounding stress, either alone or in combination with UV radiation, produces antioxidant phenolic compounds. One such compound is chlorogenic acid (CHA), renowned for its potential to mitigate metabolic syndrome, combat colon cancer, and support cognitive and neural development.[50]

Carrot pomace waste amounts to a substantial 175,000 tons annually worldwide. Previous efforts to valorize carrot waste primarily focused on extracting nutraceuticals like carotenoids and dietary fiber.[51] This study takes a novel approach by investigating the impact of UVC light exposure (at 11.8 W m – 2, for 0, 30, 60, and 120 minutes) and storage duration (48 hours at 25°C) on the accumulation of phenolic compounds and antioxidant activity (AOX) within carrot pomace. These research tools offer a promising avenue for valorizing this waste residue, paving the way for its use as a raw material for nutraceutical extraction or conversion into a valuable food ingredient globally.[52]

Value-added carrot products

Consistency is the reducing parameter to use carrots in restaurants as "carrot sticks." Over time, the shelf life of the sticks gradually decreases to a range of 2 weeks to approximately 4 to 6 weeks. Synergistic use enhances the carrot stick's storage period of antimicrobials, flavonoids, cellular components, and vacuum packaging. The preparation of Gazella, a delightful Indian sweet, involving the cooking of shredded carrots in milk, their combination with cane sugar, and moderate frying in hydrogenated oil. This method, noted for yielding the highest sensory consistency in Gazella made from carrot shreds, involves treating the particles with 35 g of sucrose per 100 g. Carrot halwa is a popular sweet dish in north India. This product incorporates hydrogenated vegetable oil, sugar, milk powder, and dried fruit.[44] It is produced by cooking shredded carrots and accumulating cream cheese, milk powder, coconut powder, and dry fruit. "Kanwal Carrot Dessert" is a mixture that can be rehydrated by adding two to three parts of water and clarified butter. During the storage cycle, the sensory excellence values of the Carrot Kheer mix and Carrot Milk Cake produced decreased. These shreds, with a moisture content suitable for tray packaging, have retained approximately 52% of β-carotene, 59.8% of total carotenes, and 25.3% of vitamin C, compared to intermediate dried carrot shreds. The ability of carrot juice to increase its shelf-life and yogurt satisfactoriness led to the production of blended carrot yogurt. Homogenized milk with the additional first course is added to carrot juice at various amounts (3 to 15%) and incubated at 45oC for 7 hours at cooled temperatures.[35]

Powdered carrot

Carrot is a nutritious root vegetable high in β-carotene with various colors, Thiamine, B-vitamin, riboflavin, and minerals. Carrot pomace powder contains fat (1.75%), protein (10.06%), ash (7.29%), and (69.85%) fiber. Therefore, by improving the cake formulation. The nutritional value of dried carrot powder will increase.[37]

In producing fiber-rich sponge cake, carrot powder is incorporated at varying levels ranging from 0% to 30%.[53] The exact amount of carrot powder used depends on the desired characteristics and specifications of the sponge cake. The results indicated that increasing the amount of carrot powder used led to a further increase in the apparent viscosity of the cake batter. The 30% carrot powder batter displayed the highest viscosity among all samples. Therefore, a cake with carrot powder has higher β-carotene, ash, complex carbohydrates, and moisture. The survey content showed reverse trends. The use of 10% dried carrot powder resulted in a reduction in hardness, chewiness, and cake gumminess. The sample containing 10% carrot powder displayed a darker, reddish, and more yellowish crumb color, making it one of the preferred choices. The pigments and chemicals in carrots are responsible for the observed change in crumb color in the sample containing 10% carrot powder. The orange color of carrots is attributed to the presence of carotenoids, which are naturally occurring pigments. When carrot powder is added to baked items, these carotenoids can make the crumb red and yellowish. Additionally, carrot powder increased the cakes' fiber content and water absorption. Substituting 20% of the carrot powder for the control cake resulted in changes in texture parameters, with inflexibility, chewiness, cohesiveness, resilience, and springiness being observed as 1.88, 0.35, 1.37, 0.81, and 0.54 times, respectively.[44]

The monitor sample volume was 272.26 cm3 less than the cake, which held 20% carrot amount. There was no significant variance between the two, the overall suitability of the 20% carrot powder control sample and Cake. Aside from influencing the physicochemical and physiological dimensions, carrot Pomace improved the cake's nutritional values by raising the anthocyanin levels, phenolic acids, and antioxidant activity.[13]

Muffins presented lower L * and b * values and water in addition to higher fiber content, activity (aw), specific volume, and inflexibility. In contrast to a rice meal, using black carrot pomace resulted in more significant water and oil absorption. When combined with xanthan gum, the formulation achieved an optimal interaction and impact at a 6% inclusion level in the gluten-free muffin.

Carrots are known as versatile plants. Ancestral carrots in northern Arabia and Iran may have displayed hues such as yellow or purple. In baking, a cake containing 5 to 30% carrot pomace was baked at a temperature of 195°C for 20 minutes. The carrot powder cake exhibited its highest viscosity when the carrot powder content reached 30%. Reducing the particle's size and increasing its pomace level increases the batter's viscosity. As the powder concentration increases, ash and moisture in the cake increase considerably, but protein and carbohydrate content decreases due to the high heat used in the cake development. The cake also falls with an upsurge in the amount of carrot powder. The volume decreases at 5, 10, 20, and 30% to 66.99, 62.95, 59.61, and 56.29 cm^3. The cake level decreases with rising pomace levels. Adding carrot powder to the cake batter enhances its viscosity. Ash and humidity increase as carrot powder increases.[53]

Conclusion

Carrots are rich in various beneficial compounds, including flavonoids, carotenoids, vitamins, polyacetylenes, and minerals, offering numerous health advantages. Carotenoids, polyphenols, and vitamins found in carrots contribute to their antioxidant, anticarcinogenic, and immune-boosting properties, supporting the idea that carrots are good for eye health. Regular consumption of carrots and carrot pomace may reduce the risk of heart failure, lower hypertension risk, promote liver cleansing, aid in eliminating bile waste from the liver, and relieve bronchitis. Carrot pomace powder has been successfully utilized in formulating and developing various products, including bakery items and extruded goods. Considering the many health benefits mentioned in this study and supported by past research, it is advisable to include carrots in our daily diet as their consumption can contribute to overall health. Research on carrot pomace also suggests that harnessing carrots' functional, therapeutic, and nutritional properties leads to healthier products.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data supporting this study's findings are available from the corresponding author upon request.

Ethical approval

The study does not involve any human or animal testing.

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