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An Examination about the Potential Health Benefits of Beetroot: Pink Wonder of Nature

Ashutosh Pathak*[1], Neha Singh Yadav[2], Priya Rai[3], Vibha Tripathi[4], Divya Rao[5], Pawan Kumar[6]

[1]Institute of Pharmacy, Dr. Shakuntala Misra National Rehabilitation University, Mohan Rd, Sarosa Bharosa, Lucknow, Uttar Pradesh, India 226017
[2]Department of Intellectual Disability, Dr. Shakuntala Misra National Rehabilitation University, Mohan Rd, Sarosa Bharosa, Lucknow, Uttar Pradesh, India 226017
[3]Azad institute of Pharmacy & Research Bijnor Banthra Rd, Bijnor, Natkur, Uttar Pradesh, India 226002
[4]Yashraj Institute of Pharmacy, Gomti Nagar Extension Sector 6, Gomti Nagar, Lucknow, Uttar Pradesh, India - 226010
[5]Dr M. C. Saxena College of Pharmacy, 171 Barawankala, Mall Road, IIM Road, Dubagga, Lucknow, Uttar Pradesh, India, 226101
[6]Institute of Engineering and Technology, Dr. Shakuntala Misra National Rehabilitation University, Mohan Rd, Sarosa Bharosa, Lucknow, Uttar Pradesh, India – 226017
*Corresponding Author E-mail: rrscopashu1986@gmail.com
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Abstract

The renowned dietary variety and profusion of bioactive components of beetroot (*Beta vulgaris*) provide several wellness benefits. Its medicinal uses, processing of meals, preservation techniques, and new nano formulation of drugs approaches are all covered in detail in the following article. A nutritious food with anti-oxidants, anti-viral, antibacterial, and inflammatory qualities, beetroot is distinguished by its abundance of mineral substances, proteins, phenolic compounds, phytochemicals and Betalains. The main bioactive ingredients in beetroot, betalains and nitrates, are of special importance. While nitrates help lower blood cholesterol levels, sugar levels, and hypertension and improve sports performance, betalains fight reactive oxygen species, stop harming DNA, and have anticancer effects. These substances demonstrate beetroot's ability to delicacy an assortment of diseases, together with malignance and heart problems. Besides just being consumed unprocessed, beets are used extensively in the food industry as natural meal coloration and in other premium products. When made via dripping techniques, powdered beetroot has a wide range of uses in meat-based drinks, jams, and sweets. Its leaves also offer extra dietary benefits since they include beta-carotene and other carotenoids. Employing a variety of processes of extraction, research is being conducted to optimize the dietary value of beets and its secondary products while investigating novel approaches, such as nano formulations, to further expand its medicinal potential. The molecular processes and certain disease-specific consequences of beets ingredients will require additional research for complete comprehension, but doing so will pave the road for more targeted medicinal applications and help fulfil its potential to improve human well-being and health.

Keywords: Antioxidant, Dietary supplements, Phytochemicals Analysis, Bioavailability, Beetroot

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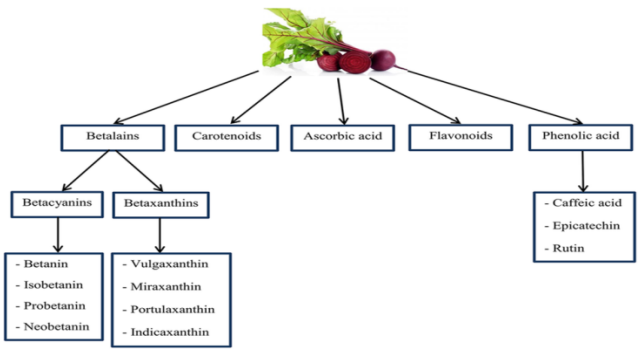
Graphical Abstract



Introduction

A balanced diet that incorporates are referred to as "fortified foods," that are becoming more and more popular, is one of the more secure approaches that people are currently seeking to improve their general well-being and standard of life (Stoica *et al*., 2025). details amaranthaceous species includes beetroot (*Beta vulgaris*), sometimes known as coloured red beetroot as well gardening beetroot, which serves as a root crop that is grown extensively worldwide because of its commercial, medical, and dietary advantages. Throughout long ago, beetroot has been extensively utilised throughout the eastern Mediterranean zone; it was first prized because of its lush greenery and then because it's meaty root. His excellent dietary composition along with its abundance of multiple bioactive ingredients contributed to its recognition as an all-natural medicinal product and culinary delight in addition to a source of nourishment. Because of its substantial number of betalain pigments, including betacyanin's (reddish-violet) and betaxanthins (yellow) (Ali *et al*., 2025), beetroot stands out for its vivid colour and strong antioxidant effects. Apart from betalains themselves, beetroot is a rich source of phenolic molecules, saponins, flavonoids, nitrates from the diet, and vital antioxidants and vitamins including vitamin C (Arulmani *et al*., 2025), iron, potassium, and folate. Improved liver elimination, anti-inflammatory and antioxidant properties, better blood vessel function, and possible anticancer and antidiabetic effects are just a few of the many health advantages that these phytochemicals support. Additionally, the dietary nitrates in beetroot are converted into nitric oxide, which is a substance that helps with vasodilation, enhances blood flow, and is especially advantageous for athletes and those with high blood pressure. Consuming a diet rich in veggies and fruits may seem to have endless health advantages (Yap *et al*., 2025). Heart wellness, defines towards free radicals, cancers of the oral cavity, throat, prostate tissue, and the intestines bowel movements, and maybe a preventative measure against diverticulitis (the formation of small, susceptible to irritation blisters within the colon) are some of these. The leafy green plant beets (*Beta vulgaris* L.) are a member of the Amaranthaceae family (Guo *et al*., 2025). The antioxidant vitamin C, Fiber from the diet, and several vital nutrients like potassium and manganese are all found in beets (Coimbra *et al*., 2025). Potassium is essential for the proper operation of muscles and neurons. Additionally, beetroot includes vitamin B, which aids in bloodstream and liver cleansing (Anggraini *et al*., 2025). It has minerals that are found naturally and give bones durability. For such reasons, ancient Arab medicines have traditionally utilized beetroot to treat a variety of ailments. In addition to being rich in nutrients such as vitamins and minerals and other elements, it also includes unique plant-based constituents with a variety of medicinal uses, making it an excellent dietary additive. It has high antioxidant properties. In the past, beet root was used as a stimulant and was believed to enhance human sexuality hormones (Sanchez-Orozco *et al*., 2025). The juice from beets was therefore consumed as a folk remedy for a sexual insufficiency. This additionally serves for alleviating renal and urinary tract stones. Beets extracts can dramatically slow the growth of malignancies in a range of animal specimens when added to water for consumption. Beets also lessen the symptoms of brain damage because it improves blood circulation to the brain (Küçükgöz *et al*., 2025).

Fig. 1 The Beetroot diagram

Beetroot has also been demonstrated to benefit elderly individuals with cognitive loss. Numerous components of the herb are used in healthcare, involving as its expectorant, anti-inflammation carminative, diuretic, anti-bacterial, anti-fungal, and antioxidant attributes (Mottola *et al*., 2025). Beetroot offers medicinal advantages as well, showing promise in protecting proteins from denaturation. This kind of plants prefers soil with a pH between 5.5 and 6.2 that has a lot of nutrients in it. The cultivation cycle might last anywhere from 60 to 100 days throughout the summer and winter, depending on the varietals and agricultural practices. The beetroot harvest requires a protracted period of intense cold to finish its reproduction cycle because it is a biannual crop. Beetroot is also rich in minerals (Guo *et al*., 2025). The beetroot harvest requires a protracted period of intense cold to finish its reproduction cycle because it is a biannual crop (Marzetti *et al*.,2025). Beetroot is also rich in minerals. The mineral content varies depending on how beet root is consumed. Iron (Fe), zinc (Zn), potassium (Na), sodium (Na), (K), magnesium (Mg+2), and phosphorus (P) are the metal amounts (Tosif *et al*., 2025). 35 calories are included in a typical beetroot (Irfan *et al*., 2025). Betacyanin is the pigment that gives beetroot its deep red colour (Carboué *et al*., 2025). This helps to prevent cancer of the intestines. Its plentiful supply of silica is necessary for healthy, strong bones, the epidermis and hair as well as for the body to use calcium to its maximum capacity (Saleem *et al*., 2025). Beetroot juice was used as the initial dietary NO3 supplement formulation. Based on the objectives of preliminary research or clinical research in addition to the test population, which includes volunteers, it has served as a prime for the vast majority of new medications that have been lately introduced. Beets are combined without the addition of water in a food centrifuge processor to produce fresh, concentrate beetroot juice (Marzetti *et al*., 2025 and Paula *et al*., 2025).

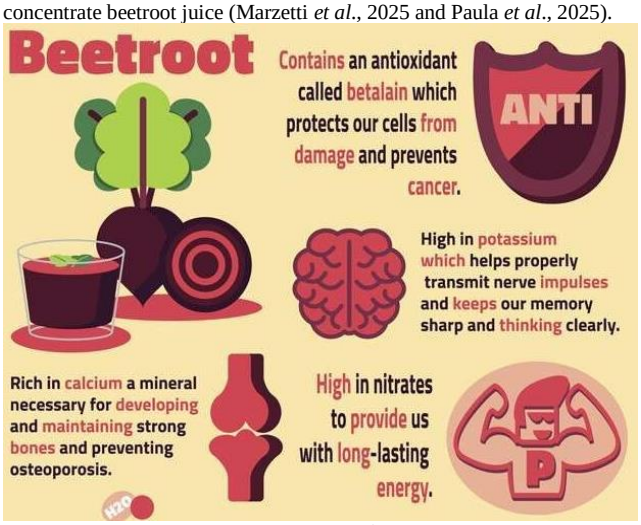


Fig.2 Functions of beetroot

Functional and Chemical Properties:

Beetalains are abundant in beets. The two subcategories of betalains are betaxanthins, which are orange-yellow pigments, and betacyanin's, which are reddish-violet pigment. They possess antimicrobial properties (Gonzaga *et al*., 2025). The betalains in beets are abundant. Two subclasses of betalains are known as betaxanthins (yellow-orange pigments) and betacyanin's (red-violet pigments). They have antimicrobial properties and have the capacity to prevent the growth of cancerous cells in people, in addition to its antiviral properties (Mahmoud *et al*., 2025). Because red beets are high in antioxidant-rich substances, eating them can help stave off illnesses associated with aging. Red beetroot has been identified as one of the veggies with the greatest capacity for antioxidants (Darvish *et al*., 2025). A family of substances known as betacyanin's has the ability to scavenge radicals and serve as antioxidants. Additionally, they prevent cervical and bladder cancer cells from proliferating in vitro. Additionally, red beetroot has antioxidant properties. One intake of red beetroot juice enhanced the excretion of antioxidant substances such betalains in the urine (Subrahmanyeswari *et al*., 2025). Red beets include betalains and other phenolic compounds that enhance antioxidant status and guard against lipid oxidative damage (Siddiqui *et al*., 2025). Red beetroot's antioxidant activity is associated with antioxidants' role in rescuing radicals that are harmful and, consequently, in preventing illnesses including cancer and heart issues. Additionally, it has been shown that betalains, which raise oxidative obstruction, enhance the antioxidant activity of human low-density lipoproteins (Beigizadeh *et al*., 2025, Liu *et al*., 2025, Varga *et al*., 2025, Kim *et al*., 2025, He *et al*. 2025, Azevedo *et al*., 2025 and Khot *et al*., 2025).

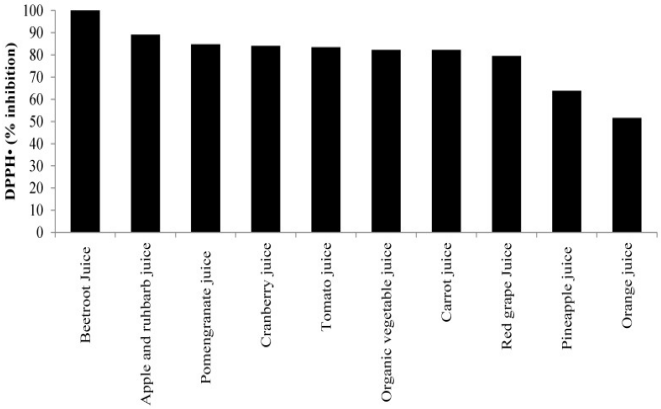


Fig. 3 Ten well-known fruits and veggies drinks that are sold in British supermarkets are compared for their 2,2-diphenyl-1- picrylhydrazyl (DPPH), or inhibitory capability (%) (values according to statistics).

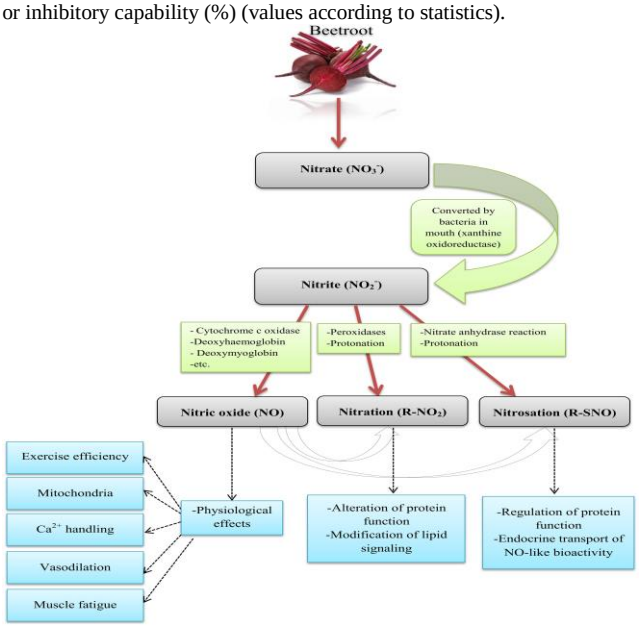
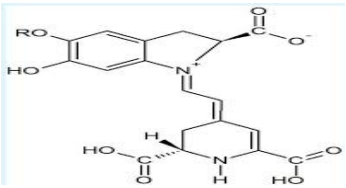
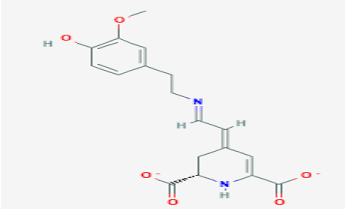


Fig. 4 the processes via which humans produce NO using beetroot

Table 1: Chemical structures of Beetroot Pigments

Pigments	Structure
Betacyanin (Thiruvengadam *et al*., 2025)	
Betaxanthin (Alhalabi *et al*., 2024)	

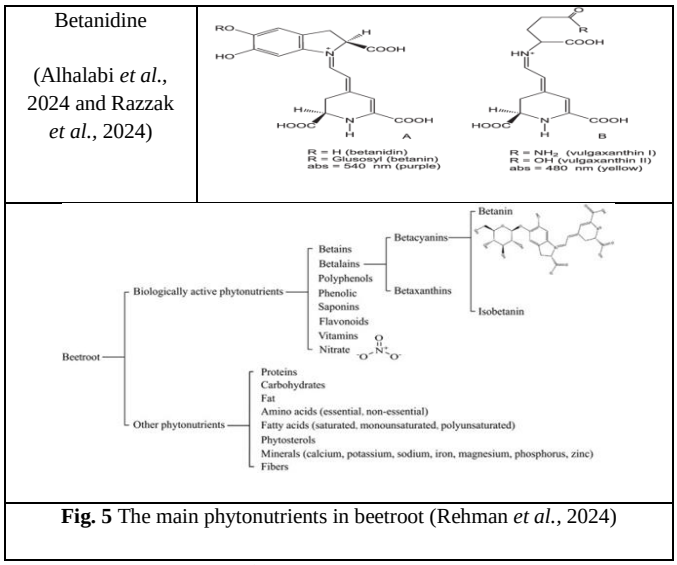


Fig. 5 The main phytonutrients in beetroot (Rehman *et al.*, 2024)

Table 1. Nutritional value of 200 gm red beetroot (Chen *et al*., 2024, Jones *et al*., 2024, Bashir *et al*., 2024, Grönroos *et al*., 2024, Rehman *et al*., 2024 and Delleli *et al*., 2023)

Macronutrient	Amount in gm
Carbohydrate	19.12gm
Fat	0.34gm
Protein	3.22gm
Fibre	5.6gm
Micro nutrients	
Potassium	650mg
Sodium	156gm
Phosphorus	80gm
Calcium	32gm
Magnesium	46gm
Iron	1.60gm
Zinc	0.70mg
Vitamins	
Vitamin A	722U
Vitamin B1	0.084mg
Vitamin B2	0.080mg
Vitamin B3	0.688mg
Vitamin B5	0.310mg
Vitamin B6	0.134mg
Vitamin B7	ND
Vitamin B9	218mg
Vitamin B12	ND
Vitamin C	9.8mg
Vitamin D	ND
Vitamin E	0.600mg
Vitamin K	0.6mg
Pigments	
Betacyanin	75-95%

Table 2. Taxonomical classification of beetroot (de Oliveira *et al*., 2023, Rojas-Valverde *et al*., 2021, Bangar *et al*., 2022, Jones *et al*., 2022, Alhalabi *et al*., 2022, Rojano-Ortega *et al*., 2022 and Mudgal *et al*., 2022)

Kingdom	Plantae
Subkingdom	Tracheobionta
Super division	Spermatophyta
Division	Magnoliophyta
Class	Magnoliopsida
Subclass	Caryophyllidae
Order	Caryophyllates
Family	Family
Genus	Beta
Species	B. vulgaris

Harvesting and Cultivation

Beetroot is grown from seed, which takes two to three months to mature. Deep, sloppy, damp, sandy soils that drain well are ideal for beetroot growth. For seed germination, temperatures should be between 4.5 and 30 °C. Although it can withstand a pH of beyond 7.6, beetroot prefers the pH level of 5.8 to 7.0. An essential tool for recommending nutrient dosages for beetroot is the benefit of fertilization based on soil analysis. Beets are typically ripe for harvesting 75 to 90 days in the warmer months and 100 to 120 days in the winter. It may be cultivated from early summer to the middle of autumn. Beetroot is mostly farmed in West Bengal, Maharashtra, Uttar Pradesh, Himachal Pradesh, and Haryana in India. Beetroot is kept in artificially cooled chambers or on the ground (field). One popular technique for extending the lifespan of red beets is cold storage. In addition, storage is restricted to low degrees for a period of seven to ten days. The beetroot plant is biennial, requiring a period of intense cold to go through the reproductive stage of the cycle (Benjamim *et al*., 2022, Chen *et al*., 2022 and Moreira *et al*., 20220.

Fig. 6 Beetroot: ways to include in our diet

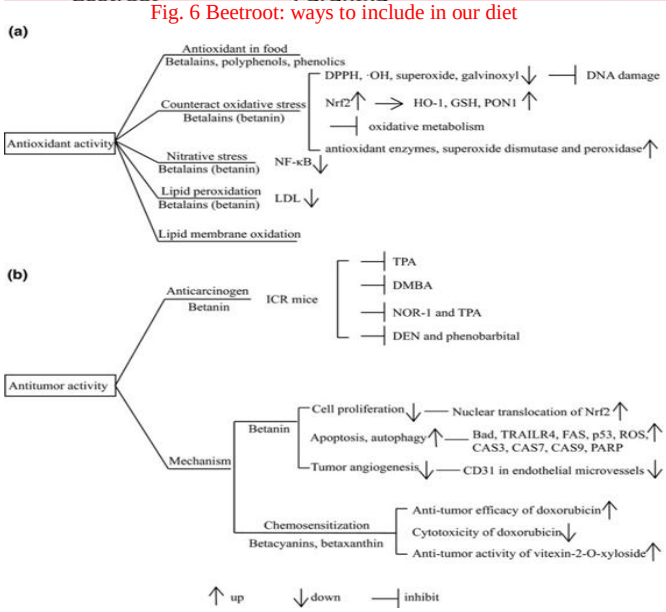


Fig. 7 Diagram showing the beetroot's anticancer (b) and antioxidant (a) properties together. The following are examples: DPPH, 2,2diphenyl-1-picrylhydrazyl; Nrf2, nuclear factor (erythroid-derived 2)-like 2; HO1, heme oxygenase; GSH, glutathione; PON1, paraoxonase 1; NF-κB, nuclear factor-kappa B; NOR-1, (±)-(E)-4-methyl-2-[(E)-hydroxyamino]-5-nitro-6-methoxy-3-hexanamide; DMA, 7,12-dimethylbenz-(a)anthracene; LDL, low-density lipoprotein; TPA, 12-O-tetradecanoylphorbol-13-acetate; DEN, WHICH WAS N-nitrosodiethylamine ; TRAILR4, tumour necrosis factor-related apoptosis-inducing ligand 4; factor-associated suicide (FAS); oxygen species that are reactive (ROS); caspase 3; caspase 7; proteolytic 9; and poly ADP-ribose polymerase (PARP) (Amirpoor *et al*., 2022 and Bashir *et al*., 2024)

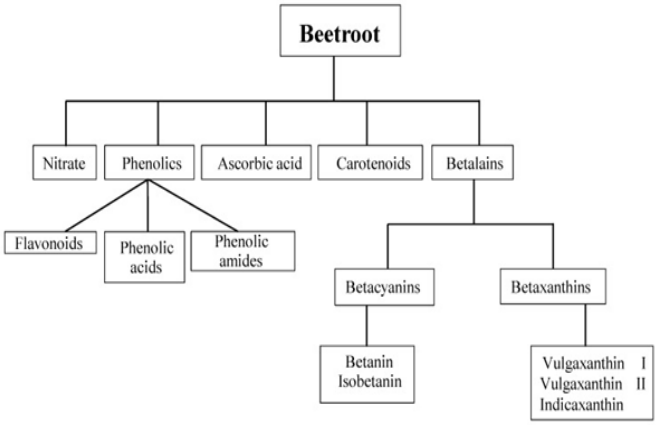
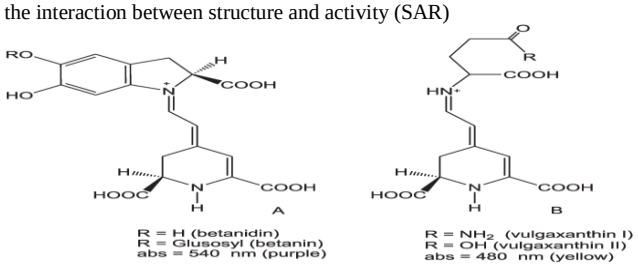


Fig. 8 A brief description concerning beetroot's possibly medicinal properties

Betalains (betacyanin's and betaxanthins): their chemical makeup along with the interaction between structure and activity (SAR)



Crops comprising the Caryophyllales group, such as beet root, serve as the primary source of betalains, also known as betalains, a group of pigments with water-soluble properties which include nitrogen. They fit within the following categories: Colouring substances that are reddish-violet (betacyanin's, for instance) betaxanthins, which are orange and yellow carotenoids (violaxanthin, for example).$C_8H_9NO_5$ is the molecular makeup. The structure includes a 1,2,4,5-tetrahydropyridine rings accompanied by a nitrogen-rich luminescent substance attached to the aromatic rings. The molecular makeup of bethanin includes a carbohydrate component (glycosylation takes place around location 5), double bonds formed by conjugation, along with hydroxyl groups made up of phenol. Phenolic Hydroxyl Groups (-OH upon heterocyclic rings) provide protons for the release of radicals, thereby increasing oxidative action. The connected dual-bonded mechanism is in charge of colour and stabilising radicals that are unstable. Comparing betaxanthins against aglycones as well as protein substitutes, glycoprotein (the sugar moiety) increases dispersion also endurance, promotes accessibility, also might marginally lessen reactive sequestration. Influences some biological processes such as colour, and electron transfer. Teams of Amines with Carboxyl's Metal ion elimination, affinity to molecules in the environment, and polarisation (in betacyanin's) Cyclo- DOPA Group helps with antioxidants along with eliminating free radicals' qualities; it is necessary for the reddish-violet hue. pH the sensitivity of although betalains begin to break down at greater pH values or at warmer temperatures, they are somewhat resilient around pH 3–7. An intricate web of messenger molecules including digestive enzymes triggers an allergic reaction in anticipation of cell injury as well trauma. The production of reactive ROS, which include HOCl, or hypochlorous acid, and hydroxyl radicals (•OH), usually marks the start of this chemical reaction. Many exceptionally reactive species have the ability to trigger important anti-inflammatory mechanisms and cause additionally injury to cells. (including COX-1 along with COX-2, respectively) along with the lipoxygenases (LOX) enzymes, particularly five-lipoxygenase (LOX-5) along with twelve-lipoxygenase (LOX-12), all of which have been among the earliest offenders. These digestive enzymes transform the arachidonic acid through pro-inflammatory chemicals that exacerbate discomfort, redness, along with discomfort, including prostaglandin E2, also known as (PGE2), prostaglandin F2 (PGF2), along with leukotrienes, respectively (Varshney *et al*., 2022, Usmani *et al*., 2022, Muir *et al*., 2022, Trych *et al*., 2022, Caliceti *et al*., 2022, Pathak *et al*., 2023, Pathak *et al*., 2023, Pathak *et al*., 2024).

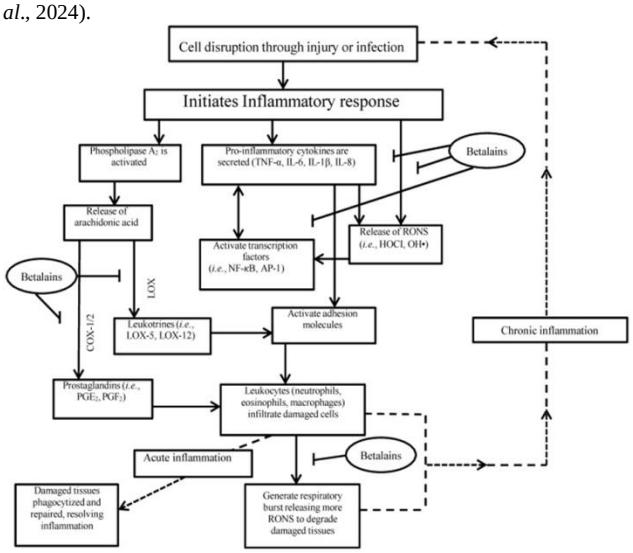


Fig. 9 A representation illustrates the potential routes and the chain of inflammatory reactions in reaction to biological assault

Mechanism of metabolism and pharmacokinetics of beetroot

Beetroot contains a lot of nitrates, a substance which is converted to nitrite and then to the compound nitric oxide (NO). Nitrates are frequently converted to nitrate and subsequently to nitric oxide immediately after consumption (by oral bacteria, later in the body). A crucial signalling molecule, NO regulates blood pressure, vasodilation, and other processes. Research indicates that after consuming beetroot, plasma nitrate/nitrite (collectively NO_x) increases. Less bioavailable are betalains. In human trials, detectable betanin was not found in plasma at the anticipated periods, even after ingesting beetroot juice or whole beetroot, both of which contain significant amounts of betanin. This implies inadequate absorption, quick metabolism or destruction, or maybe conversion into difficult-to-measure metabolite. Excretion: Although the levels generally minimal, the presence of certain mineral compounds or their by-products of breakdown in urine suggests some absorption or transit throughout the digestive system. The process of betalain and metabolism begins with tyrosine, a type of amino acid, which is transformed into sodium betalamic acid by a number of enzymatic reactions via the pathway involving shikimate. This acid then reacts with amines or amino acids to produce betaxanthins, an antioxidant, or it interacts with its analogues of cyclo dihydroxyphenylalanine (DOPA) to produce betacyanin's, which are pigments. Biochemical durability: Because betalains are molecules that dissolve in the presence of water, their long-term stability is influenced by a number of factors, including the pH level, ambient temperature, along with sunlight exposure. Even though they might deteriorate under unfavourable circumstances, they are usually steady. Pharmacology of Radioactive Collecting along with Antioxidant Structure: The previously interlinked structures of betalains and other antioxidants, particularly the betanin compound betanidin, and others, include polyphenols hydroxyl pairs that enable the exchange of electric charges or hydrogen in order to neutralise reactive nitrogen oxides and reactive oxygen species (ROS). The method of computational chemistry (also known as density functionality modelling) has been used in several research to determine whether chemical compounds are more responsive and to study the scavenging of various radical (OH, super oxygen, among.) (Arazi *et al*., 2021).

Table 3. Commercial products related to Beetroots (Mirmiran *et al*., 2020, Gong *et al*., 2022 and Clifford *et al*., 2015)

Product	Property	Diagrammatic representation
Beet Juice	Beetroot (Beta vulgarius) juice functions as a functional element since it includes nitrates and antioxidants that may have health advantages. Beetroot is receiving significant attention because the retail market targets athletic beverages based on inorganic nitrate (NO3), one of its active components. Diet nitrate intake has been connected tonitrate-mediated physiological benefits in humans, including improved blood vessel dilation, controlling hypertension, and arterial control. Beetroot juice nitrate supplementation increases skeletal muscle oxygen transport and vascular regulation, which enhances endurance during exercise.	
Beetroot Powder	Because fresh beetroot contains a lot of water, it can be converted into powder to extend its shelf life. While consumers are increasingly evaluating synthetic dyes seriously, there is significant interest in using natural food colouring. However, betalains are less often employed in food processing than anthocyanins and carotenoids, despite the fact that these coloured compounds are sustainable between pH 3 and 7.	
Beetroot Candy	Given its caloric and therapeutic value, beetroot ought to be a part of everyone's diet. Additionally, beetroot is available all year round and may be turned into beetroot candy. displayed an experiment in which attempts were made for creating a satiating, more healthy and appealing beetroot candy using ingredients like pectin, sugar, and citric acid in different proportions. This beetroot candy is a healthy alternative to the artificially seasoned candy accessible at the local market.	
Beetroot Jam	Fruit pulp, sweetness, pectin, acidic substances, and other additives that help preserve the fruit for a long period are used to make jam, an intermediate moisture product. An excellent. Jam has a semi-jelled composition that makes it simple to spread, a vivid colour, an excellent flavour, and a smooth, uniform consistency free of fruit fragments. Beetroot's inherent rich reddish-purple hue makes it one of the best vegetables for making vegetable jam	

Beetroot Cookies	Beetroots have no cholesterol and just 45 kcal per 100 g of body weight. carried out a study to enhance cookies' nutritional value using Beetroot powder was fortified at several concentrations and its chemical and physical makeup was investigated. When comparing to standard cookies, the nutritional assessment showed that the higher replacement level of beetroot powder boosted the nutritious content (crude protein, crude fiber, and minerals). Additionally, beetroot powder improved the cookies' overall acceptance while raising their hardness level.	

Future Aspects

In particular, the domains of therapeutic dietary supplements, supplements, along with disease prevention hold great promise for future generations of beetroot research and clinical use. Beetroot distinguishes noteworthy because of its extensive chemical makeup of pharmacological chemicals, including betalains, which are nitrates from food, including polyphenols, all of which are beneficial for consumers seeking organic, vegetable-based medical treatments. Through sophisticated manufacturing and extraction methods like fermenting overall containerisation, subsequent research should concentrate on improving these chemicals' durability overall accessibility. Further clinical investigations especially drug development are probably in store as a result of the vegetable's potential for treatment in treating long-term ailments including high blood sugar, diabetes, and some types of carcinomas. New developments regarding farming might potentially result in beetroot cultivars that are more environment change-adaptable along with contain more phytochemicals. additionally, there is possibility of creation of products that targets sportsmen as well as older people due to the increasing curiosity in beetroot's function in exercise nutrition as well as mental wellness. The whole beetroot's many wellness benefits, in addition to its renewable source and adaptability, make it a promising ingredient in subsequent health-conscious foods while medications.

Conclusion

Alternatively, the wild subspecies have fibrous, dark roots that are frequently woody and swollen. Depending on the growth technique, beetroot, a biennial that blossoms in its second year of growth, can reach a maximum height of 120 cm or 200 cm. It's expanding plant that grows year-round. Usually, versions appear every two years. Cultivar root is meaty, slightly to highly swollen, and a deep red, whitish, or yellow. In contrast, the wild subspecies' roots are fibrous, dark, and frequently swollen and hard. Beetroot has been utilized in conventional medicine for many decades to treat a wide range of illnesses, including dandruff, sexual dysfunction, gastrointestinal and joint pain, and indigestion. Beets are a reduced-fat veggie. that is also high in protein, soluble fibre, carbohydrates, and starches, and it contains little calories. Beetroot roots are a good source of vitamins A, C, E, and K. Antioxidants such triterpenes, sesquiterpenoids, carotenoids, coumarins, flavonoids (including kaempferol, astragalin, rhamnocitrin, rhamnetin, and tiliroside), betalains, and phenolic compounds are abundant in them, along with folic acid. Finally, the beetroot (*Beta vulgaris*) constitutes a very nutrient-dense vegetable with roots which contains several different phytochemical ingredients that help explain its many health advantages. Its main active ingredients include phenolic substances, saponins and flavonoids, nitrites, carotene, betalains and their derivatives (including the pigment betanin), and vital nutrients like minerals and vitamins. In addition to strengthening the functioning of the liver, improving the efficiency of metabolism, and perhaps lowering the possibility of long-term illnesses including cancer, Type 2 diabetes, along with elevated blood pressure, these components combine to provide effective antioxidant, anti-inflammatory, as well as cardiopulmonary actions. The ability of the root vegetable's elevated nitrate content to increase blood flow and decrease arterial pressure is particularly noteworthy. The diverse medicinal composition of beetroot makes it a valuable dietary supplement with potential uses in dietary treatment and health prevention. Complex distinct arrangement of betalains particularly betacyanins and their derivatives like betanin especially the coupled networks, glycosylation sequences and polyphenol hydroxyls, among others, is intimately linked to their unique pharmacological action. They are strong naturally occurring antioxidants featuring a lot of promise for use in food, medicine, and cosmetics because of their chemical structure–activity link. Stabilised nutrients while enhanced pharmaceutical compositions may result from further investigation regarding their effectiveness.

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