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Maira Abdul Razzak[1], Mian Kamran Sharif[1*], Tabana Naz[1], Muhammad Arham Rauf[1], Fareeha Shahid[1], Rameen Shahzad[1], Roma Saleem[2], Tahreem Aslam[1], Aqsa Inam[1]

[1]National Institute of Food Science and Technology, University of Agriculture, Faisalabad-Pakistan

[2] Human Nutrition and Dietetics, University of Agriculture, Sub-Campus Toba Tek Singh-Pakistan

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Abstract

Purpose: Lifestyle modification and sedentary life have led to multiple comorbidities which necessitate exploitation of underutilized novel ingredients in daily life. This comprehensive review aimed at providing valuable insight into the diverse pharmacological activities of beetroot bioactive compounds and their health enhancing properties. Furthermore, this review explored emerging research by scientific community for utilization of beetroot in the development of novel functional food products.

Materials and Methods: The scientific studies focusing on the biological activity and therapeutic potential of beetroot for health parameters were included in this study. Database search was made using google scholar, PubMed and research gate which generated a total of 200 papers. Out of which, only 63 met the inclusion criteria of this study. Inclusion criteria included literature focusing on beetroot's bioavailability, plant pigments, bioactive compounds, health benefits, as well as studies describing food applications. This review includes studies between 2014 and 2023.

Findings: The main findings suggested that a prominent bioactive compound and natural betalain pigment in beetroot, exhibits potential anti-inflammatory, anti-carcinogenic and anti-depressive properties. The anti-oxidant activity of betalain is effective against oxidative stress and play a role in preventing and mitigating chronic diseases. Bioactive components including, nitrate content, betanin and betacyanin, potentially modulate blood pressure and promote cardiovascular health. Furthermore, beetroot derived polyphenols, carotenoids, vitamins and minerals contribute to bone health, immune function and overall well-being. Food product development based studies demonstrate an overall improvement in the nutritional and sensory profile.

Implications to Theory, Practice and Policy: Further research on bioactive components of multiple varieties of beetroot is recommended to reassess the underlying mechanisms and optimal dosage for unlocking their potential for medicinal, nutraceuticals and dietary interventions. More research is needed by food industrialists and scientists to explore the potential of beetroot pigments as non-synthetic food additives particularly color enhancer in various food formulations.

Keywords: *Beetroot, Bioactive Compounds, Betalain, Anti-Oxidant Potential, Health Benefits, Non-Synthetic Food Additive, Food Applications [Q18, O13, & I15]*

1.0 INTRODUCTION

Vegetables are known for their health-enhancing properties because they are an excellent source of nutrients and energy. 4-5 servings of vegetables have been recommended for a functional human body [1]. Plant based food such as vegetables, fruits, and whole grains has nutritional and medicinal effects on the human body. These foods contain a broad spectrum of phytochemical compounds contributing to their health-enhancing properties. Notably, phytochemical classes of vegetables *i.e.*, carotenoids, phenolic and flavonoid compounds, and alkaloids, have been extensively studied [2]. The exploration of composition of these compounds highlights their significance in lessening the rate of health ailments and improving the overall quality of life [2].

Beetroot (*Beta vulgaris* L.), a versatile vegetable, has been benefiting humans for years with its medicinal properties, it was utilized for food and beverages during the 3rd century. Red beet was used for the first time for its various applications in the state of Babylonia in the eighth century [3]. It is also being consumed as a supplemented food and as table vegetable [4]. Currently, it is frequently employed in manufacturing industries as a food coloring additive known as *E162* and is regularly consumed as part of the typical diet, either fresh or after thermal processing or fermentation. All components of this plant have therapeutic benefits, including anti-inflammatory, diuretic, expectorant, anti-oxidant, anti-depressant, anti-microbial, anti-fungal, anti-depressant, and carminative hepato-protective or cardiovascular health protector [5].

In a study, Georgiev and his team [6] described the anti-oxidant potential of the betalain and phenolics in beetroot, indicating a protective function of these compounds in oxidative process as well as beneficial function of inorganic nitrates against blood pressure (BP) and cardiovascular diseases (CVDs) [7]. Beetroot has been in demand as new ‘superfood’ due to studies claiming that beets, consumed in any form, decrease the risk of diabetes, lowers blood pressure, and improve hair growth [8] It is believed to have anti-inflammatory and anti-oxidant potential, hepato-protective and anti-carcinogenic effect [9] improved athletic performance, and wound healing properties [10]. Beet is a natural food with the highest level of sugar content and nitrates that augments energy levels in athletes [3].

Origin of Beetroot

Beetroot is a plant with dark purplish-red color. It belongs to the family *Chenopodiaceae* and the subfamily of *Betoideae*. Red beet was used for the first time for its various applications in the state of Babylonia in the eighth century [3]. Although beetroot has been benefiting humans for years with its medicinal properties, it was utilized for food and beverages during the 3rd century. European records show that beetroot was cultivated before the tenth century. The roots and leaves of red beets were used by Romans and Greeks as vegetables and for their medicinal characteristics [11]. Now, beetroots are indigenous to the Mediterranean region. Beet plant is an herbaceous biennial and excessively cultivated from June to November on the coasts of Europe, North Africa, Asia, and some parts of America [12].

Worldwide Beetroot Production

Beetroot has a worldwide distribution. In 2014, 269,714 million tonnes of beetroot production were found worldwide. In France, approximately 37,844,567 tonnes and 33,513,369 tonnes of beetroot were produced by Russia in 2014. United States, Poland, Germany, Turkey, Egypt, Europe, Ukraine, and China are among the major beetroot producing countries [13]. One of the most extensively grown root vegetables in Poland, it is also relatively well-liked throughout Europe.

Around 314 thousand tonnes of red beets were produced in Poland in 2014, according to data from the Central Statistical Office, a 5.3% rise over the previous year [14].

Varieties of Beetroot

Crimson globe, Early wonder, Detroit dark green, and Crosby Egyptian are four major beetroot varieties. Uniform, smooth roots, and dark red flesh belong to Detroit Dark Red beetroot. Crimson Globe beetroot has medium-dark red flesh and little shoulders. Crosby Egyptian beetroot is dark purplish from inside and has indistinct zones. It has a flat globe. They obtain maturity after 60 days of sowing. Flattened root, green leaves, red veiny globe, smooth textured round shoulders, and dark red flesh having lighter red zones are the characteristics of Early wonder [3].

Nutrition Profile of Beetroot

Red beets are real superfood with diversity of nutrients, including vitamins (A, C, E, K, B), minerals *i.e.* potassium, zinc, sodium, phosphorous, calcium, and magnesium and folic acid, see Table 1. The chemical composition (%) shows the presence of moisture (87.58), dietary fiber (2.8), fats (0.16), protein (1.61), ash (1.08) and carbohydrates (9.56) [18]. Factors like genetics, harvesting conditions, different kind of varieties and ecological conditions may vary the chemical composition of the beets. Nutritional compounds distribution varies in peel, stem, root and leaf of beetroots [14]. Carotenoid is rich in leaves of beetroot than tubers because carotenoids, alpha-beta carotene accumulate the chloroplast of plants [5]. Micronutrients in beetroot help fight cancer and lower blood pressure, both of which are crucial for cardiovascular health [17]. They also include a sizable amount of anti-oxidants, betalains and phenolic chemicals, all of which are known to possess variety of positive health effects [15]. Red beetroot in particular include phenolic acids *i.e.* caffeine, syringic acid, and ferulic acid, flavonoids *i.e.* rhamnocitrin, rhamnetin, and kaempferol, and amino acids *i.e.* threonine, valine, cysteine, methionine, isoleucine [16].

Table 1: Micronutrient Composition of Beet Root and Leaves [18]

Micronutrient	Source	Unit	Amount
		Minerals	
Calcium (Ca)	Root	mg	16
	Leaves	mg	2,220
Potassium (K)	Root	mg	325
	Leaves	mg	1,440
Magnesium (Mg)	Root	mg	23
	Leaves	mg	350
Phosphorus (P)	Root	mg	40
	Leaves	mg	330
Iron (Fe)	Root	mg	0.80
	Leaves	mg	16.90
Sodium (Na)	Root	mg	78
Zinc (Zn)	Root	mg	0.35
Vitamins			
Vitamin K	Leaves	mg	280
Vitamin C	Root	mg	10.01
Vitamin A	Root	µg	2
	Leaves	mg	3.93
Vitamin B_1	Root	mg	0.031
Vitamin B_2	Root	mg	0.027
Vitamin B_3	Root	mg	0.331
Vitamin B_5	Root	mg	0.145
Vitamin B_6	Root	mg	0.067
Vitamin B_9	Root	µg	80

Bioactive Compounds of Beetroot

Beetroot represents a significant root vegetable category. Figure 1 presents its major bioactive compounds. Beets are becoming more and more popular due to diversity of its active ingredients such as betalain, polyphenols, carotenoids, flavonoids and nitrates, which are water-soluble pigments and have positive nutritional and physiological functions [19].

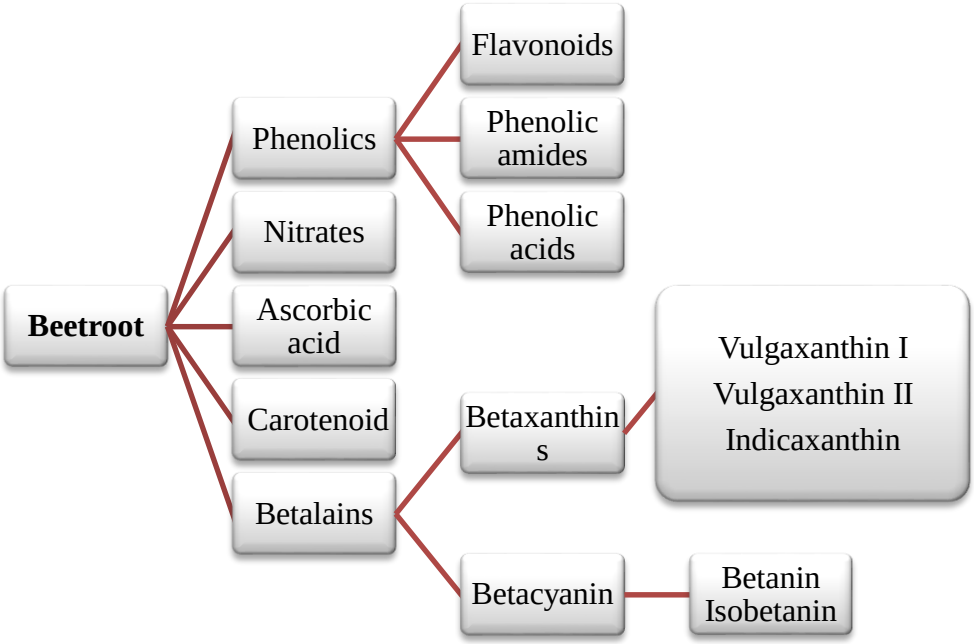

Figure 1: Bioactive Compounds of Beetroot [9]

Phytochemicals (Phenolics/Flavonoids)

Phytochemicals are present in the plants in abundant amount. Red beetroot consumption is healthy for the body since it contains useful bioactive chemicals in addition to betalains such as flavonoids, phenolic acids, and anti-oxidants which are highly absorbed and bioavailable by humans. According to researchers, betalain, a compound found in red beetroot, ranks among the top ten vegetable species with the strongest anti-oxidant qualities. Beets had the highest total phenolic content, according to a study by Vinson [20]**.** Oxalic acid present in red beetroot, and its extract also contains significant flavonoids, saponins and triterpenes [18]. Generally, least phenolic contents are present in the roots portion. Flavonoids present in abundant amount are responsible for coloring the stems, flowers and leaves of the beets. Flavonoids being biologically active compounds having health benefitting anti-oxidant properties [17]. During the processing of vegetables, flavonoid content can be lost. Therefore, to make beetroot consumption efficient, the evaluation of beetroot formulation containing flavonoids should be done properly. Vasconcellos *et al.,* [21] studied the total amount of phenolics in different beetroot products like chips, juice, cooked beetroot (CB) and beetroot powder (BP) and compared them. Their study indicated that 2.79 and 3.67 GAE mg/g of total polyphenol was found in CB and juice, respectively, which was higher than beet chips (0.75 GAE mg/g). Due to loss of phenolics during the process of drying, beetroot chips and powder contained lower total phenolic content as compared to cooked beetroot and juice.

In a study by Da Silva [7], beetroot gel was produced after processing the beetroot juice. The purpose of the study was to enhance the dietary nitrates, anti-oxidant, and phenolic content in the beetroot gel and check the health effects it imparts on the human body. The formulated gel was investigated for physicochemical parameters. After checking the results from the study, it was found out that gel was enriched with nitrates and contained a greater number of phenolic, phytochemicals like flavonoids and saponins. The anti-oxidant levels, fiber, and carbohydrates were also enhanced. The gel showed greater overall acceptability with better acceptance of taste and texture. Higher levels of nitrates in the gel decrease cholesterol and blood pressure. A total of 26 triterpene saponins, including betavulgarosides I-X, were found in beetroot. On the other hand, betroot roots were not found to contain betavulgarosides IX or X. It was once believed that the biosynthesis of the triterpene oligoglycosides betavulgarosides I-IX, which have different acetal- and dioxolane-type substituents, involved the oxidative breakdown of a terminal monosaccharide unit [15].

Betalains

The richest source of betalains is red beetroot. They are pigment of higher plant family of *Caryophyllales* order. Total of seventy betalains are known to nature and they are classified on the basis of their chemical structure. The major bioactive chemical family of betalains is another one that is naturally present in beetroot together with nitrate. Color of the betalain is red and the pH stability ranges from 3 to 7. In the food business, betalains-hydrophilic nitrogenous pigments-are frequently employed as natural colorants for commodities such processed meat, ice cream, and baked goods. According to its color, betalains are divided into two main groups: betacyanins have a reddish-violet hue, while betaxanthins with yellow-orange hue. In terms of their chemical makeup, betacyanins are composed of cyclo-3,4-dihydroxyphenylalanine and betalamic acid [22].

The application of betalain as a natural colorant is gaining trend in the food industry because it's non-toxic, non-poisonous, anti-allergic, anti-oxidant and anti-cancerous nature imparts potential health benefits. The number of synthetic dyes allowed by the FDA has been reduced from 700 to 7 [23]. The formation of betalains is claimed to require tyrosine as a precursor. Tyrosinase's diphenol/DOPA oxidase activity, which is brought on by the massive accumulation of tyrosine, catalyses the conversion of dihydroxyphenylalanine (DOPA) to cyclo DOPA (hydroxylated by tyrosine hydroxylase). Hence, the first step in the production of betalain is the hydroxylation of tyrosine to DOPA, which is followed by the cleavage of the aromatic ring to produce betalamic acid [15].

Due to the red color property of betalain, it is used in product development in food industries. The aim is to produce safe and healthy food and improve the nutritional value of the food product [25]. Red beet additives have high water solubility and are non-toxic. The major source of betalain is beetroot and is being used in products to prevent discoloration of food and make it nutrient enriched [26]. The fundamental issue that has been discovered in patients with diseases associated with cognitive impairment, such as dementia and Alzheimer's diseases, is disturbance in the blood circulation of the brain. The beet's nitrate content, which is digested to produce nitric oxide (NO), and the betalain can help with circulatory issues [24].

Carotenoids

Beetroot possess abundant amount of carotenoids, which act as strong anti-oxidants and are essential in managing and preventing various diseases. In relation to being photosynthetic

accessory pigments, carotenoids protect biological components like DNA from free radical damage by acting as scavengers for oxygen radicals produced by chloroplasts during photosynthesis [15]. They belong to the class of tetraterpenoids and represented in smaller amounts in beetroot. Carotenoids obtained from beets have shown inhibition of mutagenesis, thus, reducing the risk of various cancers [27]. Lutein and Beta-carotene, two kind carotenoids in the red beets act as potent anti-oxidants and immuno-enhancers. In a study, 1.9mg/100g of carotene was found in red beets [28]. Lycopene, an important carotenoid is gaining attention related to its anti-oxidant property and was reported to be highest (3.46mg per 100g) in beetroot among different vegetables tested in Bangladesh [29].

Bioavailability

Another study conducted by Wiczkowski and his researchers [30] interindividual variability on betacyanins bioavailability by ingestion of different red beetroot products in humans was studied. Beetroot juice and crunchy beetroot slices having isobetanin and betanin were voluntarily consumed by 12 subjects. They did high-performance liquid chromatography for betalain identification and analysis. Results from the analysis of the urine sample of people who consumed beetroot juice and crunchy slices contained betacyanins as well as their aglycones. After 1st two hours, the highest excretion rate of betacyanins that was 64nmol/hour, in the urine sample of people who consumed beetroot juice was found. Excretion rate was observed after 2 to 4 hours for the people having beetroot slices (66nmol/hour). They concluded that the total excretion rate of betacyanins was close to 0.3% after ingesting both products and ranged from 0.12 to 0.58%. Conversion of nitrates into nitrosamines can trigger carcenogenesis, various defects in the human feature, and endocrinolgical disorders [31]. Nitrates from the beetroot are reckoned one of the most beneficial source of nutrients at the present times [9]. Beetroot is a good source of nitrates. Nitric oxide availability in *In-vivo* increases after the ingestion of beetroot and results in the management of endothelial functions and prevention of various diseases like hypertention [32].

Health-Enhancing Properties

Vegetables, being a rich source of many bioactive ingredients provides various nutritional and health benefiting attributes and serves as a crucial part of our everyday diet. Among vegetables, beetroot has piqued the interest of researchers due to its high concentration of nitrate (NO_3), a compound with significant nutritional benefits for people with cardiovascular disease via endogenous nitric oxide production (NO) [32] as well as its status as a functional food [9]. Additionally, betalain pigment that is primarily produced by plants of the *Caryophyllales* order, are useful as pharmaceutical agents and dietary supplements due to their anti-inflammatory, anti-cancerous, and anti-hypertensive properties among several others [33], as depicted in Figure 2.

The number of diseases have been increasing day by day due to sedentary lifestyle of people. Metabolic syndrome is a growing health issue in developed and developing countries with the co-occurrence of numerous diseases like hypertension, CVDs, diabetes, *etc*. People are looking for safer alternatives to improve their quality of life. The introduction of vegetables into the daily diet has become crucial [34]. Beetroot has been in demand as a new 'superfood" due to studies claiming that beets, consumed in any form, lower risk of blood pressure, and improve athletic performance [8]. Red beetroot is believed to have an anti-inflammatory effect and has also been recognized as a functional food. Its nutritional and therapeutic tool can be evaluated against various health ailments [35]. Table 2 displays some health promoting benefits of beetroot bioactive compounds.

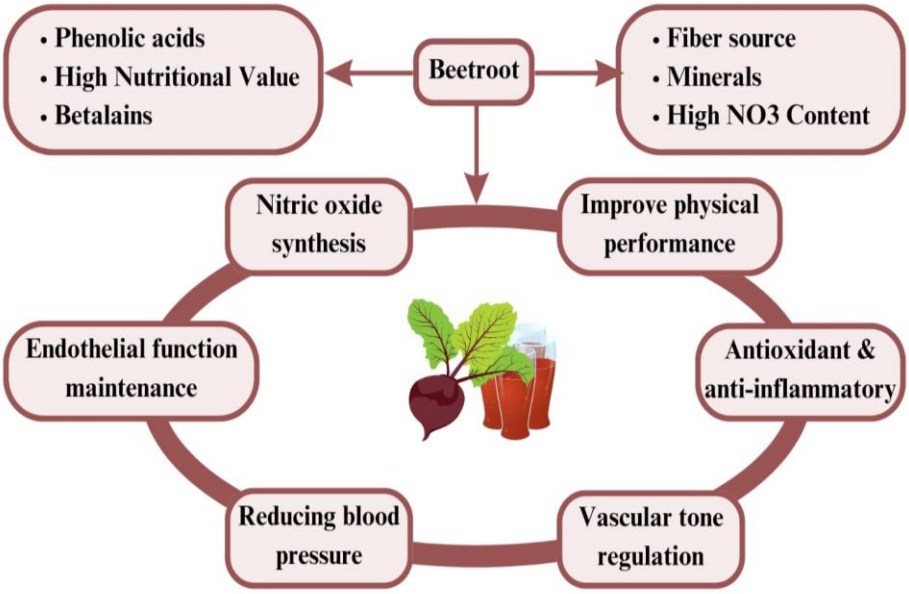

Figure 2: Health Implications of Beetroot Formulations [32]

Anti-Oxidant and Anti-Inflammatory Property

Beetroot is categorized among ten potential plants with the highest anti-oxidant potential [1]. In humans, the anti-oxidant activity of betalain also augments low-density lipoproteins thus, providing oxidation resistance. Betalain extract has the potential to reduce inflammation and protect slim lining of blood vessels [36]. Intrinsic response of the body is directed by the inflammation. Physical and biological incentive like shock and septicity, agents that cause disease give homeostasis interruption and ground for harm. Prostaglandins play fundamental role in the inflammatory response as their biosynthesis is considerably augmented in inflamed tissue causing redness, swelling, weakness and short-term pain at the site of the inflammation. Natural substances like betalain has led the researchers to investigate their anti-inflammatory processes. Figure 3 illustrates the anti-inflammatory process of btalain in response to cell damage by injury.

Home processing effects on the *in vitro* bioavailability of beet root bioactive components and their anti-oxidant properties were investigated. Highest recovery in jam, for total phenolics (16%) and total anti-oxidant capacity (1.3%), were revealed by the *in vitro* digestion procedure. Comparative data to analyze the impact of various home-processing techniques on anti-oxidant capacity of beetroot products were established through aforementioned study [37].

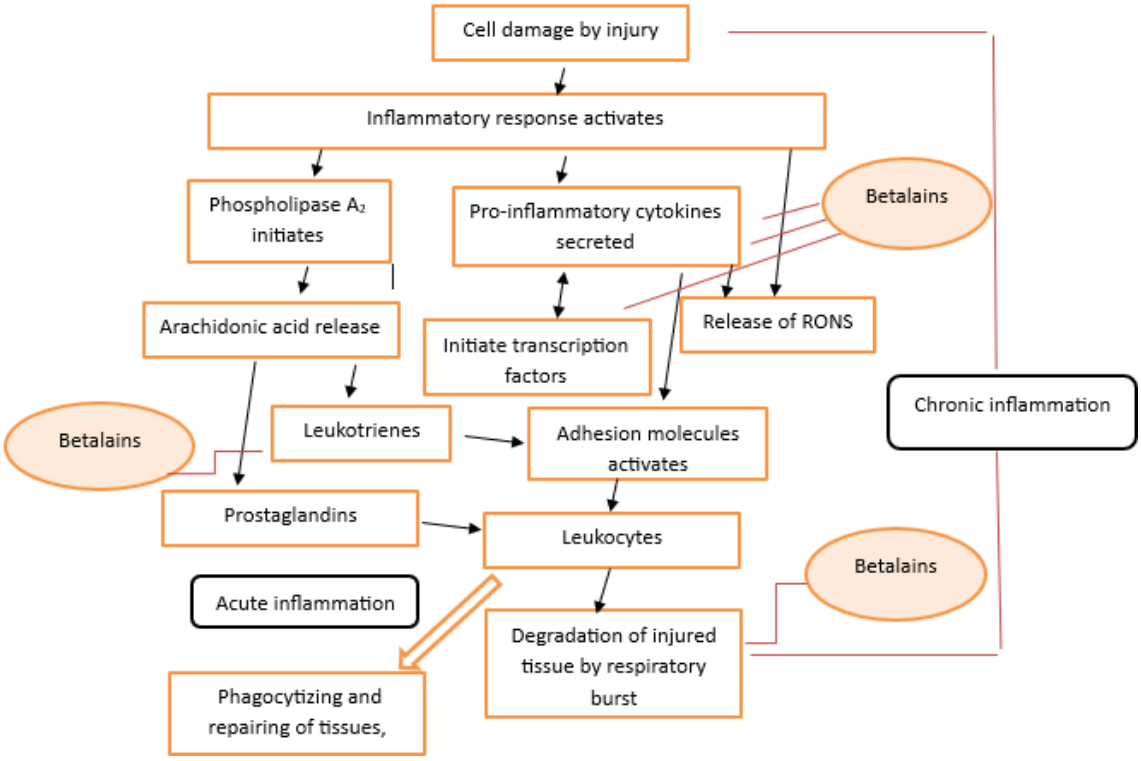

Figure 3: The Inflammatory Cascade in Response to Cellular Attack [9]

In a study, beetroot gel was produced after processing the beetroot juice [7]. The purpose of the study was to enhance the dietary nitrates, anti-oxidant, and phenolic content in the beetroot gel and check the health effects it imparts on the human body. The formulated gel was investigated for physicochemical parameters. After checking the results from the study, it was found out that gel was enriched with nitrates and contained a greater number of phenolic, phytochemicals like flavonoids and saponins. The anti-oxidant levels, fiber, and carbohydrates were also enhanced. The gel showed greater overall acceptability with better acceptance of taste and texture. Higher levels of nitrates in the gel decrease cholesterol and Blood pressure.

Anti-Carcinogenic Property

Conversion of normal cells to neoplastic cells, leading to cancer, is known as carcinogenesis. Several research on beetroot found its anti-cancer, and chemo-protective function. Induction of apoptosis, interruption of cell inflammation, excess production of cytokines, and oxidase activity reduction are some of the mechanisms through which bioactive compounds of beetroot act upon its cancer prevention role [19]. Carcinogenesis may be disrupted by the beetroot and its bioactive components. The anti-cancerous activities of betalain has been demonstrated by many studies and efforts have been made to determine the mechanism behind it, as displayed in Figure 4. Researchers showed that betalain had no impact on the normal cell line by developing an insulation around injured tissues [38].

Moreover, results from various research showed that moderate and permanent consumption of table beet products may favorably affect the patient's life expectancy. Bladder and ovarian cancer cells as well as proliferation of human tumor cells are inhibited by the betacyanins [34] [39]. Incidence of esophagus, skin, liver, lung, and colon cancer is reduced by the ingestion of beetroot.

Saponins, another bioactive compound of beetroot, is helpful in the reduction of cancers. Saponin content may also vary depending on how the beetroot is processed. Saponin content in beetroot gel was nearly three times higher than in juice, at 22 and 8.22mg/g, respectively [7]. Doxorubicin (Anthracycline) is a type of chemotherapy drugs which is used to treat different kinds of cancers [40]. Das *et al*. [41] stated that adult rats which were given same combination of doxorubicin and red beet juice showed reduction in cardiac cell death and enhancing apoptosis in breast cancer cells.

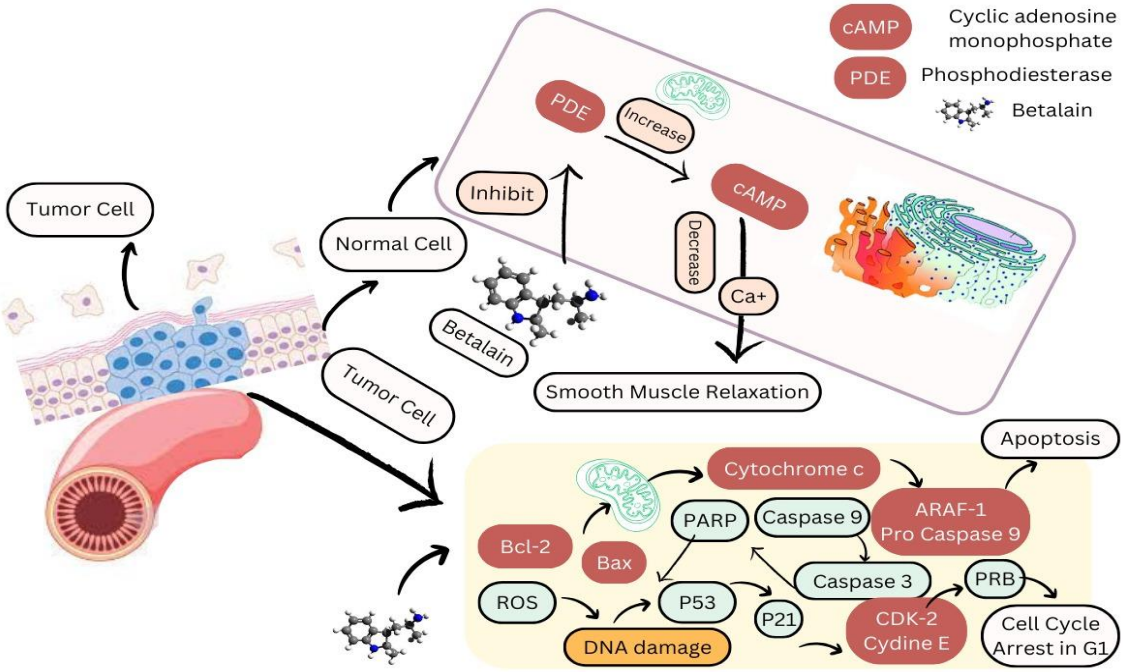

Figure 4: How Betalains Affects Normal Cell Vs Tumor Cell

Anti-Stress and Anti-Depressive Property

In the stress and anxiety related psychiatric disorders red beets have shown therapeutic potential. Sulakhiya *et al.* [44] studied the effects of beetroot extract of leaves on depression, stress, and anxiety in mice. In stressed mice, anxiolytic and antidepressant activity, as well as good antioxidant property was shown. Omega-3 can be used with Uridine (extracted from sugar beet) to prevent depression by changing mood and reducing overwhelming feelings resulting in the relaxation of the body [36].

Anti-Hypertensive Property

Nitrates from *Beta vulgaris* reduce blood pressure and also oxidize Low-density-lipoprotein [37]. Hypertension has affected approximately one billion individuals globally and is a primary purpose for cardiovascular problems. Diet high in nutritional fibers favors in lowering blood strain. A study was focused to determine the impact of RBJ (raw beet juice) and CB (cooked beetroot) on people suffering from excessive blood strain. In this, twenty-four hypertensive people aged twenty-five to sixty-eight years have been classified into 2 separate groups. For two weeks, one group consumed juice and the second group took cooked beetroot. From every group, each individual took 250ml of RBJ or 250g of CB per day for the duration of fourteen days. Both varieties of beetroot were tremendous in keeping in check blood pressure, endothelial characteristic and

inflammation, however the juice had higher significance in opposition to hypertension relative to cooked beetroot [42].

Research investigation by [7] used beetroot gel produced without any chemical components and study its beneficial effects on blood pressure and plasma nitric oxide. The sample was tested in five subjects (four men and one woman), eating a hundred gram of beetroot gel. The outcome of acute inorganic nitrate supplementation on nitric oxide production was evaluated in these subjects. Results showed that consumption of beetroot gel improved plasma nitrite threefold after 60 min of ingestion, reduced systolic blood strain by 6.2mm Hg and diastolic blood pressure reduced by 5.2mmHg, and coronary heart rate reduced by 7 beats per minute. Figure 5 shows how betalain acts for the management of blood pressure through oxidative stress reduction.

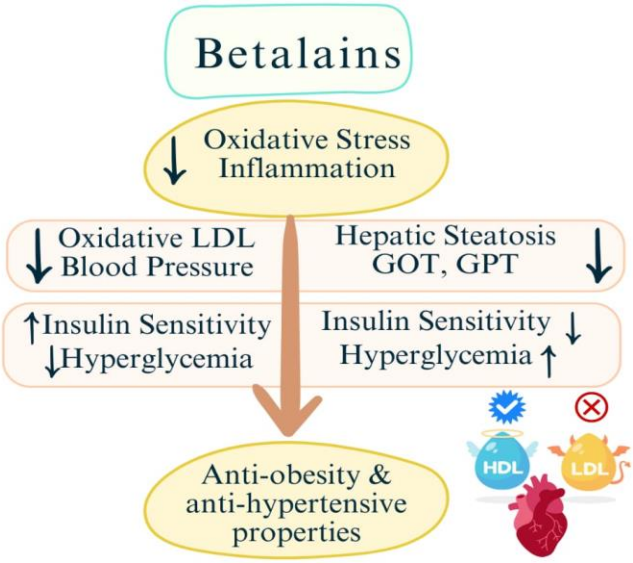

Figure 5: Therapeutic Role of Betalains

Table 2: Health Promoting Benefits of Beetroot Bioactive Compounds

Bioactive components	Sources	Health-Enhancing Properties	References
Betalain	Beetroot	• Strong anti-oxidant, anti-carcinogenic, cardio protective activity • Strong anti-inflammatory property • Anti-diabetic, hypotensive, hepato-protective, a cure for wounds • Anti-hypertensive, anti-depressive effect • Reduced oxidative hemolysis in RBCs • Anticancer activity against HEp-2 and MCF-7 cells	• [9] [19] • [36] • [9] [10] • [43], [44] • [24] • [45] [46]
Betacyanin	Beetroot	• Reduce blood pressure • Inhibit proliferation of human tumor cells • Prevent bladder and ovarian cancer	• [43] • [34] • [39]
Betanin and Iso-betanin	Beetroot	• Increase resistance to lipid peroxidation • Inhibit breast, colon, stomach, lung cancer cell • Suppressing Alzheimer's disease	• [47] • [19].
Phenolic and Flavonoid compounds	Beetroot	• Strong anti-oxidant activity, prevent cancer, reduce cardiovascular diseases • Inhibit the synthesis of microbial cell membranes	• [18]
Phytochemicals*	Beetroot	• Stimulate immune defense, hematopoietic, hepatic, and renal protection	• [36]
	Beetroot juice	• Down regulate the oxidative stress, inflammatory, and apoptosis activity • Maintain plasma NO_2 level and endothelial function • Improve physical and cognitive performance	• [48] • [49] • [50]
	Beetroot extract with ethanol	• Strong antimicrobial activity • Lipid lowering	• [51] • [52]

Processing and Food Application

Storage time of the vegetables is affected by the environmental factors and global warming. To preserve the vegetables, especially seasonal, processing is one of the most essential method. If the processing method is conducted properly, it could retain same natural nutrients as that of raw product. Frying, boiling, baking, and drying are all different ways to preserve beetroot and these

methods can affect its nutritional profile. With the rightly chosen processing method, the consumer could benefit from its health-promoting properties [5]. According to a study, after thermal processing at 80˚C for 10 minutes, peels and pulp of beetroot shows high anti-oxidant activity but the content of natural pigment betalain was declined [53]. Freeze-drying the beetroot juice in a spray dried system developed beetroot powder [21]. Various studies investigated red beets for manufacturing different food products. Sandhya and priya prepared cream cheese spread using beetroot as coloring and nutrition-enhancing agent [54]. Beetroot-based functional food and dietary supplements are available in the market such as beetroot juice, gels, fermented and fractionated beetroot juice, dried beet powder (in the form of tablets, capsules), crunchy beetroot slices, and crisps [30].

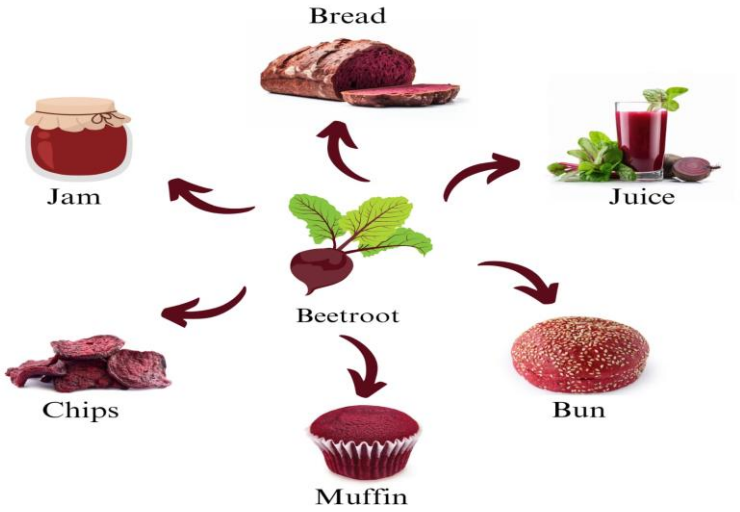

Figure 6: Different Food Applications of Beetroot [32]

Not everyone is aware of the benefits of red beets even though they are being eaten in considerable quantities. Different beetroot based product at the markets is available to satisfy consumers preferences and culinary traditions and also to increase and maintain the functionality of the products. Meeting the demand of consumers for healthier options may lead to an increase in sales and market share for products containing beetroot as well beetroot cultivation and agricultural sector expansion. For food application, beetroot has been investigated for its color, flavor and nutritional aspect, by various food industries and researchers making it a super food. These are consumed both raw and cooked form as salad and stews. Nowadays, beetroots are commercially being used for juice and pickle production [11]. In Australian sandwiches, beet is commonly found ingredient. Fresh leaves and stem of beetroot are steamed and eaten, and older stems are stir-fried. Beetroot additives are non-allergenic and inexpensive. Additionally, Deep red-color beetroots are employed in the color enhancement of various products. Therefore, natural colorants are more anticipated than synthetic colorant for commercial application as food additives [11]. Potential application of beetroot in various food products have been outlined in Table 3.

2.0 CONCLUSION AND RECOMMENDATION

The bioactive compounds of beetroot such as betalains, carotenoids, polyphenols, and flavonoids

demonstrated a wide range of pharmacological activities that underscore its health enhancing potential. The high anti-oxidant potential of betalain is effective against oxidative stress, a key factor in the development of numerous chronic diseases. Moreover, nitrate content, betanin and betacyanin of beetroot showed their extensive potential for modulating blood pressure, chemo-protection and cardiovascular health, simultaneously. The implications of this study are multifaceted and suggest its usage in array of industrial applications that could range from developing food products and dietary supplements to incorporating beetroot extracts in pharmaceutical formulations. This way it can also positively impact various sectors of the economy, from agriculture to consumer goods.

Table 3: Potential Application of Beetroot in Various Food Products

Sr#	Food Products	Forms of Red Beetroot (Betalains)	Findings	References
1	Yogurt	Incorporation of 2% of beetroot powder	Enhanced sensory acceptance, rheological properties, and physicochemical attributes	[55]
2	Baked rolls	Addition of 2-10% of beetroot powder	Wheat dough with good hydration and farinographic properties and improved physical and sensory characteristics of baked rolls	[56]
3	Jelly	100mL of beetroot juice was used to develop jellies	Good quality jelly was formed	[57]
4	Candy	Beetroot pomace utilization up to 0-10%	The phytochemical properties of the candies were improved	[58]
5	Noodles	Addition of 10-40% of beetroot pulp	Noodles containing 30% beetroot pulp had the best nutritional, cooking, and overall acceptance	[17]
6	Dairy free drinks	Fresh beetroot	Beetroot drink was a good product that was low in cholesterol and high in nutrients	[59]
7	Bread	Supplementation of beetroot powder up to 70%	Developed bread with 10% BP was accepted and carried high nutrition contents	[60]
8	Jam	Beetroot pulp incorporation up to 60%	Beetroot pulp can be successfully used in the development of a low sugar extra vegetable jam.	[61]
9	Muffins	Use of beetroot extract as a natural colorant	Beetroot can serve as an alternate to harmful synthetic colorants and contains high anti-oxidant levels	[62]
10	Biscuits	Utilization of beetroot powder up to 15%	According to the records, biscuits with 5% beetroot powder had better physical as well as sensory attributes.	[63]

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