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Red Beetroot (*Beta vulgaris* L. *var rubra* L.) is a Potential Source of Nitrate as a Functional Food: A Review

T.D. Widyaningsih[1], A.H. Fitriah[1], S.N. Wulan[1], H. Sujuti[2]

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ABSTRACT

Beetroot is known for the common varieties which are the red beetroot (*Beta vulgaris* L.var *Rubra* L.), characterized by a dark red tuber and the white beetroot/cut beetroot (*Beta vulgaris* L. var *Cicla* L.) with a whitish red tuber. Beetroot is also known for its potential bioactive content, such as nitrate, phenolics, betalains, ascorbic acid, carotenoids and saponins, which are processed into various functional foods of high nutritional value. This article aims to review role of the nitrate as a bioactive compound in red beetroot, its benefits as a functional food ingredient and its benefits for health. The research was conducted at Brawijaya University Malang, Indonesia during 2024. Nitrate is a major potential component in beetroot that has been widely studied as an implementation in health improvement such as metabolic disorders. Nitrate is naturally formed in plants and subsequently converted to nitric oxide (NO) in the human body which is known to have beneficial effects for clinical application. NO could regulate metabolic disorder-induced metabolic diseases, such as reduced blood pressure, increased oxygen, nutrient delivery to the active muscle and mediator for neurotransmission, vasodilatation, nerve function and also as immune defense. Beetroot can have added value if it is converted into a functional product. Beetroot can be formulated as a fresh product, fermented, bread, powder, chips, gel and cereal bar. Functional beetroot production can be a new strategy for increasing the nutritional content with high bioaccessibility such as nitrate, potassium and antioxidants which have the potential to improve heart health and sports performance.

Key words: Bioactive compound, Functional food, Nitrate, Nitric oxide, Red beetroot.

Beetroots are plants that have been grown for medicinal purposes for thousands of years. According to records written in Europe, beetroots were cultivated before the tenth century (Yashwant 2015). Beetroots are a type of root vegetable source of natural antioxidants (Chhikara *et al*. 2019), a source of dietary fiber, a source of minerals (potassium, sodium, iron, copper, magnesium, calcium, phosphorus and zinc), a source of vitamins (retinol, ascorbic acid and B-complex), as well as being rich in bioactive compounds such as nitrate, carotenoids, ascorbic acids, triterpenes, betalains, phenolics and saponins mentioned in Fig 1 (Baião *et al*., 2016; Chhikara *et al*., 2019; Clifford *et al*., 2015; Hadipour *et al*., 2020) and often known as NO Diet (Baião *et al*., 2017; Nowacka *et al*., 2019) because it is rich in nitrate, so beetroot is a high-nitrate plant (Lidder and Webb, 2013). Dietary nitrates and nitrites serve as effective NO (*Nitric Oxide*) donors under conditions of hypoxia and ischemia (Bryan and Ivy, 2015). NO causes a vasodilatory effect and increases blood flow to the muscles (Moazami *et al*., 2015). It takes > 6.3 mmol to increase NO levels and decrease blood pressure in normal people and Cardio Vascular Disease (CVD) patients (Baião *et al*., 2020). The high nitrate content in beetroot juice can increase the athlete's VO_2 Max which biologically affects the utilization of O_2 regulators by muscle contractors so that the distribution of O_2 according to muscle needs and nitrate supplementation until the fifteenth day can increase mitochondrial mass so that it also increases the use of NO in mitochondria to produce energy (Sanrebayu *et al*., 2020).

[1]Department of Food Science and Biotechnology, Brawijaya University, Jl. Veteran No. 10-11, Ketawanggede, Lowokwaru District, Malang City, East Java 65145, Indonesia.
[2]Faculty of Medicine, Brawijaya University, Jl. Veteran No. 10-11, Ketawanggede, Lowokwaru District, Malang City, East Java 65145, Indonesia.

Corresponding Author: A.H. Fitriah, Department of Food Science and Biotechnology, Brawijaya University, Jl. Veteran No. 10-11, Ketawanggede, Lowokwaru District, Malang City, East Java 65145, Indonesia. Email: arsinah_habibah@student.ub.ac.id

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Beetroots Originated in Mesopotamia and from Europe and Asia Minor in the 8th century. Several varieties of beet such as yellow beet (1700s) and sugar beet developed by the Prussians in the 1800's, now the more popular red beetroot comes from the Mediterranean region, widely cultivated in Europe, America and throughout Asia (Chawla *et al*., 2016; Zohary *et al*., 2012). Two well-known beetroot varieties are the red beetroot (*Beta vulgaris* L. *var Rubra* L.) which is characterized by a dark red tuber and the white beetroot/cut beetroot (*Beta vulgaris* L.*var cicla* L.) with a whitish red tuber. Beetroots are a promising commodity for cultivation because they can be harvested every 2.5-3 months after the seeds are sown, Even though the two types of beetroots cannot flower and set seeds in Indonesia the seeds are still imported from abroad but can grow well in Indonesia, especially in the highlands with an altitude of > 1,000 m asl for red beetroots and at an altitude of 500 m asl for white beetroots. Beetroots are unable to form tubers if grown in lowlands. Therefore beetroots are widely grown on the island of Java, especially Cipanas, Lembang, Pangalengan and Batu (Asian Journal, 2017).

At the stage of growth, beet plants need direct exposure to sunlight for around 6-8 hours. It needs regular watering especially when the topsoil is dry. It needs to be kept moist but not wet to avoid rot and fungus caused by excessive watering. The sowing season in Bangalore (India) is in July and August which is the best season for sowing seeds. The sowing method uses row sowing. Sow the seeds at a depth of 2 cm and each seed should be sown at intervals of 5-10 cm (GreenMyLife, 2018). Beetroots develop better in deep, looser, acidic soil that is rich in organic matter and light, the optimum temperature ranges from 10^{o}C-20^{o}C. The best color, taste and quality are achieved in cool weather through the stages of the reproductive cycle. The appearance of oval to heart-shaped leaves occurs in the vegetative phase, around the stem, which grows upright. Emission of flower tassels occurs with the production of 2-3 mm lenticular seeds, consisting of gromeruli during the reproductive stage. The root system consists of a main root and smaller roots with lateral branches. The taproot is dark purplish red, round to long in shape and develops almost at ground level (Kumar, 2015).

The way to benefit from beetroot, in the form of traditional formulas such as cooked vegetables or fresh juices, requires a very large amount of beetroot (Baião *et al*., 2016; 2017; 2018; Da Silva *et al*., 2016) but if too much will cause discomfort to the stomach and can cause nausea and vomiting. Beetroot juice is a source of nutrients and rich in bioactive compounds. Freshly extracted beetroot juice contains 62.20% Antioxidant activity, contains 990.7 mg/100 ml total phenols, 790 mg/L anthocyanins and 520.3 mg/L betanin, so it can be used as added value in food formulation (Arora *et al*., 2019). Therefore it is necessary to supplement beetroot with the right formulation and the appropriate portion as well as effective nitrate concentration and other bioactive compounds as an alternative that is suitable for consumption such as consuming natural vegetables, by maintaining the composition of nitrate and other bioactive compounds contained in beetroot (Baião *et al*., 2017).

This article aims to review nitrate as a bioactive compound in red beetroot, its benefits as a food ingredient, its mechanism as a functional food and its benefits for health.

Beta vulgaris

Beta vulgaris is also known as beetroot. Beetroots belong to the Chenopodiaceae family which includes around 1400 species which are divided into 105 genera (Chawla *et al*., 2016) and are members of the dicot family. Beetroots are classified in the Amarantaceae family, Genus Beta and Beta vulgaris species (Indonesian Ministry of Health, 2018). The edible part of the beetroot is the root. The main root is long, sharp and sturdy and the side roots form a dense texture. Roots are generally spherical or cylindrical in color red-purple/ yellow-golden/red-white depending on the beetroot variety. Beetroot leaves emerge from the hypocotyl corolla and vary in leaf size, shape and color. Seeds are known as multigerm seeds because 1 seed can produce more than 1 sprout. The outer part of the cork seed contains phenolic compounds and inhibits germination as a physical barrier. The stems are decumbent, erect and branched a lot. The flowers are very small with 5 petals (Kezi and Sumathy, 2014). Here's a description of beetroot's different parts (Fig 2).

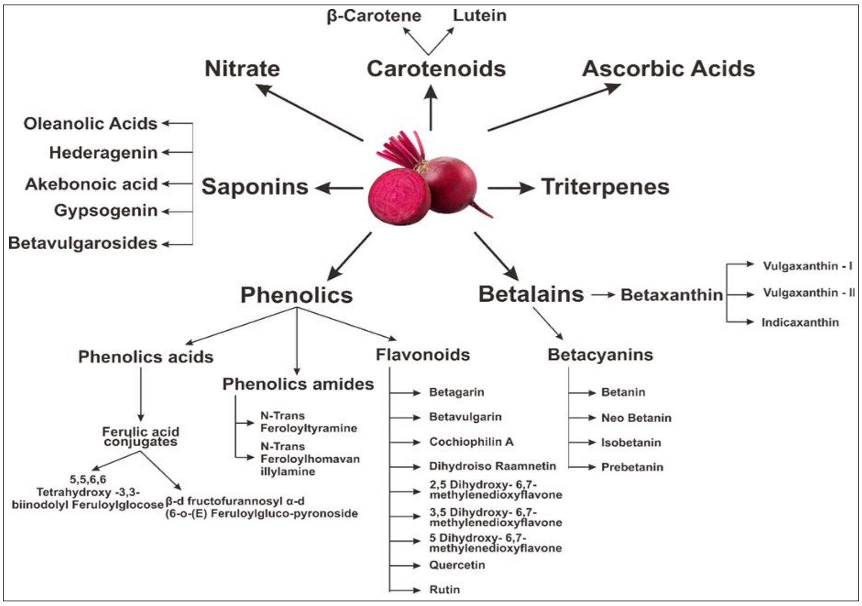

Fig 1: Bioactive compounds in beets (Baião *et al*., 2016; Chhikara *et al*., 2019; Clifford *et al*., 2015; Hadipour *et al*., 2020).

Taproot

This is the most commonly consumed part of the beetroot. It is a thick, fleshy taproot that can range in shape from globular to long and tapered. The skin is thin and smooth and while most people are familiar with the dark purplish-red variety, some beets can also be nearly white, orange, or even have concentric red and white rings. The flesh has a sweet and earthy taste and is often used in salads, soups, or as a side dish.

Leaves (Beet greens)

The leaves that grow from the top of the taproot are also edible and nutritious. They are typically a dark green color with red petioles (leaf stems) and midribs. Beet greens can be cooked like spinach or chard and are rich in vitamins and minerals.

Stems

The stems connecting the leaves to the root are also edible. They are often sautéed or used in stir-fries.

All parts of the beetroot plant-the root, leaves and stems-are safe to eat and can be incorporated into a variety of dishes (Biancardi *et al*., 2010).

In order for beet plants to grow optimally to produce quality crops, it is necessary to control pests that can cause crop failure. Pest control can be done as follows:

1. Flea beetles: do not threaten plants, only reduce value due to hollow leaves.
2. Cercospora leaf spot disease: causes significant losses, especially in late summer (high temperature, high humidity, long leaf wet periods throughout the night). Impact: beets fail to grow to full size if severe. Controlled by spraying Mencozeb 2 g/L.
3. Rhizoctonia Root Rot. Impact: kills and stunts plants. Controlled with Carbendazim 1 g/L (GreenMyLife, 2018).

The nutritional composition of beets in 100 grams of ingredients as stated in the 2017 Indonesian Food Composition Table (TKPI) and 2018 United States Department of Agriculture (USDA) can be seen in the Table 1.

Beets not only consist of macronutrients and micronutrients, but beets are a functional food source because they have benefits for various diseases by containing important components called bioactive compounds such as vitamins, minerals, phenols, carotenoids, nitrates, ascorbic acid and betalains. The effects of phytochemicals depend on the bioaccessibility of nutrients during the digestive process (Liliana and Oana-Viorela, 2020).

Beets are also a plant that is rich in nitrates, so beets are a plant that is high in nitrate content. Table 2 shows the average nitrate content in vegetables in mg/kg, mmol in UK portions as a guide to estimating the number of nitrate units per portion (1 nitrate unit = 1 mmol) to estimate nitrate intake or to modify/alter intake as desired. Tap water and mineral water are included in the table intended for comparison (Lidder and Webb, 2013).

Beetroot are an important source of inorganic nitrate with varying amounts of nitrate. It is reported that there is a 10-fold variation between single varieties (Mirmiran, 2020). Some studies report nitrate levels in beetroot ranging from 644 - 1800 mg/kg (Lidder and Webb, 2013), although some studies found higher amounts of nitrate in beetroot, such as beetroot juice containing 4965 mg/L nitrate (Corleto *et al*., 2018). Raw beetroot contains 4420 mg/kg but this amount increases drastically to 42415 mg/kg after the dehydration process (Sucu and Turp, 2018), likewise, beetroot powder contains 14037 mg/kg nitrate (Ozaki *et al*., 2021). In addition, fermenting beetroot juice and extract allows the conversion of nitrates to nitrites first (Choi *et al*., 2017), thus increasing the protective effect, which can be added to meat products in the form of nitrites (Hwang *et al*., 2017; 2018).

Nitrate and nitrite production in plants

Nitrate and nitrite is produced in plant by nitrogen cycle. Nitrogen cycle is a fundamental biogeochemical process of a crop development that converts nitrogen into various forms, allowing it to move from the atmosphere to the soil, organisms, and back to the atmosphere (Astier; 2018;

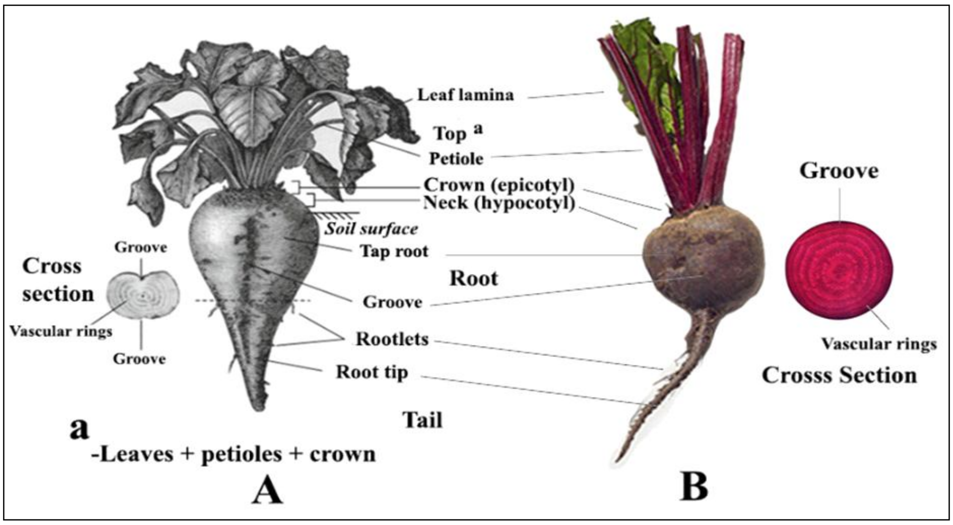

Fig 2: (A) Beet physiology, (B) Red beet physiology Biancardi, *et al*., 2010.

Valenzuela, 2023). Atmospheric N becomes available to plants *via* a series of microbial transformations in the soil (Geisseler, 2010; Grzyb, 2021). The process of the nitrogen cycle consists of several stages, including nitrogen fixation, nitrification, assimilation, ammonification and denitrifi-cation (Grzyb, 2021; Brochado *et al.*, 2023). Nitrogen fixation is the initial step of the nitrogen cycle, where atmospheric nitrogen (N2) is converted into ammonia (NH3).The symbiotic nitrogen fixation is an indispensable process in the nitrogen cycle, where bacteria of the genus Rhizobium establish symbiotic associations with leguminous plants, such as the common bean (*Phaseolus vulgaris*), soybean (*Glycine max*) and pea (*Pisum sativum*) (Brito, 2011; Cunha, 2023; Kamran, 2023). These bacteria have the ability to convert atmospheric nitrogen into a form assimilable by plants (Brochado *et al.*, 2023).

After nitrogen fixation, the next stages is nitrification which converting ammonia (NH_3) into nitrite (NO_2) and then into nitrate (NO_3). This process is carried out by nitrifying bacteria in the soil, ammonia (NH_3) is first converted into nitrite by Nitrosomonas bacteria and then into nitrate by Nitrobacter bacteria. Nitrates (NO_3) are the primary source of nitrogen for plants and they can be taken up by plant roots and used to synthesize amino acids and other nitrogen-containing compounds (Valenzuela, 2023). Nitrification plays a crucial role in transforming organic nitrogen compounds into readily accessible inorganic forms for plants (Brochado, 2023).

Assimilation is a next stages that incorporating ammonia (NH_3) and nitrates (NO_3^-) into biological tissues, such as plant and animal cells. This incorporation allows organisms to utilize nitrogen for the synthesis of essential molecules, such as proteins and nucleic acids (Mokhele, 2012, Zhu, 2023). After assimilation, processing of ammonification occur when organisms excrete waste or die, the nitrogen in their tissues is in the form of organic nitrogen. Various

Table 1: Composition of nutrients in 100 g of beets.

Nutrients		Content per 100 g	
Macro nutrients		87.58	
Water (g)		43	
Energy (kcal)		9.56-9.96	
Carbohydrates (g)		7.96	
Sugar (g)		2-2.8	
Dietary fiber (g)		1.61-1.68	
Proteinsfat (g)		0.17-0.18	
Saturated fatty acids (g)		0.027	
MUFA (g)		0.032	
PUFA (g)		0.060	
Phytosterols (mg)		25	
Cholesterol (mg)		0	
Essential and non-essential amino acids			
Tryptophan (g)	0.019	Cystine (g)	0.019
Isoleucine (g)	0.048	Arginine (g)	0.042
Leucine (g)	0.068	Histidine (g)	0.021
Lysine (g)	0.058	Alanine (g)	0.060
Threonine (g)	0.047	Glutamic acid (g)	0.428
Methionine (g)	0.018	Glycine (g)	0.031
Phenylalanine (g)	0.046	Proline (g)	0.042
Tyrosine (g)	0.038	Aspartic acid (g)	0.116
Valine (g)	0.056	Serine (g)	0.059
Micronutrients			
Vitamin	**Mineral**		
Carotenoids (µg)	2	Na (mg)	77
Thiamine (mg)	0.031	Ca (mg)	16
Riboflavin (mg)	0.27	Fe (mg)	0.79
Niacin (mg)	0.331	P (mg)	38
Pantothenic acid (mg)	0.145	K (mg)	305
Vitamin B6 (mg)	0.067	Mg (mg)	23
Ascorbic acid (mg)	3.6	Zn (mg)	0.35

The nutritional composition of beets in 100 grams of ingredients as stated in the 2017 Indonesian Food Composition Table (TKPI) and 2018 United States Department of Agriculture (USDA).

fungi and prokaryotes then decompose the tissue and release inorganic nitrogen back into the environment, making it available for uptake by plants and other microorganisms for growth (Kuypers, 2018). Nitrate-N that is not taken up by plants, because it is soluble, may be leached below the root zone, it may be converted to dinitrogen (N_2) or nitrous oxide (N_2O) gases by heterotrophic bacteria, called denitrification process (Grzyb, 2021; Wang, 2022).

Red beetroot as a functional food

Benefits of red beetroot as a functional ingredient in various food products

Beetroots can have added value if they can be made into a product (Table 3). Beetroot can be formulated as fresh juice, fermented juice, bread, powder, chips, gel and cereal-bar which have been tested on healthy and unhealthy volunteers as a food supplement. Several products made from red beetroot are in great demand among the public, such as juice, yogurt, candy, jam, jelly, powder and ice cream (Czyżewska *et al*., 2006; Baião *et al*., 2017; 2018; Hobbs *et al*., 2014). Red beetroot is a tuber vegetable rich in nutrients and bioactive compounds, traditionally used in various food products because of its red color. Cereal-based products such as bread, pastries, biscuits, pasta and noodles are food sources of carbohydrates and protein but lack micronutrients and fiber, thereby increasing consumer demand for healthy foods that provide nutrient-dense foods (Rousta *et al*. 2021).

The addition of red beetroot fiber to bread, rolls, cakes, cupcakes, biscuits and cookies can increase the fiber, ash and protein content while reducing the fat content due to the higher nutritional content of beetroot powder (Hobbs *et al*., 2014; Nagib and Zidan 2019; Daunaravièiûtë *et al*., 2020).

Beetroots can be added to ready-to-eat snacks such as extruded products and breakfast cereals. Formulated as a functional snack with an attractive pink to red color it is very popular with consumers because of its delicious taste, texture and attractive appearance (Abdul Alam *et al*., 2018; Lisiecka and Wójtowicz, 2021). Red beetroot powder and beetroot juice can be used as a natural coloring in butter, mayonnaise, cream cheese spread and cream cheese which functions as a natural antimicrobial, reduces lipid oxides, suppresses the growth of bacteria and fungi and reduces peroxide levels. This is because the antioxidant activity of beetroots is higher, resulting in dairy products with a longer shelf life (Raikos *et al*., 2016, Asadaii *et al*., 2020).

The addition of beetroots in milk-based drinks such as yogurt and fermented buttermilk drinks can reduce acidity, increase antioxidant properties, antibacterial

Table 2: Nitrate content in plants (Lidder dan Webb 2013).

Vegetables	Average nitrate content (mg/kg)	Average nitrate content [mmol per UK portion (80 g)]	Estimated nitrate content per UK portion (80 g) 1 unit of nitrate = 1 mmol (62 mg)
High	1890 (113-2650)	2.44 (1.57-3.42)	
Rocket / Arugula	2597 (2597)	3.35 (3.35-3.35)	
Spinach	2137(965-4259)	2.76 (1.24-5.50)	
Lettuce	1893 (970-2782)	2.44 (1.26-3.60)	2
Radish	1868 (1060-2600)	2.41 (1.37-3.35)	
Beetroot	1459 (644-1800)	1.88 (0.84-2.32)	
Chinese cabbage	1388 (1040-1859)	1.79 (1.34-2.40)	
Medium	316 (168-518)	0.41 (0.22-0.67)	
Turnip	624 (307-908)	0.80 (0.40-1.18)	
Cabbage	513 (333-725)	0.66 (0.44-0.94)	
Mung beans	496 (449-585)	0.64 (0.58-0.76)	
Leeks	398 (56-841)	0.51 (0.006-1.08)	½
Leek	353(145-477)	0.46 (0.19-0.61)	
Cucumber	240 (151-384)	0.31 (0.19-0.50)	
Carrot	222 (121-316)	0.29 (0.16-0.40)	
Potato	220 (81-713)	0.28 (0.10-0.92)	
Garlic	183 (34-455)	0.24 (0.05-0.58)	
Red paprika	117 (93-140)	0.15 (0.11-0.18)	
Green paprika	111 (76-159)	0.14 (0.10-0.21)	
Low	78 (25-203)	0.10 (0.03-0.27)	1/10
Onion	87 (23-235)	0.11 (0.03-0.31)	
Tomato	69 (27-170)	0.09 (0.03-0.23)	
Water	**(mg/l)**	**(250 ml glass)**	**(250 ml glass)**
Tap water	26 (22.8-30.3)	0.10 (0.09-0.12)	1/10
Mineral water	2.6 (<0.1-6.3)	0.01 (<0.0004-0.025)	1/100

Table 3: Application of red beetroot in food products (Sneh *et al*. 2022).

Product	Form of beetroot	Quantity added	Product quality	References
Biscuit	Beetroot powder	0%, 5%, 10% and 15%	- Beetroot @5% is the most acceptable level in biscuits. - Beetroot powder cake contains higher levels of betanin,vitamin C, minerals and dietary fibers.	Srivastava and Singh 2018
Bread with and without oil	Beetroot juice	-	- Beetroot juice enriched bread showed higher nutritionalvalue. - Bread reared using beetroot as a natural colorant showedhigher antioxidant activity and total phenolic content thanbread prepared with commercial colorants. - overall acceptability of bread using natural colorants isfairly accepted among consumers.	Lim 2018
Cake	Beetroot powder	0%, 5%, 10%, 15% and 20%	- Nutritional cake quality in terms of protein, ash and dietaryfiber content increased with beetroot powder. -Beetroot powder @ 15% in cake formulation is highly accepted with the highest overall acceptability scores than control	Lucky *et al.* 2020
Cookies	Beetroot powder	0%, 10%, 15% and 20%	- Increasing beetroot concentration decreased the lightnessvalue while the redness value increased. - Hardness and Fracturability of the cookies reduced withincreasing beetroot powder level - Cookies with beetroot powder had higher dietary fiber,potassium, magnesium and phosphorus content. - Cookies with 15% beetroot powder were most acceptable	Aulia and Sunarharum 2020
Cupcake	Beetroot powder	0%, 2.5%, 5.0%, 7.5% and10%	- Beetroot powder increased the muffin weight while volumeand specific volume decreased. - Lightness value decreased while the redness value of crumband crust increased with beetroot powder addition. - the bacterial count and yeast and mold count were lowestin beetroot powder incorporated muffins throughout thestorage than control muffins.	Alshehry 2019

Table 3: Continue....

Table 3: Continue....

Ice cream	Beetroot Juice	1%, 2% and 5%	- Beetroot juice enhances the nutritional value of ice cream. - Overrun of ice cream decreased while melting resistance increased with juice addition. - Ice cream with beetroot juice had higher antioxidant activity, total phenols, crude fiber, B-carotene andbetalains. - Ice cream with beetroot juice @5% had a high organoleptic acceptability.	Ateteallah *et al.* 2019
Noodles	Beetroot powder	0% and 5%	-Beetroot powder inclusion increased the ash and dietary fiber content ofnoodles while fat and protein decreased. - the noodles exhibit higher zinc, magnesium and iron content. - Beetroot powder substitution increased the cooking time, water absorption,and swelling index of noodles. - the lightness value decreased while the redness value of noodles increasedwith beetroot powder. - antioxidant activity, total phenolic content and flavonoid content ofnoodles increased with beetroot powder addition. - Beetroot powder inclusion in noodles showed no significant differencescompared to control noodles	Abozed and Ahmed 2021
Pasta (fettuccine)	Beetroot powder	0%, 5%, 10% and 15%	-Beetroot powder substitution decreased the protein and fat content while soluble fiber and ash content increased. - water absorption and cooking time of noodles decreased while solid loss,volume displace-ment and water retention capacity increased. - Beetroot powder substitution increased the antioxidant activity, totalphenolic content and Betalin content in noodles. - Pasta formulated with the highest beetroot powder level registered thehighest scores for sensory attributes.	Oliveira Filho *et al.* 2021

Table 3: Continue....

Table 3: Continue....

Sausages	Beetroot extract and beetroot powder	Beetroot extract 0% and 5% Beetroot powder 0% and 2%	- the addition of beetroot in extract and powder form decreased thepH and tBars values of the sausages. - the addition of beetroot powder and extract decreased thelightness value of the sausages while the redness value increased. - the appearance, color, flavor, texture and overall acceptability scorewere higher for the sausages with beetroot than the control.	Aykún-dinçer *et al.* 2021
Yoghurt	Beetroot powder	0%, 1% and 2%	- Beetroot powder increased the total solid and protein content while fat decreased. - Viscosity and acidity of the yogurt supplemented with beetroot powder increased, while syneresis and pHdecreased. - Yogurt with 2% beetroot powder had improved color high overall acceptability.	Shalaby and Hassenin 2020

potential, total phenolic content, survival of probiotic bacteria Streptococcus thermophiles and Lactobacillus and increase consumer acceptance (Ganguly *et al*., 2017; Hashem 2018; Ahmad and Ali, 2019). The addition of 10% red beetroot powder to cookies is more acceptable (Murlidhar *et al*., 2017) and the quality of spray-dried beetroot powder stored for a long period is better stored in LAP packaging compared to HDPE (Singh and Hathan, 2017). The addition of 10% beetroot powder can also increase the elasticity of snack bars, significantly reduce hardness, the most acceptable texture and sensory properties, have higher ash content, carbohydrates, antioxidant activity, flavonoids and total phenols (Tangariya *et al*., 2022). Consumption of functional beetroot gelly is a new strategy to provide nutritional content with high bioaccessibility such as nitrate, potassium and antioxidants which have the potential to improve heart health and sports performance (Silva *et al*., 2016; Morgado *et al*., 2016).

Health benefits of nitrate and nitrite in red beetroot

Nitrates (NO_3-) and nitrites (NO_2-) are naturally occurring substances in fruits and vegetables, which humans are encouraged to consume because of their beneficial health effects. On the other side, nitrates and nitrites are used as food additives such as sausages, ham and other processed meat (Levine, 2012; Song, 2015). Nitrate and nitrite in humans are present due to diet or produced by the action of endogenous L-arginine-NO synthase (Nuji, 2017; Mcneal, 2021). Nitrate (NO_3-) in food is converted in the human body to nitrite (NO_2-) and subsequently to nitric oxide (NO) generated by NOS (NO synthase) enzymes that oxidize in the blood and tissue. In the blood, exogenous NO3 mixes with endogenous NO_3- produced via the oxidation of NO (Shannon, 2021; Redaelli, 2022).

Nitric oxide in the body is a compound that is known to have beneficial effects for clinical application. NO could regulate metabolic disorder-induced cardiovascular diseases and other metabolic disease, such as reduced blood pressure and increased oxygen and nutrient delivery to the active muscle and also as a mediator for neurotransmission, vasodilatation, nerve function and immune defense (Ma, 2018; Zamani, 2021; Andrabi, 2023). Under conditions of illness or senescence, the activity of eNOS (endothelial nitric oxide synthase) was reduced and the production of NO was decreased (Novensa, 2011; Rogers, 2013). Thus indicating exogenous source of NO supplement might have a potential treatment for patients undergoing illness or senescence (Ma, 2018).

NO is known to be a potent vasodilator to cause a BP reduction. NO generated in the vasculature causes relaxation in vascular smooth muscle, which subsequently results in vasodilation (Levine, 2012; Redaelli, 2022). The nitrite anion is a cell-signaling molecule, which is considered a storage pool of NO as well as a NO-independent signal. Dietary nitrate- enhanced nitrite is capable of increasing cyclic guanosine 32 ,52 -monophosphate (cGMP) levels in tissues and contributing to blood vessel vasodilation via a mechanism that lies upstream from activation of soluble guanylyl cyclase (sGC) (Liu, 2020).

Moreover, the synthesis of NO was reduced in obese mice (Siervo, 2011). Metabolic disorder-induced high blood pressure, insulin resistance and carbohydrate tolerance were found in eNOS (endothelial nitric oxide synthase)-knockout mice. Dietary nitrate effectively supplements NO by the activated exogenous NO_3-NO_2-NO pathway under conditions of hypoxia. Nitrate enhanced exercise tolerance by the NO-cGMP-PPAR pathway and increased the metabolism of fatty acid in skeletal muscle cells (Ashmore, 2015). Exogenous nitrate could activate the cGMP pathway in mice and promote the conversion of white adipose to brown adipose, therefore enhancing fat metabolism and decreasing body weight (Roberts, 2015).

NO also contributes to improved wound healing by upregulating angiogenic factors, such as TGF-ß and VEGF, which ensures adequate blood supply for healing. However, in cases of impaired wound healing, inadequate NO synthases and low levels of available NO lead to decreased collagen deposition, unregulated inflammatory responses, tissue hypoxia and prolonged healing time (Malone-Povolny, 2019). Recently, hypoxia-induced oxidative stress conditions have been suggested to facilitate the depletion of antioxidants and thus promote cysteine oxidation and subsequently lead to an enhanced Cgb generation of NO in the presence of nitrite during hypoxia (Bescós, 2012; Reeder, 2018).

CONCLUSION

Red beetroot is a superfood that has been used as a therapeutic and functional food ingredient since ancient times. This paper summarizes the entire scope of red beetroot and its use as a value-added product. It is useful as a food coloring agent in many dairy and food products. The Nitrate content in red beets through the physiological role of NO which functions as vasodilation, efficient use of O_2 during exercise, the immune system, as a neurotransmitter and as an inhibitor of platelet adhesion. It also has anti-microbial, anti-hypertensive, anti- inflammatory, anti-hyperglycemic properties, etc. This plant has many health benefits and provides an opportunity for researchers to develop various products derived from red beets that have added value.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Informed consent

All animal procedures for experiments were approved by the Committee of Experimental Animal care and handling techniques were approved by the University of Animal Care Committee.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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