Watermelon as a potential fruit snack

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\textbf{ABSTRACT}

With the rapid increase in cardiovascular diseases, health-conscious consumers are increasingly showing more interest in foods that provide health benefits beyond the provision of essential nutrients. Watermelon contains phytochemicals such as lycopene, vitamin C, \(\beta\)-carotene, and Total polyphenolic content that possess anti-inflammatory, anticancer, and antioxidant properties. Dietary intake of these products with antioxidants properties is important in maintaining human health and well-being. These reduces incidence of chronic diseases such as hypertension, diabetes, cancer, and some coronary heart diseases, through inhibiting formation of free radicals and reactive oxygen species. The presence of these phytochemicals enhances its potential use as a functional ingredient in food application. This paper aims to characterize the phytochemicals found in watermelon, and emphasis is directed toward the role of natural antioxidants in reducing the risk of chronic diseases to discourage the use of synthetic antioxidants. Moreover, another focus is on seeking the recognition of watermelon as a potential snack and to support its traditional consumption.

\textbf{Abbreviations:} WJC: Watermelon juice concentrate; ROS: Reactive oxygen species; DNA: Deoxyribonucleic acid; CVD: Cardiovascular diseases; BHA: Butylated hydroxyanisole; BHT: Butylated hydroxytoluene; WHO: World Health Organization; SVCT: Sodium-dependent vitamin C transporters; LDL: Low-density lipoprotein; HDL: High-density lipoprotein; HPPPEF: High-pressure processing and pulse electric field; TS: thermosonication

\section*{Introduction}

A trend in snacking has increased markedly in recent years. However, unlike in past years, consumers are conscious about their health due to heavy burden of noncommunicable diseases like hypertension, diabetes, cancer, and cardiovascular diseases (CVD).\cite{1} As a result, their perception of food has progressed from being affected mainly by taste and appearance to considering the concept of optimal nutrition by avoiding foods that are associated with nutritional inadequacy.

The recent dietary recommendation of increasing the intake of diet rich in natural antioxidants has generated an interest in replacing energy-dense snack per day with fruits that possess antioxidants.\cite{2,3} This trend also creates a demand in the food industry for production of nutritious food preferably from natural origins in order to satisfy consumer needs. In this context, consumers are encouraged to snack on natural products such as fruit and vegetables. Watermelon (\textit{Citrullus lanatus}) is an exotic quintessential fruit that contains nutrients and phytochemicals reported to be beneficial to human health.\cite{1,4} It is a good source of vitamins B, C, and E as well as minerals such as phosphorus, magnesium, calcium, and iron.\cite{5} Epidemiological studies have demonstrated that it
possesses antioxidants with anti-inflammatory, antihypertensive properties as well as a protective effect against carbon tetrachloride-induced toxicity.\textsuperscript{[1,4]} Literature has recorded that natural phytochemicals such as polyphenols, vitamin C, β-carotene, and lycopene mediate their effect via other mechanisms such as regulation of cell growth, immune system response, and modulation of gene expression.\textsuperscript{[2,4,6]} Identification of health-promoting compounds in watermelon fruit and their benefits to human health are the focus of the study. It is hoped that the accumulated information will encourage watermelon consumption.

\section*{Background of watermelon}

Watermelon is a member of the Cucurbitaceae family native to tropical areas of Africa near Kalahari Desert.\textsuperscript{[6,7]} Botanists refer it as a “pepo” which is a fruit having a thick rind and fleshy center.\textsuperscript{[8]} It is largely consumed as refreshing summer fruit, much appreciated by the consumers because of its refreshing capability, attractive color, delicate taste, and high water content to quench the summer thirst.\textsuperscript{[5]} According to Oberio and Sogi,\textsuperscript{[9]} watermelon fruits yield 55.3\% juice, 31.5\% rind, and 10.4\% pomace. Carotenoids such as lycopene and β-carotene are responsible for the red and orange colors of the watermelon, respectively (Figure 1). The sweetness of watermelon is mainly due to a combination of sucrose, glucose, and fructose. Sucrose and glucose account for 20–40\% and fructose for 30–50\% of total sugars in a ripe watermelon.\textsuperscript{[10]}

The chemical components of watermelon enhances its capacity to scavenging the low-density lipoprotein (LDL) and high-density lipoprotein (HDL) in a cell membrane.\textsuperscript{[10,11]} A plethora of evidence shows that it can be effective for weight loss due to its low sodium, saturated fat, and cholesterol (Table 1). Several epidemiological and retrospective clinical studies have evinced a positive correlation between diet rich in phytochemicals and reduced risk of CVD (Table 2). As a result, consumption of watermelon has been associated with various health benefits such as lowering the risk of developing heart diseases, age-related degenerative pathologies, and some kinds of cancer.\textsuperscript{[1,5]} In addition, it is also a rich source of citrulline, which is a nonessential amino acid.\textsuperscript{[19]}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{watermelon_cultivars.png}
\caption{Images of different watermelon cultivars.\textsuperscript{[6]}}
\end{figure}
Watermelon utilization

Consumption of raw watermelon fruit on hot summer days is a common practice which has been observed across the world; however, to increase utilization and availability throughout the year, watermelon is processed into variety of commercial products.\(^1\)\(^2\)\(^3\) In addition, Kim et al.\(^2\)\(^4\) and Jumde et al.\(^2\)\(^5\) stated that the lycopene-rich nature and health benefits of the watermelon juice make it an excellent choice for preparing additional functional foods in order to increase utilization. It has been used in the production of a variety of products like juice, smoothies, jams, sweets, and sauces.\(^2\)\(^6\) To fit in the needs of modern lifestyle, freshly cut watermelon stands out as convenient ready-to-eat novel snack for consumers who are health-conscious but have less time for food preparation.\(^2\)\(^7\) However, packaged watermelon products are still commercially rare in most countries.

Formation and prevention of diseases in a human body

A healthy and normal human body is sustained by all the biochemical reactions that take place in the cells and organelles of our bodies. Ijah et al.\(^4\) reported that oxidation reaction leads to formation of

Table 1. Phytochemical content of fresh watermelon juice per 100 g.

| Parameter     | Value          | Reference |
|---------------|----------------|-----------|
| Energy        | 30–46.2 Kcal   | [12]      |
| Carbohydrates | 7.6–11.6 g     | [12]      |
| Protein       | 0.6–0.9 g      | [14]      |
| Total fat     | 0–0.15 g       | [14]      |
| Cholesterol   | 0.00–0.01 mg   | [12]      |
| Dietary fiber | 0.4–0.61 g     | [14]      |
| Vitamin A     | 569–864.88 IU  | [12,14]   |
| Vitamin C     | 8.1–12.31 mg   | [12]      |
| Lycopene      | 3.38–11.34 mg  | [9]       |
| Sodium        | 0.0–0.001 g    | [12]      |
| Ash           | 5.2–5.4%       | [14]      |
| Moisture      | 93.12–95.2%    | [9]       |
| Calcium       | 7 mg           | [12]      |
| Iron          | 0.24 mg        | [12]      |
| Magnesium     | 10 mg          | [12]      |
| Potassium     | 112 mg         | [12]      |
| Phosphorus    | 11 mg          | [12]      |

Table 2. Diseases and associated health benefits of some quality parameters.

| Disease                          | Parameter  | Outcomes                                                                 | Reference |
|----------------------------------|------------|---------------------------------------------------------------------------|-----------|
| Obese postmenopausal women       | Citrulline | Improved cardiac autonomic function in sedentary obese postmenopausal women, increase plasma arginine | [13,15]   |
| Hypertension                     | Lycopene   | Improved plasma agitation                                                 | [1]       |
| Stroke                           | Vitamin C  | Stroke reduction                                                          | [16,17]   |
| Breast cancer patients           | Lycopene   | Serum lycopene associated with decreased risk                             | [6,11]    |
| Osteoporosis                     | Lycopene   | Can counteract the damaging effects of oxidative stress which causes osteoporosis | [1]       |
| Liver disease                    | Vitamin C  | Decrease of 58.2% serum alanine aminotransferase and 49.4% of high-sensitivity C-reactive protein and also minimize damage and slow disease progression | [16]      |
| Human metabolism                 | Vitamin C  | Least risk of inadequacy or adverse health effects.                       | [16]      |
| CVD mortality                    | β-carotene | Reduced the hazard ration in CVD and coronary heart diseases              | [1]       |
| High cholesterol in macrophage cell line | Lycopene | Lowered cholesterol synthesis                                             | [18]      |
| Low libido                       | Citrulline | Improve erectile functions                                                | [19]      |
| Flue and scurvy                  | Vitamin C  | Prevents and treats variety of ailments, scurvy, and a simple cold        | [1,20]    |
| Eye health                       | Vitamin A  | Enhances optimal eye functioning                                          | [12]      |
Free radicals in a human body. Free radicals are highly unstable atoms, ions, or molecules that actively react with other molecules and affect the normal functioning of the deoxyribonucleic acid (DNA) and cell membrane.\cite{24,25} The cellular redox process of free radicals and reactive molecules leads to the formation of reactive oxygen species (ROS) that plays a dual role as both toxic and beneficial compounds.\cite{26} In fact, chemical reactions, free radicals, and some redox reactions are a source of oxidative stress of macromolecules in living cells.\cite{5} This leads to damage of the cellular components including lipids, DNA, and proteins.\cite{6} This destruction results in diseases such as CVD, cancer, and neurodegenerative diseases (Figure 2). CVD is reported to be the major cause of death in the European countries; it is further forecasted that in 2030 the number of deaths due to cardiovascular disorders will be around 23.6 million.\cite{27}

Modifiable factors (e.g. high cholesterol, obesity, arterial hypertension, and diabetes) as well as non-modifiable factors such as age, race and heredity are factors that accelerate formation of diseases in a human body.\cite{4,5,28} In addition, Kulczynski et al.\cite{27} reported that, lifestyle risk factors such as snacking on unhealthy food, eating habits, lack of exercise, smoking, and alcohol intake also have significant effect on formation of diseases. It is believed that a balanced diet which includes adequate nutrients and phytochemicals is crucial in inhibiting the damage effects of free radical through improvement of body’s antioxidant status.\cite{4} Romdhane et al.\cite{5} reported that antioxidants are molecules capable of scavenging oxidation reaction. Antioxidants have the ability to trap ROS and prevent its formation (Figure 2). They are also capable of inhibiting and neutralizing free radicals and their actions by (1) electron transfer; (2) electron addition, which results in radical adduct formation; and (3) hydrogen atom transfer at level of prevention, interception, and repair of diseases.\cite{27}

Phytochemicals such as lycopene and β-carotene have shown to have antioxidant, anti-inflammatory, and hypotensive properties; therefore, their inclusion on diet results in positive effects on the human body.\cite{28,29} They (1) prevent oxidative changes in the plasma lipoprotein structure, (2) prevent macular degeneration and the development of cataracts, (3) prevent oxidized LDL formation, (4) reduce the nitrogen oxide bioavailability and they synthesis prostacyclin (PGI2), which causes blood vessels to relax and become reduced.\cite{27} They may also enhance the immune system function and inhibit tumor progression in some cancers.\cite{9}

Synthetic antioxidants such as butylated hydroxyanisole and butylated hydroxytoluene are often used in the food, cosmetic, and pharmaceutical industries.\cite{30} However, these antioxidants are expensive and are reported to be detrimental to human health resulting in dangerous health effects, including liver damage and carcinogenesis.\cite{5} The risks and concerns associated with the use of synthetic antioxidants and antimicrobials have triggered the interest of consumers toward consumption of food rich in natural antioxidants as an alternative. Accumulating evidences favor the use of natural antioxidants and presume them to be safer than synthetic antioxidants because they display little or no toxic side.\cite{2,29,31}

As a result, attention in identifying natural sources of antioxidants that can be used as potential inhibitors of diseases with less side effects has increased. Watermelon contains sufficient nutrients and phytochemicals which have antioxidant properties and therefore helpful in the prevention of diseases such as hypertension and arthritis.\cite{17} In fact, many researchers proved that consumption of watermelon is a practical approach leading to the reduction of chronic disease.\cite{5,6} These properties make watermelon as a useful functional ingredient.\cite{27}

**Watermelon nutrition and health benefits**

Consumption of watermelon is desirable by consumers as it shows many positive biological effects, which are mostly connected to being fat-free, cholesterol-free, low in sodium, rich in minerals and phytochemicals.\cite{22} As a result, consumption of watermelon provides long-term health benefits such as reduced risk of heart disease, improved blood pressure in hypertension patients, decrease LDL oxidation, and exert a cardio protective effect.\cite{10} Compared to well-known fruits like tomatoes,
Watermelon consumption inhibits the absorption of phytochemicals (lycopene, polyphenols, vitamin C). Free radicals can be generated from unhealthy lifestyles (smoking, alcohol consumption, lack of exercise, unhealthy diet), nutritional deficiency, and natural causes (Aging, menopause, and environmental factors). These free radicals interact with cellular biomolecules (lipids, proteins, and DNA), leading to oxidized biomolecules (damaged cells). Inhibitors such as antioxidants can inhibit these processes and prevent chronic diseases (cancer, hypertension, diabetes, heart attack, and cardiovascular diseases).

Figure 2. Formation of diseases and action of phytochemicals. [Ref]
strawberries, and guavas, watermelon has higher antioxidant capacity.\textsuperscript{[1]} Carbohydrates, vitamins, and fiber are the major components that make up watermelon (Table 1). All these components are present in their most beneficial forms. Watermelon has recently received attention for its fewer quantities of fats; it is therefore considered a constituent of a healthy diet low in cholesterol and sodium.\textsuperscript{[22]} Owing to its reported nutrients, watermelon is regarded as a medicinal plant.\textsuperscript{[15,17]}

As fruit, it has low energy density and is therefore recommended for weight management.\textsuperscript{[22]} Adedeji and Oluwalana\textsuperscript{[32]} indicated that watermelon is a good source of minerals and vitamins since it contains 11 minerals and 19 vitamins. It has vitamins such as thiamine, riboflavin, niacin, and folate. In addition, it has minerals such as potassium, magnesium, calcium, phosphorus, and iron.\textsuperscript{[4,33]} Owing to these properties, watermelon consumption can be useful in maintaining acid–base balance in the body that has a major role in normal physiology, maintaining appetite and normal digestion.\textsuperscript{[1]} In addition, Adedeji and Oluwalana\textsuperscript{[32]} reported that minerals such as calcium and potassium play an important role in cell regulation, maintenance of the cell structure, and cell differentiation process.

Bailey et al.\textsuperscript{[25]} found that supplementation with watermelon juice improves aspects of vascular health in individual with hypertension. Presence of vitamins makes watermelon to be helpful in supporting normal vision and skin health, managing cholesterol, supporting normal appetite and nervous system function and may be involved in normal muscle contraction.\textsuperscript{[34,35]} The World Health Organization (WHO) recommends that the optimal diet for everyone is through the consumption of a low-fat, fiber-rich carbohydrates.\textsuperscript{[36]} Watermelon juice and pulp contain considerable amounts of fiber and carbohydrates. Fiber plays a significant role in blood cholesterol, which helps in the prevention of large bowel diseases while carbohydrates are the source of energy for the cells.\textsuperscript{[34]} Ijah et al.\textsuperscript{[4]} and Alam et al.\textsuperscript{[37]} indicated that watermelon is rich in vitamin B, which is responsible for the production of energy in the body. Taking into consideration these health-promoting parameters, watermelon extracts can be incorporated in to cosmetics, food, and pharmaceutical products.

**Phytochemicals and their contribution to human health**

Consumption of food rich in phytochemicals has long-term benefits to human health. Watermelon has the following phytochemicals:

**Lycopene**

Lycopene (C\textsubscript{40}H\textsubscript{56}) is a carotenoid with the highest degree of unsaturation;\textsuperscript{[29]} it is a straight chain hydrocarbon with 13 double bonds, 11 of which are conjugated.\textsuperscript{[6,19]} Lycopene is available in trans configuration from natural sources (Figure 3) while in a human plasma, lycopene is an isomeric mixture containing 50% of the total lycopene as cis isomers.\textsuperscript{[2]} It is visible as a red pigment that gives fruits such as watermelon, guava, red bell peppers, and tomato their desirable color.\textsuperscript{[19]} Lycopene contributes to about 21–43% of the total carotenoids and is accumulated in the human tissue.\textsuperscript{[2]}

Lycopene is derived from fruits and vegetables.\textsuperscript{[30]} Therefore, it is incorporated into the body through diet. The estimated lycopene intake in developed countries is 5–7 mg/day and it is assumed that approximately 10–30% lycopene is absorbed in the body.\textsuperscript{[39]} After consumption, lycopene enters the stomach for digestion, it changes into a lipid phase, which is dispersed under the influence of bile salts and pancreatic lipases.\textsuperscript{[9,39]} Formed liposomes are absorbed through the intestinal walls via passive transport and using a transporter – scavenger receptor class B type 1 protein.\textsuperscript{[27]} It is further incorporated into lipid micelles in the small intestine and eventually distributed in a form of chylomicrons to fatty tissues and organs such as liver, testes, seminal vesicles, and adrenal glands.\textsuperscript{[2]}

Lycopene is a strong antioxidant; therefore, it is an effective free radical scavenger and oxygen quencher among all carotenoids.\textsuperscript{[9,40,41]} In fact, lycopene-scavenging rate is higher than β-carotene and tocopherol; in vitro studies have proven lycopene twice as potent as β-carotene and ten times that of α-tocopherol in terms of its singlet oxygen quenching ability activity.\textsuperscript{[6,27]} Initially, it was
reported that tomato contains the highest amount of lycopene than all fruits. However, recent study by Oberio and Sogi has reported watermelon as the fruit containing the highest bioavailable lycopene which is about 60% more than that found in tomato which makes it the lycopene leader among fresh produce. Thermal processing induces isomerization of lycopene bioavailability. Hence a heat-processed tomato is said to contain more bioavailable lycopene than a fresh tomato.

Watermelon pomace is reported to be a concentrated source of lycopene as compared to the juice. Oberoi and Sogi found watermelon pomace to be 20–24 mg/100 g. Studies are still ongoing to determine the part of watermelon that contains the most concentrated source of lycopene. The quantity of lycopene in watermelon varies according to cultivar type and growing conditions. Lycopene has become a compound of interest to both food and health researchers due to its reported benefits on human health. Lycopene has a higher ratio of 1:12 to carotene in a watermelon and this yields remarkable antioxidant capacity. It bears significant potential for consideration in both the treatment and the prevention of some chronic diseases (Figure 3). According to this specific characteristic, foods high in lycopene are referred to as functional foods.

Recently, demand for natural form of lycopene has increased, mainly because it is effective at curbing the destructive free radicals including nitrogen dioxide, sulfide, singlet oxygen, and inhibiting DNA and cellular membrane damage. Because of its antioxidant functions, it reduces lipids by preventing the formation of enzymes involved in cholesterol synthesis. Johary et al. have reported that while lycopene is recognized for its importance as an antioxidant, its biological effect is also influenced by other mechanism such as intercellular gap junction communication, hormonal and immune system. Physical and chemical mechanisms are two major mechanisms that

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Figure 3. Chemical structure of β-carotene, lycopene, and its isomers obtained by thermal processing.
have been established to explain the antioxidant properties and anticarcinogenic activities of lycopene.\(^2\) Elumalai et al.\(^2\) further explained that physical mechanism involves conveying of energy from free radicals to lycopene forming excited isomerized lycopene.

In relation to lycopene being helpful in the body, Naz et al.\(^6\) further reported that its activity depends on its molecular and physicochemical properties and site of action within the cells. For example, lycopene is fat soluble; therefore, its absorption is improved by the presence of oil in the diet.\(^1\) Oberio and Sogi\(^9\) reported that intake of lycopene is associated with decreased risk of various cancers such as breast, colon, stomach, oral cavity, prostate, and lung cancer. Functional drinks derived from lycopene have potential to reduce malignant transformation of oxidized cholesterol in diabetic state.\(^6\) Lycopene restrains the carcinogen-induced phosphorylation of regulatory proteins and ceases cell division at the G0-G1 cell cycle phase.\(^2\)

Lycopene prevents inflammation by reducing production of pro-inflammatory mediators including interleukins, nitric oxide, tumor necrosis factor, and the transcription nuclear factor in macrophages CVD and stroke.\(^1,11\) Evidence in literature shows that lycopene has tumor suppressor activity; it also decreases cellular proliferation induced by insulin-like growth factors that have an effect on mitogens in various cancer cell lines and further inhibits abnormal cellular growth in the body.\(^42\) In addition, regulation of gap–junction communication in embryo fibroblast cells gives lycopene its anticarcinogenic effects.\(^2\) As a result, intake of lycopene-containing products is associated with a reduced incidence of cervical, breast, bladder, and prostate cancers.\(^9,29\)

Johary et al.\(^42\) further indicated that lycopene is involved in the regulation of intrathymic differentiation, which is a mechanism that plays an important role in stopping the growth of mammary tumor. Through this mechanism, cells are able to communicate with each other to ensure proper cell and organ function. Epidemiological studies have suggested that pathogenesis of insulin resistance and diabetes may result from inadequate intake of dietary lycopene; this may be because serum lycopene has a reverse relationship with tissue and mortality of cerebrovascular diseases.\(^2\)

The consumption of fruits that are rich in lycopene such as watermelon is therefore considered pivotal due to the role it plays in prevention of chronic diseases; it is nontoxic without known side effects. Further research is crucial to articulate underlying mechanisms of lycopene on human health. Areas of interest may be based on formulating daily allowance based on age and health disorders as well as interaction of lycopene with other phytochemicals.

**β-carotene**

β-carotene is a lipophilic macronutrient and an insoluble vitamin which includes a group of unsaturated nutritional organic compounds including retinoic, retinal, and retinol.\(^143\) It is made of 40 carbon atoms and contains 11 conjugated and 2 unconjugated double bonds.\(^27\) β-carotene has a very low solubility in number of solvents such as water and ethanol due to its highly conjugated long chain.\(^44\) Visible as the orange color in fruits and vegetables, it serves as a precursor for vitamin A in a human body.\(^35\) Lin et al.\(^45\) indicated that β-carotene is absorbed in an intestine directly by intestinal epithelial cells. β-carotene is obtained in trans configuration form and transformed to cis isomers through photo-induced and thermal isomerization (Figure 3).

Chen et al.\(^46\) stated that β-carotene cannot be synthesized by the body; therefore, it is primarily derived from plant-based foods such as carrots, sweet potatoes, spinach, watermelon, and mangos. β-carotene can be utilized as a functional food ingredient; however, it is poorly bioavailable and its absorption is lower than 10%.\(^45\) Watermelon contains substantial quantities of β-carotene.\(^35\) Kim et al.\(^21\) reported β-carotene content of fresh watermelon flesh to be 4.82 mg/g. As with other phytochemicals, the amount of β-carotene varies according to cultivar type and environmental factors.\(^11\) It has the ability to exhibit both antioxidant activity and pro-oxidant properties.\(^46\) Because of these properties, β-carotene has desirable power in inactivating certain ROS and is useful in neuroprotective effect protecting against LDL and HDL.\(^10,43,47\) β-carotene inhibits free radical through transferring electrons which lead to formation of carotenoid cation radical and hydrogen atom transfer.\(^27\)
The antioxidant potential of β-carotene has been widely investigated and some positive results have been reported. Among other important effects on human health, β-carotene intensifies platelet aggregation increasing the growth factor expression, which leads to the reconstruction of blood vessel walls. Among other functions, it has been shown to be important for the maintenance of the immune system; it supports cell growth and differentiation playing a role in the formation and maintenance of the heart, kidney, and other organs. β-carotene-enriched diet neutralizes the damaging molecules which results in defying age naturally. It helps the body to absorb light in the eyes for good vision and further functions as growth factor for epithelial cells and modulates gene function mainly due to the enzyme dioxygenase, which is present in the human small intestine mucosa, and it converts β-carotene into retino. According to Nzamwita et al., this nutrient is essential for maintaining the integrity of epithelial tissues, growth, and the proper functioning of the immune system. It is known for the prevention scurvy. β-carotene is also known for its potential anticancer attributes. It plays an important role in reducing the risk type 2-diabetes and lowering metabolic syndrome in middle-aged adults. It may also enhance the immune system function and inhibit tumor progression in some cancers.

Children, pregnant and lactating women are reported to be the most vulnerable groups to vitamin A deficiency. The WHO has reported that about 250 million preschool children are affected by vitamin A deficiency as a result about 250,000–500,000 of these children become blind every year. Due to the health benefits of this phytochemical, the demand for it as an additive in for functional food applications as well as a supplement is growing.

**Vitamin C**

Vitamin C (C₆H₈O₆) is used as a general description for all organic compounds exhibiting biological activity of ascorbic acid. Pacier and Martirosyan further reported that vitamin C was first identified in citrus fruit, vegetables, and adrenal glands as hexuronic acid in the 1920s by a Hungarian biochemist Albert Szent-Györgyi. It is an essential nutrient that cannot be synthesized by the human body; therefore, it has to be incorporated in the body through diet. Vitamin C is a water-soluble essential nutrient that is frequently added to a variety of food products for nutrient enhancement and supplementation important for biosynthesis of collagen and certain hormones.

Pacier and Martirosyan mentioned that ascorbate transportation in a human body involves two sodium-dependent vitamin C transporters (SVCT): SVCT1 and SVCT2. Most of it is transported by SVCT1 in epithelial cells (e.g. liver, intestine, and kidney) and then SVCT2 transports the rest in specialized cells such as brain and eye. Vitamin C is classified as chain breaking antioxidant which inhibits lipid peroxidation. As a result, several cohort studies have recommended consumption of food naturally containing vitamin C as opposed to synthetic supplements. Pacier and Martirosyan reported that the main concentrations of vitamin C are located in the brain and adrenal cells.

Watermelon has been identified a good source of vitamin C. According to Oberio and Sogi, fresh watermelon juice contains 3.72 mg/100 g. As with other parameters, vitamin C vary due to difference in the watermelon cultivars and environmental factors. A cup of watermelon juice contains 20% of the daily value for vitamin C. Pacier and Martirosyan indicated that at least 10 mg dosage daily will prevent nutritive deficiency and scurry. However, 90–500 mg daily is recommended for optimal benefits.

Vitamin C may improve the quality of life for cancer patients in several potential mechanisms. Patients with cancer usually suffers from vitamin C deficiency and are exposed to very high oxidative stress. Therefore, oral intake of this vitamin through natural sources may relief fatigue and various other symptoms caused by a state of chronic vitamin C deficiency in these patients. However, cancer pain varies among individual patients as a result, vitamin C requirements differ depending on tumor types. Vitamin C also has a potential to cut off the blood supply to growing
cancers and therefore inhibits cancer cell growth.\textsuperscript{[28]} The other mechanism is that vitamin C has anticancer properties;\textsuperscript{[4]} therefore, consumption of foods that contain this vitamin C may suppress cancer cell in patients by generating pro-oxidant activity, depending on blood concentrations.\textsuperscript{[5,50]}

In addition, as an antioxidant, it protects oxidation of LDL and HDL,\textsuperscript{[51]} preventing cell damage by free radicals.\textsuperscript{[29]} It suppresses oxidants, which can lead to the development of chronic diseases.\textsuperscript{[16,51]} It has long been reported beneficial in the prevention and treatment of a variety of ailments, scurvy, simple cold as well as being stress resistant.\textsuperscript{[18,20]} In addition to its numerous health effects, it plays a role in cognitive functions due to its high concentration in the brain.\textsuperscript{[16]} It is also reported to be essential factor in the synthesis of carnitine, norepinephrine, and collagen.\textsuperscript{[16]}

Hong et al.\textsuperscript{[24]} reported that increased consumption of vitamin C may have positive effect on antioxidant status of smokers by reducing the oxidative stress of former and current smokers. Available data from research studies on animals suggest that vitamin C deficiency in newborns could cause impaired spatial memory due to decreased neurons, whereas in adults it results in certain degenerative diseases such as dopamine auto toxicity, a major component of Parkinson’s disease.\textsuperscript{[16]} With hypertension currently being a major concern in the health facilities, vitamin C has been shown to lower blood pressure in patients with hypertension.\textsuperscript{[1]} Vitamin C decreases more quickly with increased oxidative stress, so higher intakes can help to better manage the increased emotional/physical pressure.\textsuperscript{[16]}

Another group of individuals who are at risk includes those who are suffering from certain addictions, obese pregnant women, and those who have more stressful environment.\textsuperscript{[52]} Blood pressure of patients living with hypertension dropped by 9.1% in patients who were given a dosage of 2 g and subsequent daily doses of 500 mg for 1 month.\textsuperscript{[16]} These result from less consumption of fruits that are an essential source of this phytochemical. A proper intake of vitamin C-enriched diet over a lifetime will help to maintain our current health and prevent future ailments.\textsuperscript{[6,51]} As with other phytochemicals, consumption of natural vitamin C is recommended as opposed to synthetic ones in the form of supplements. Future studies should focus on method to determine the optimal oral intake of vitamin C for individual cancer patients.

\textbf{Citrulline}

According to Sonteriou et al.,\textsuperscript{[21]} citrulline is a non-protein amino acid that is reported to be abundant in watermelon. The researchers further reported that citrulline is an effective precursor for arginine and a metabolic intermediate in nitric oxide cycle. It has emerged as an important amino acid, a product of the nitric oxide cycle. Citrulline is considered a potent osmolyte and radical scavenger against drought/salt stress.\textsuperscript{[7]} Hong et al.\textsuperscript{[24]} mentioned that the most abundant citrulline is found in a watermelon, varying in amounts from 0.7 to 3.6 mg/g fresh. Kyriacou et al.\textsuperscript{[7]} reported that a recent study done on 56 cultivars found the mean value of citrulline as 3.1 mg g\textsuperscript{-1} that shows no correlation with cultivar type. Research is still ongoing to determine which part of the watermelon contains more citrulline than the other (flesh, juice, and rind).

Odewunmi et al.\textsuperscript{[53]} reported that citrulline is produced naturally in the body by an enzymatic reaction of nitrogen–carbon contained l-glutamine and is mainly absorbed in the intestine. A natural source of citrulline may be more bioavailable than a synthetic source.\textsuperscript{[31]} A cohort study reported that subjects consuming a constant high level of watermelon juice with each of three meals had increased plasma arginine and ornithine concentrations compared with subjects not given dietary watermelon.\textsuperscript{[15]} These results demonstrate that plasma concentration of arginine can be increased through the intake of citrulline from watermelon juice.

As an efficient hydroxyl radical scavenger and a strong antioxidant, a diet rich in citrulline is associated with several health benefits.\textsuperscript{[19]} Citrulline was found to be efficient in sections such as skeletal, pharmacology, immunology, and neurology.\textsuperscript{[53]} It has been reported to improve sexual stamina and erectile functions\textsuperscript{[19]} although the exact mechanism of how it happens is still not known. As an amino acid, it is important for young adults with trauma, burn injury, massive small bowel resection, and renal failure.\textsuperscript{[4]} It has also been found to be important in the prevention of anemia.\textsuperscript{[51]}
Furthermore, citrulline is reported to be helpful in muscle relaxation and performances.\textsuperscript{[19]} Owing to this function, it can be crucial for enhancing sports nutrition. Total cholesterol, LDL cholesterol, and HDL cholesterol levels have shown to be significantly improved by a supplementation of L-arginine and L-citrulline.\textsuperscript{[1,19,51]} Hong et al.\textsuperscript{[24]} reported that oral consumption of L-arginine enhances endothelial function in coronary artery disease patients. Research is still ongoing to evaluate citrulline for its functional role as a radical scavenger against salt stress/drought.

In a study by Moinard et al.\textsuperscript{[54]} on malnourished aged rats, an improvement of muscle mass, muscle strength, and locomotor activity was observed after feeding the rats with citrulline-enriched diet. Wong and colleagues investigated the effect of citrulline-enriched diet on obese postmenopausal women. Their study reported 8 weeks of supplementation with L-citrulline has improved obese postmenopausal women’s cardiac sympathovagal balance.\textsuperscript{[13]}

**Total polyphonic content**

Polyphenols, commonly known as polyphenolic compounds, are defined as structural class organic chemicals characterized by the presence of large multiples of phenol structural units including phenolic acids, flavonoids, stilbenes, and lignans.\textsuperscript{[17]} They are said to contain at least two hydroxyl groups attached to an aromatic ring which is due to the presence of the –OH group.\textsuperscript{[55]} They are the most dominant antioxidant in a diet derived from fruits and vegetables.\textsuperscript{[31]} After oral intake and absorption, they go through extensive enzymatic modifications, resulting in the synthesis of glucuronidated, methylated, and sulfated compounds at intestinal and liver levels.\textsuperscript{[18]}

Total polyphenols of fresh watermelon juice are reported to be 16.94–20.23 mg GAE/100 ml.\textsuperscript{[56]} Increasing scientific evidence has suggested that due to their antioxidant properties, daily consumption of foods and beverages rich in polyphenols induces positive effects on human health, which results in having specific biological activities affecting gene expression, cell signaling, and adhesion.\textsuperscript{[31]} They have the ability to stop the formation of ROS in a human body.\textsuperscript{[51]} García-Pérez et al.\textsuperscript{[57]} have stipulated that the benefits of preventing or repairing the damages inflicted by ROS and free radicals in the body such as obesity and diabetes are usually attributed to activity of phenolic compounds. Their study further suggested that these benefits are related to mechanisms of modulation of multiple signaling pathways in pancreatic β-cells skeletal myofibers hepatocytes, adipocytes, and antioxidants effects.\textsuperscript{[57]}

*In vitro* and *in vivo* studies have proven that polyphenols possess anticancer and anti-inflammatory activities.\textsuperscript{[1]} It has shown to be effective in prevention of “psoriasis disease”, a skin disorder affecting up to 2% of the world’s population driven by the immune system.\textsuperscript{[57]} Moreover, it results in protective effects against a series of diseases such as diabetes, neurodegenerative disorders, osteoporosis, inflammation, arthritis, high arterial pressure, and headaches.\textsuperscript{[18,51]} However, the health effects of polyphenols depend on both their respective intakes and their bioavailability.\textsuperscript{[31]} Thus, consumption of watermelon juice can serve as a medicinal alternative.\textsuperscript{[51]} Polyphenols have evoked considerable interest among nutritionists, food manufacturers, and consumers because of their safety and potential therapeutic value.\textsuperscript{[30]} Research is still ongoing to identify and characterize which of the hundreds of existing polyphenols are likely to be contained by watermelon.

**Watermelon preservation**

Watermelon is perishable in nature because of its high pH (5.2–6.7) and high water activity ranging between 0.97 and 0.99.\textsuperscript{[28]} It is therefore susceptible to pathogenic microorganism due to the gram-positive bacteria, which are very sensitive to low acidity.\textsuperscript{[56]} Watermelon can be considered a potentially hazardous food owing to its low acid nature;\textsuperscript{[4]} as a result, the preservation of watermelon juice is important. To extend the shelf life and increase utilization, watermelon juice is processed into various products considering consumer’s need for safe, nutritious and convenient food. However, processing can result in loss of watermelon nutrients and phytochemicals (Table 3). Jumde et al.\textsuperscript{[22]} observed that during processing, fruits go through
units of operations like peeling, size reduction, mixing, and treatment. In the fruit juice industry, high-temperature short-time processing is mostly applied. Although this method is effective in minimizing microorganisms and enzymes, it degrades the nutritional and antioxidant content of the fruit juices.\[60]\n
Currently, numerous researches have been done on utilization of innovative processing technologies that rarely affect low molecular weight molecules like color, aroma compounds, minerals, nutrients, and antioxidants during units of operation.\[^{31,56}\] Heat is reported to negatively affect the quality parameters of watermelon because of its thermo-sensitive nature.\[^{28,56}\] Temperature of above 78°C is reported to have detrimental effect on color change, separation of particles, as well as change in flavor.\[60]\] As a result, alternative processing technologies that are cost efficient and do not compromise quality of the product should be applied during processing.\[^{28}\]

Since watermelon quality parameters are easily depleted by heat treatment,\[^{56}\] non-thermal processing methods must be utilized to minimize the degradation.\[^{31,61}\] Opposed to thermal technology, nonthermal processing is effective in retention of nutrients, flavor, and color during processing.\[^{59}\] High-pressure processing and pulse electric field are among processing methods that can retain the quality parameters.\[^{58}\] A combination of ultrasound and moderate heat known as thermosonication is also more effective in enzymatic and microbial inactivation without affecting juice quality.\[^{59}\] Heat processing transforms lycopene and β-carotene from trans configuration cis isomers (Figure 3) making them more bioavailable.

### Future perspectives

Even though watermelon was found to be the highest source of lycopene and citrulline among all fruits, research has found that at least 85% of our dietary lycopene is supplied by tomato and tomato-based products; therefore, there is a need to produce more watermelon-based products. Since watermelon shows compatibility with other fruits, it can be used together with those fruits to manufacture products that are more commercial. Research has indicated that the lycopene content of watermelon is not totally depleted by processing methods.\[^{59}\] Therefore, lycopene can be extracted from the watermelon to be used in pharmaceuticals and food manufacturing industries as an ingredient. Monitoring quality attributes of watermelons during processing is still an ongoing research in order to produce high-quality products.\[^{61}\] Moving forward into the future, it is important to determine the internal qualities of watermelon as affected by maturity and processing in order provide intensive understanding to food processors.

### Concluding remarks

Snacking has become a habit among consumers in recent years. These snacking trends together with unhealthy life styles may promote the formation of ROS and free radicals which results in non-communicable diseases. As a result, replacing energy-dense snacks with fruits is encouraged. As a functional food, watermelon is a quintessential summer fruit loaded with phytochemicals. These

| Processing method | Effect on antioxidants | References |
|-------------------|------------------------|------------|
| High-intensity pulsed electric field | Reduces vitamin C, high retention of lycopene, and antioxidants capacity in watermelon juice | \[^{49}\] |
| Pulsed electric field | High retention of lycopene | \[^{58}\] |
| Drying | Loss in lycopene and vitamin C, degrade antioxidants capacity and total polyphenols | \[^{1}\] |
| Thermosonication | Increase in lycopene, phenolic content is not much affected and ascorbic acid is retained, free radicals scavenging activity mostly not affected | \[^{59}\] |
| Pasteurization and sterilization | Degradation of vitamin C, degradation of lycopene and polyphenols | \[^{60}\] |
| High pressure processing | Preserve vitamins and citrulline, increase lycopene | \[^{31,59}\] |
phytochemicals have been reported for their pharmacological activities and therapeutic properties such as analgesic, laxative, anti-diarrheal, gastroprotective, hepatoprotective, antibacterial, antifungal, antimicrobial, anti-ulcer, antioxidant, and anti-inflammatory. In addition, it is fat-free and has very low sodium and only has 40 calories per cup. These quality parameters have the ability to promote the body’s own natural healing process, playing a role in both the prevention and the amelioration of various diseases by suppressing the free radicals, decreasing oxidative stress leading to decrease in the risk of chronic diseases such as cancers, hypertension, diabetes, skin problem, CVD, and asthma. It is also helpful in obese women, pregnant women, athletes, smokers, and those with alcohol addiction. Owing to these important nutritional parameters, snacking on 1 cup/152 g per day of watermelon juice over a lifetime can help to maintain good health and prevent future ailments.

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