Journal of Food Measurement and Characterization (2023) 17:5045–5061
https://doi.org/10.1007/s11694-023-02012-5

REVIEW PAPER

Composition, bioactive potential and food applications of watermelon (*citrullus lanatus*) seeds – a review

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Received: 21 January 2021 / Accepted: 12 June 2023 / Published online: 26 June 2023
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Abstract

Watermelon (*Citrullus lanatus*) is one of the most consumed fruits in the world due to its sweet taste and high-water content. However, its consumption generates by-products namely seeds and rind. Watermelon seeds have been extensively studied and several scientific reports have previously demonstrated their richness in terms of nutrients (fat, protein, fiber, minerals and vitamins) as well as phytochemical molecules with a wide spectrum of biological activities with a positive impact on human health. Thus, the objective of this review is to summarize the latest information on the composition, phytochemicals, biological activities as well as food applications of watermelon seeds. In order to achieve this objective, several articles published, between 2011 and 2022, in renowned database were consulted. This review allowed to demonstrate the nutritional richness of watermelon seeds in minerals (K and P) and in vitamins, in particular tocopherols and vitamin E; their richness in proteins, fibers and especially in lipids making the seeds a considerable source of lipid extraction, as well as their content in bioactive molecules with beneficial effects on human health. The results of this overview highlight the importance of the recovery of watermelon seeds and their uses as a novel ingredient in the formulation of new functional food products. Watermelon seeds can also be an important alternative source for the extraction of bioactive molecules to improve human health and well-being. This encourages the consumption of watermelon seeds and motivates industrial companies in the food and pharmaceutical sectors to integrate this new element in order to develop products with added value.

Keywords *Citrullus lanatus* · By-product · Biochemical composition · Bioactive potential · Application in food industry

Introduction

Nowadays, the consumption of fruits and vegetables is linked to human health and well-being. This, increased their culture to ensure their availability throughout the year. However, the consumption of fruit is, in the majority of cases, accompanied by dumping of a lot of waste (rinds, peels and seeds) which create environmental hazard if measures are not taken to dispose them properly. Watermelon (*Citrullus lanatus*) is one of the most consumed species of *Cucurbitaceae*. It is a refreshing fruit due to its high-water content (92% of the total weight) [1]. According to FAO data in 2021 [2], China emerged as the world's largest producer of watermelon with 61,013,536.64 tons of the fruit. The area that China devoted to the production of this agricultural product in 2021 was 1,415,941 hectares, resulting in a yield of approximately 4.31 kg/m². Turkey comes in the second position, producing 3,468,717 tons of watermelon in 2021 across an area of 72,949 hectares, with a yield of around 4.75 kg/m². With 3,254,000 tons, an area of 119,000 hectares and a yield of about 2.73 kg/m², India claimed the third spot in the world for the production of this fruit. Brazil ranked fourth with 2,141,970 tons of watermelon spread over an area of 91,922 hectares, and a yield of approximately 2.33 kg/m². The fifth position is occupied by Iran with 1,251,415.25 tons of watermelon produced on an area of 54,897 hectares with a yield of 2.28 kg/m². Watermelon has health benefits due to the presence of various nutrients, in particular citrulline, and

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bioactive molecules such as lycopene and polyphenols [3, 4]. Nevertheless, while the pulp of watermelon is consumed or processed into other products such as juices, nectars, concentrates, jams and more, the seeds are usually discarded away as waste. This 'waste material' could create ecological problems related to proliferation of insects and rodent as stated by Falade et al. [5], particularly in developing countries where agricultural residue disposal practices are even less controlled. Seeds, called by-products, are a significant source of protein, fat, fiber and minerals that are indispensable to the human body function [6]. Fruits seeds, including watermelon, are widely utilized as a source of oil extraction used for food or medicinal purposes as mentioned in several recent studies such as that of Giuffrè and Capocasale [7] on tomato seed oil and Kolanowski and Zakrzewska [8] on apple seeds for edible uses; Górnas and Rudzinska [9] on seed oil from nine fruit species, including watermelon, for cosmetic, pharmaceutical and energy use and that of Giuffré and Nobile [10] on seed oil of the bergamot fruit. Furthermore, seeds represent a precious source of nutrients and mainly phytochemicals with several biological activities [3, 11, 12]. This exceptional composition is the source of the beneficial health effects demonstrated in several scientific reports such as antimicrobial and antifungal, antidiabetic and antihyperlipidemic; antioxidant activity, hepatoprotective effect and many others [1, 6, 13]. In Arabian and Asian regions, the seeds are used for human consumption as snacks after salting and roasting or to prepare a number of consumables including flour and sauces [12, 14], or even as basic elements in physical treatments such as a coagulating agent in water treatments [15]. But more recently, researchers are increasingly interested to study the watermelon seeds properties and orientating their research towards using them in the formulation of new functional food products. For example, watermelon seeds have been used as a gluten substitute in cookies making by mixing watermelon seed flour with wheat flour [16]. Thus, the use of those by-products as ingredient in new food products with added value will create ready market for the underutilized watermelon seeds which can generate considerable income for the producing country by stimulating their economy and can also solve disposal problems and protect the environment. Numerous previous scientific reports have dealt with watermelon seeds. However, the current synthesis brings together, for the first time, the latest information on the micro and macronutrient composition of watermelon seeds, provides the latest developments on their bioactive potential and their food applications. Several articles were consulted, nevertheless, 116 recent scientific research (2011–2022) where most of them were published in revues indexed in renowned databases (Thomson Reuters and Scopus) have been retained for this purpose.

Structure, composition and nutritional value of watermelon fruit

Watermelon (*Citrullus lanatus*) is a fruit belonging to the *Cucurbitaceae* family, which contains 130 genera and 800 species with some species of economic importance such as melon (*Cucumis melo* L.), cucumber (*Cucumis sativus* L), pumpkin (*Cucurbita* L. spp) [17]. The fruit of the watermelon is a particular berry, spherical in shape, more or less oblong, its diameter varies from 30 to 60 cm and the rind from 10 to 40 mm thick. This fruit, dark green in color often marbled with white, whose flesh is red, yellow, due to the presence of carotenoids including β-carotene and lycopene [18], greenish or white and with black or red seeds, most often weighs between 4 and 16 kg, but fruits of 120 kg have been recorded. Watermelon is a summer fruit highly appreciated by consumers because of its sweet taste and its refreshing ability due to high water content which can be up to 92% of the total weight. The fruit has four main parts (Fig. 1): (i) the skin or peel which corresponds to the surface layer of the fruit (ii) the rind or exocarp which is the green and white outer part; (iii) the flesh (endocarp and mesocarp) which is the edible and colored part containing mainly the juice and (iv) the seeds which are eliminated when consuming the fruit. Chakrabarty et al. [19] indicated that the watermelon rind and seeds are solid wastes that constitute 30% of the total weight of watermelon and Łopusiewicz [1] specified that seeds constitute 1 to 4% of total fruit weight. Depending on the variety, watermelon has a diverse composition. A large proportion of the fruit is constituted by water over 90% and the presence of vitamin C is to noticed also like in other fruits. The fruit is characterized by the presence of sugars, on average of 6% at the origin of its sweet taste. In all its aspects, the watermelon fruit has an interesting nutritional value, including the rind and seeds (Table 1).

Chemical composition of watermelon seeds

Watermelon fruit is amply consumed in the world giving a significant quantity of seeds, which are frequently thrown as wastes. Nowadays, with the rapid increase in several diseases, health-conscious consumers have shown increasing interest for watermelon seeds that provide health benefits beyond providing essential nutrients. The available literature on nutritional composition of watermelon seeds shows different rates of protein, fat, fiber, moisture, ash and carbohydrate contents (Table 2).

Proteins

Watermelon seeds are regarded to be a good source of protein. According to the literature, protein content of seeds

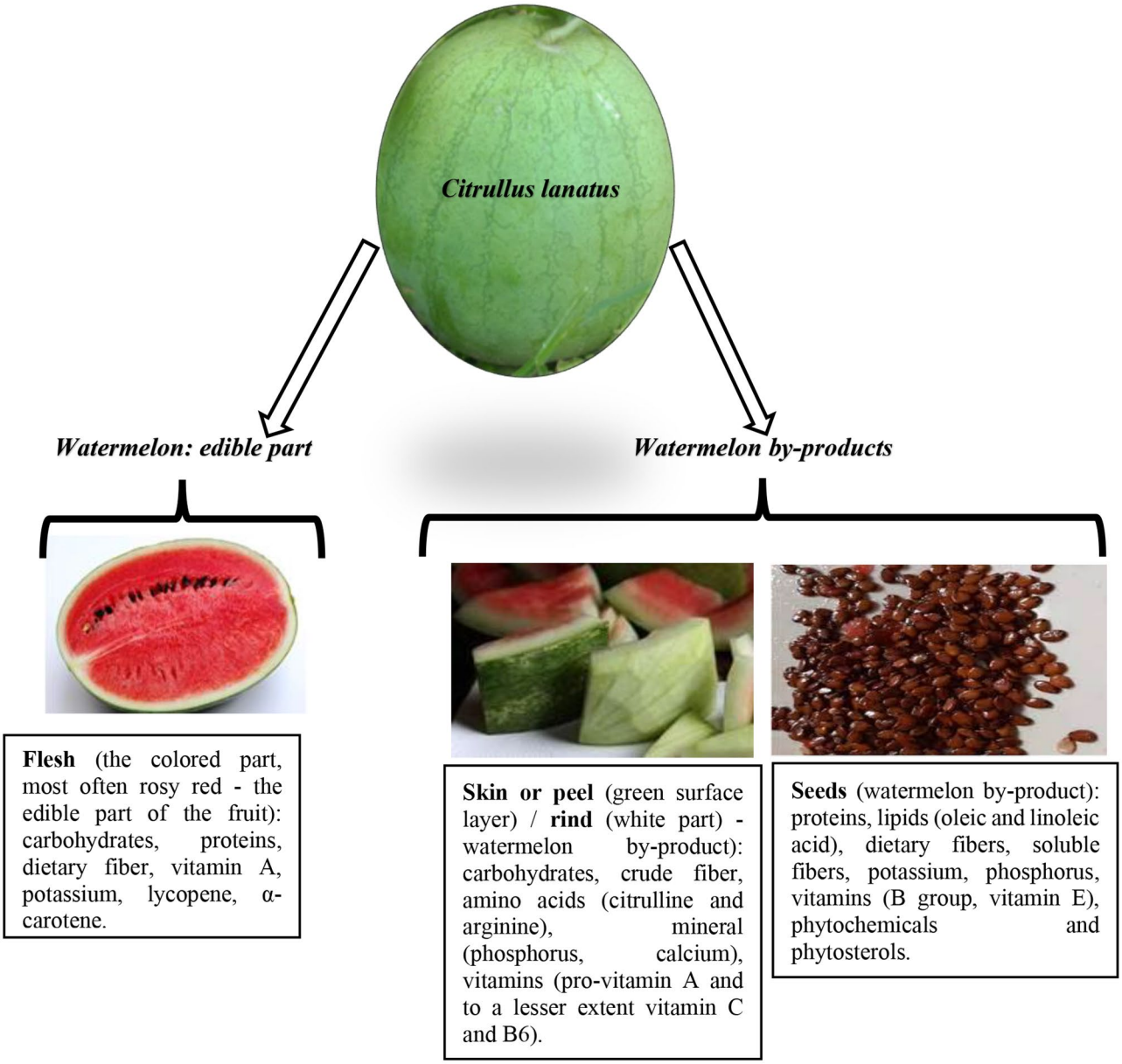


Fig. 1 The main parts of watermelon (*Citrullus lanatus*) and the nutrient content of each part.

varies approximately between 16% up to 49% with an average of 27.70%. Existing evidences suppose that, the watermelon seed proteins show less anti-nutritional factors (which could be reduced by boiling and roasting), with a good in vitro digestibility [16, 28]. In 2011, Wani et al. [28] proposed the use of watermelon seed flour as nutritional and functional ingredients in food formulations due to the significant content of extractable proteins. However, proteins are not only important quantitatively, but also qualitatively in terms of essential amino acids proportions. In fact, the presence of both essential and non-essential amino acids has been reported in watermelon seeds as indicated in several researches (Table 3). Falade et al. [5] stated that non-essential amino acid namely arginine, glutamic and aspartic acids were the most abundant amino acids in watermelon seeds from Nigerian "Rothmas" and "Sugar Baby" cultivars with the highest values reported for "Rothmas" watermelon. Whereas, the amino acid scores showed that lysine (47 to 54%) is the limiting essential amino acid. Ibrahim et al. [29] found the same results where the authors noted that glutamic acid, arginine and aspartic acid were found to be in higher concentration in all organs (roots, leaves, stem, green crust, white crust, kernel and seed) of the watermelon plant (*Citrullus vulgaris*). Rather similar results were reported by Egbuonu [25] on the "Charlston Gray" variety watermelon seed flour from Nigeria, where the author noted that

Table 1 Proximate composition of edible portion of *Citrullus lanatus* fruit

Nutrient	Flesh	
	Composition	Reference
Gross energy (kcal/g)	0.335 ± 0.000	[20]
Macronutrients (%)		
Crude proteins	0.980 ± 0.055	[20]
Crude fat	0.293 ± 0.015	
Crude fiber	0.727 ± 0.020	
Moisture	92.390 ± 0.017	
Ash	0.407 ± 0.020	
Total sugar	92.390 ± 0.017	
Micronutrients		
Minerals (mg/100 g)		
Sodium, Na	1	[21]
Calcium, Ca	7	
Iron, Fe	0.24	
Magnesium, Mg	10	
Potassium, K	112	
Phosphorus, P	11	
Zinc, Zn	0.1	
Vitamins (per 100 g)		
Vitamine C (mg)	8.1	[21]
Thiamine (mg)	0.033	
Riboflavine (mg)	0.021	
Niacin (mg)	0.178	
Vitamine B_6 (mg)	0.045	
Folate (µg)	3	
Vitamine A (µg)	28	
Vitamine A (IU)	569	
Vitamine E (α-tochopherol) (mg)	0.05	

Table 3 Aminoacid profile of *Citrullis lanatus* (watermelon) seeds

Amino acid	Reference			
	[5]	[29]	[30]	[28]
Essential amino acids				
Lysine (Lys)	3.05	4.4	1.01 ± 0.04	2.92 ± 0.04
Leucine (Leu)	5.65	7.1	2.09 ± 0.01	7.19 ± 0.09
Isoleucine (Ile)	3.48	4.7	4.27 ± 0.10	5.21 ± 0.02
Cysteine (Cys)	0.043	1.0	0.39 ± 0.02	6.09 ± 0.04
Methionine (Met)	2.17	1.1	/	0.88 ± 0.02
Phenylalanine (Phe)	4.35	6.0	/	5.83 ± 0.05
Tyrosine (Tyr)	3.48	1.3	/	3.96 ± 0.04
Threonine (Thr)	2.61	3.3	/	3.17 ± 0.07
Valine (Val)	3.48	5.9	1.71 ± 0.03	4.23 ± 0.09
Histidine (His)	2.17	2.7	0.80 ± 0.00	2.15 ± 0.08
Tryptophan	/	/	0.40 ± 0.00	1.17 ± 0.04
Non - Essential amino acids				
Arginine (Arg)	13.06	14.6	6.12 ± 0.06	15.21 ± 0.08
Aspartate (Asp)	6.09	8.3	2.81 ± 0.01	10.39 ± 0.04
Glycine (Gly)	1.20	5.0	2.47 ± 0.03	5.04 ± 0.06
Glutamate (Glu)	15.67	22.7	11.43 ± 0.01	16.75 ± 0.04
Proline (pro)	3.05	/	/	3.95 ± 0.08
Serine (Ser)	3.91	2.7	/	4.96 ± 0.04
Alanine (Ala)	/	5.1	1.43 ± 0.04	5.05 ± 0.06

[5], [28]: results are expressed as g/100 g protein; [29]: results are expressed as percentage (%); [30]: results are expressed as g/100 g dry weight

glutamate was the main amino acid (11.43 ± 0.01 g/100 g) followed by arginine (6.12 ± 0.06 g/100 g) and isoleucine (4.27 ± 0.10 g/100 g). Comparable results have been reported by Wani et al. [28]. Whereas, Enemor et al. [31] found that phenylalanine (5.158 g/100 g) was the highest occurring amino acid followed closely by arginine (4.977 g/100 g), valine (4.572 g/100 g), glutamate (4.462 g/100 g), serine (4.47 g/100 g) and threonine (4.25 g/100 g). The least abundant amino acid was lysine (0.315 g/100 g). Amino acids, play a considerable role in the vital functions of the organism such as protein synthesis, neurotransmission, prevention and management of metabolic syndromes, improvement of lipid metabolism, food efficiency and antioxidant capacity and many others [32, 33]. Thus, this amino acid composition (high arginine content) in the seeds of watermelon is of paramount importance from a nutritional and physiological point of view, especially in developing countries where proteins of animal origin are not within everyone's reach due to their expensiveness.

Characterization of the functional properties of proteins isolated from watermelon seeds

Functional properties of proteins are the physical or physicochemical properties that affect the proteins sensory behavior in food systems during technological transformation, culinary preparations, preservation and consumption. *Cucurbitaceae* seed protein isolates and hydrolysates,

Table 2 Nutritional composition of watermelon seeds

Composition	[22]	[12]	[23]	[24]	[25]	[26]	[27]
Gross energy*	/	354.05 ± 10.14	/	/	/	/	557
Crude proteins	49.70 ± 0.61	16.33 ± 0.97	22.3 ± 4.1	19.41 ± 2.01	30.11 ± 0.32	6.1 ± 0.06	28.33
Crude fat	32.90 ± 0.18	27.83 ± 2.63	24.1 ± 4.1	19.23 ± 1.55	45.05 ± 0.12	2.6 ± 0.06	47.37
Crude fiber	2.10 ± 0.21	43.28 ± 3.44	48.9 ± 0.6	48.26 ± 5.26	3.47 ± 0.09	7.8 ± 0.06	/
Moisture	5.06 ± 0.12	8.00 ± 0.00	25.1 ± 0.5	7.28 ± 0.81	/	10.5 ± 0.06	5.05
Ash	2.98 ± 0.18	3.00 ± 0.00	2.3 ± 0.7	3.97 ± 0.54	3.75 ± 0.11	5.1 ± 0.06	3.94
Crude Carbohydrate	6.06 ± 0.12	9.56 ± 4.65	/	1.85 ± 0.1	17.62 ± 0.02	67.8 ± 0.10	15.31

Results are expressed as percentage (%). *Energy is expressed as kcal/100 g

especially *C. lanatus*, could be potentially used as functional food ingredients due to their balanced amino acid composition and their bioactive properties as found by Ozuna and León-Galván [34]. According to these authors, the solubility is considered one of the most important characteristics of protein as it can influence other functional and bioactive properties of protein isolates and their hydrolysates. Wani et al. [28], reported a typical solubility profile of watermelon (*C. lanatus*) seed protein isolate and concentrates with minimum solubility (10.45–15.21%) at pH 4.0. Whereas, the highest solubility of 95% was achieved at pH of 11. This increase of solubility is due, according to the study, to the high amounts of aspartic and glutamic acid in the protein isolates and concentrates. A water holding capacity (WHC) and oil holding capacity (OHC) of 2.10 and 2.67 mL/g, respectively, were recorded on powder from defatted *C. lanatus* seeds [35]. According to Sonawane et al. [35], several parameters, such as size, shape, hydrophobhydrophilic balance of amino acids in the protein molecule and compounds associated with proteins, can influence the WHC of proteins. The authors reported that the proteins of watermelon seed flour would have some regions responsible for the normal WHC observed. A high value of WHC could be helpful in the formulation of meat substitute, ground meat, baked food and soup [36], which implies the possibility of using watermelon seeds proteins in the formulation of these foods. As with WHC, variations in OHC could be due to variation in protein concentration, degree of interaction with water and oil, and conformational characteristics. Wani et al. [28] have studied the emulsifying and foaming properties in watermelon (*C. lanatus*) seed protein isolate. Their results showed that foaming and emulsifying properties of watermelon seed protein isolates or concentrates were comparable to almond and melon seed proteins and stated that factors affecting the emulsion properties are molar mass, hydrophobicity, confirmation stability, charge and environmental conditions. Globally, watermelon seed meal proteins show good functional properties that offer the possibilities to their potential use as ingredients in food formulation (Table 4).

Moreover, watermelon seed protein hydrolysates have been shown to contain bioactive peptides with antioxidant activity. In fact, after purification by Sephadex G-15 and semi-preparative reversed-phase high performance liquid chromatography (RP-HPLC), Wen et al. [40] were able to sequence, by LC-MS/MS and synthesized with solid-phase synthesis method, five bioactive peptides from watermelon seed protein hydrolysates: Arg–Asp–Pro–Glu–Glu–Arg, Lys–Glu–Leu–Glu–Glu–Lys, Asp–Ala–Ala–Gly–Arg–Leu–Gln–Glu, Leu–Asp–Asp–Asp–Gly–Arg–Leu and Gly–Phe–Ala–Gly–Asp–Asp–Ala–Pro–Arg–Ala. The sequenced peptides showed desirable radical scavenging capacity against the $DPPH^+$ radical (IC_{50}: 0.216 ± 0.01–0.435 ± 0.03) and $ABTS^{\bullet+}$ radical (IC_{50}: 0.54 ± 0.02–1.23 ± 0.03), and oxygen radical absorbance capacity (ORAC) (82.36 ± 1.2–130.67 ± 2.2 μM TE/mg). Nevertheless, among them, peptide with sequence Arg–Asp–Pro–Glu–Glu–Arg exhibited the strongest antioxidant capacity beside its cytoprotective effects on HepG2 cells under induced oxidative stress by significantly inhibiting reactive oxygen species (ROS), [Ca2+]i, malondialdehyde (MDA) levels and increasing antioxidative enzyme activities (superoxide dismutase, glutathione peroxidase, and catalase).

Lipid fraction

The seeds are an important source of oil with a total content ranged between 19% and 45% making them a significant source of oil extraction. Several researches have shown that the composition of watermelon seed oil is qualitatively interesting due to its significant content of unsaturated fatty acids, especially polyunsaturated fatty acids which can reach approximately 68% (Table 5). Mahla et al. [41] have identified on selected fifteen genotypes from India (10 for higher oil content and 5 with low oil content) which were analyzed for their fatty acid profile, eleven (11) fatty acids in watermelon seed oil. Linoleic, stearic, palmitic and oleic acid were found as major fatty acids while myristic, heptadecanoic, arachidic, 9-hexadecenoic and 14-eicosenoic acid were present in traces. Linoleic acid, the single polyunsaturated fatty acid contributor, found in the range of 43.95–55.29%, which is nutritionally important, while saturated fatty acids content ranged between 32.24% and 37.61%. Significant genetic variation was observed for mono-unsaturated fatty acid. Albishri et al. [42] pointed out that the seed oil consisted of 59.6% linoleic acid and

Table 4 Some functional properties of watermelon seed proteins (*Citrullus lanatus*)

Functional properties	Reference			
	[36]	[37]	[38]	[39]
Water absorption capacity	4.8 ± 0.05 g/g	3.40 ± 0.17 g/mL	116.30 ± 0.1%	116.30 ± 0.00%
Oil absorption capacity	1.2 ± 0.2 g/g	1.51 ± 0.08 g/mL	123.5 ± 0.5%	123.5 ± 0.00%
Foaming capacity	/	5.36 ± 0.02%	23.5 ± 0.1%	21.5 ± 00
Foaming stability	/	/	62.5 ± 0.2%	60.50 ± 0.00
Emulsion capacity	72.1 ± 0.1 m^2/g	46.85 ± 0.03%	/	/
Emulsion stability	*25.5 ± 0.3 min	/	0.325 ± 0.001%	0.28 ± 0.00

[36]: results obtained on proteins hydrolysates from *C. lanatus* (India); [37], [38], [39]: results obtained on watermelon seeds flour (Nigeria); *ES index

Table 5 Fatty acids composition of watermelon seeds

Formula	Common name	Concentration in watermelon seeds oil (%)			
		Reference			
		[46]	[24]	[41]	[47]
C14:0	Myristic acid	0.04 ± 0.01	Traces	0.09 ± 0.01	0.4 ± 0.1
C16:0	Palmitic acid	10.29 ± 0.35	9.88 ± 0.86	16.6 ± 1.10	14.0 ± 0.1
C17:0	Margaric acid	0.10 ± 0.01	/	0.16 ± 0.02	0.2 ± 0.02
C18:0	Stearic acid	6.97 ± 0.26	6.96 ± 0.71	18.7 ± 1.39	6.5 ± 0.1
C20:0	Arachidic acid	0.29 ± 0.09	0.26 ± 0.03	1.19 ± 0.12	0.2 ± 0.01
C22:0	Docosanoic acid	/	/	0.16 ± 0.01	0.2 ± 0.01
C24:0	Tetracosanoic acid	/	/	0.16 ± 0.02	/
Saturated fatty acids		**17.69**	**17.1**	**37.06**	**21.5**
C16:1	Palmitoleic acid	0.07 ± 0.01	Traces	0.24 ± 0.01	0.1 ± 0.02
C17:1	Margaroleic acid	0.02 ± 0.01	/	/	/
C18:1	Oleic acid	14.76 ± 0.80	14.25 ± 1.56	13.2 ± 1.27	18.3 ± 0.2
C20:1	Gadoleic acid	0.10 ± 0.01	Traces	0.25 ± 0.03	0.1 ± 0.01
Mono unsaturated fatty acids		**14.95**	**14.25**	**13,69**	**18.5**
C18:2	Linoleic acid	67.06 ± 0.95	68.07 ± 7.56	48.8 ± 2.21	58.7 ± 0.2
C18:3	Linolenic acid	0.3 ± 0.05	Traces	/	/
Poly unsaturated fatty acids		**67.36**	**68.07**	**48.8**	**58.7**
Unsaturated fatty acids		**82.31**	**82.32**	**62.49**	**77.2**

a total of 78.4% unsaturated fatty acids. The predominant fatty acid in the oil was linoleic acid, followed by oleic, palmitic and stearic acids. Orsavova et al. [43] have linked polyunsaturated fatty acids with health benefits since they prevent several diseases including cardiovascular disease, cancer, coronary heart disease, in addition to inflammatory, thrombotic and autoimmune diseases, hypertension, type II diabetes, kidney disease and rheumatoid arthritis, ulcerative colitis, Crohn's disease and many mental troubles such as depression, schizophrenia as reported by Glick and Fischer [44]. According to Petchsomrit et al. [45], the most abundant fatty acids found in the watermelon seed oil, from Kinnaree variety grown in the Chonburi province (Thailand) were linoleic acid, which accounted for 60.10% of total fatty acid, followed by oleic acid (17.57%) and palmitic acid (12.08%), respectively. Similarly, a high concentration of unsaturated fatty acids with the predominance of linoleic and oleic fatty acids was observed in seeds oil of watermelon of both Moroccan varieties ("*Citrullus lanatus* var. lanatus" and "*Citrullus lanatus* var. citroides") [46].

In the lipid fraction of watermelon seed oil are found minor compounds called phytosterols which are secondary plant products that occur in free and esterified form as natural ingredients. They have various bioactive properties that can positively affect human health. The most important and notable benefit is its cholesterol-lowering impact by partially inhibiting cholesterol absorption in the gut [48]. While animal products are generally poor sources of tocopherols, vegetables and seed oils are the principal sources of this vitamin [49]. Among the total tocopherols found in high levels in watermelon seeds, γ-tocopherol was the predominant compound in all tested oils and the most abundant sterol was β-sitosterol [46]. The results were in agreement with those reported by Angelova-Romova et al. [47] on Bulgarian and Greek watermelon seed oils, where γ-tocopherol (92.3–97.0%) was the major component in the tocopherol fraction of the oils, α-tocopherol (5.4–2.0%) and δ- tocopherol (2.3–1.0%) were the minor in this fraction. The same results were found by De Conto et al. [50] on watermelon seed oil tocopherol content. After different extraction methods (cold pressing, traditional, and Soxhlet), Cheikhyoussef et al. [51] have noted that the dominant tocopherol for *C. lanatus* and *Acanthosicyos horridus* melon seed oils was γ-tocopherol, with the highest concentration (59.99 mg/100 g of oil) found in cold pressed *C. lanatus* seed oil. Tocopherols are minor components that occur naturally in vegetable oilseeds and are extracted along with the oils, but their concentration usually decreases with oil processing. They contribute remarkably to the oxidative stability of vegetable oils during storage and processing. Among the various isomers of tocopherols reported to date, the α-isomer has the highest vitamin E potency, while δ has the highest antioxidant activity [52]. Cheikhyoussef et al. [51] have noted that the oil extracted with Soxhlet from *C. lanatus* contained the highest amount of β-sitosterol (58.1 mg/100 g of oil) and that extracted from *A. horridus* had the lowest amount (19.84 mg/100 g of oil). Authors evidenced that β-sitosterol manifests antiviral, anti-inflammatory, and antifungal properties which adds to the potential use of these melon seed oils as nutritive and medicinal commodities. Fifteen phytosterols were identified in watermelon seeds oil in *C. lanatus* var. "Crimson"

from Tunisia, namely cholesterol, brassicasterol, 24-methylenecholesterol, campesterol, campestanol, stigmasterol, Δ5-avenasterol, Δ5,23-stigmastadienol, Δ5,24- stigmastadienol, Δ7- campesterol, Δ7- stigmastenol, Δ 7-avenasterol, clerosterol, sitosterol and sitostanol. The β-sitosterol was the predominant sterol with a content of 2298.83 mg/kg, followed by the Δ5-Avenasterol (1319.21 mg/kg). Thus, β-sitosterol and Δ 5-Avenasterol were the major sterols and together they made up 85.98% of watermelon seed oil [24]. The same results were achieved by Angelova-Romova et al. [47]. In the study of Górnas and Rudzinska [9], six phytosterols (campesterol, stigmasterol, β-sitosterol, avenasterol, Δ7-stigmasterol and cycloartenol) were identified in nine fruit seed oil including *C. lanatus*, while campestanol was noted only in minor amounts in red currant, watermelon and honeydew melon (below 0.1 mg/g of oil).

The majority of unsaturated fatty acids as omega-3 and omega-6, conjugated linoleic acids, and phytosterols have many beneficial health effects by providing the first line protection against cardiovascular diseases and immune system. Also, it is believed that these constituents can prevent obesity, affect the bone health, intervene in treating and managing depression, blood pressure, etc. [53]. As for phytosterols, the main interest of their study lies in their effectiveness in reducing the intestinal absorption of cholesterol, which prevent cardiovascular disease. In addition, it is suggested that phytosterols may protect against some of the most common types of cancer, such as breast cancer, colorectal and prostate cancer [50]. Several scientific reports support that tocopherols act as antioxidants, anti-amyloid by reducing the mitochondrial reactive oxygen species in Alzheimer's disease and have been found to play an important role in fighting against diverse diseases such as oxidative stress, diverse form of cancers, atherosclerosis, cataract among others [54, 55].

Carbohydrate

The carbohydrate content of watermelon seeds varies within a wide range from 1 up to over 15% (Table 2). According to Zubairu et al. [56], the seeds are less rich in carbohydrate compared to the rind as they present a content of 59.03% in the peel against 19.45% in the seeds. On the other hand, Ibeanu et al. [57] indicated that the carbohydrate content of the two samples (dehulled and undehulled sweet princess watermelon seeds) was significant and was found to be greater in undehulled seeds than in dehulled seeds (48.35 and 33.08 g/100 g dry weight basis), respectively. The authors added that this amount could meet 1/3 of the daily caloric intake of a healthy adult. This amount is beneficial because it spares protein as an energy source and acts as a mild natural laxative for humans by adding bulk to the diet. In the same way, the undehulled seeds were higher in dietary fiber (51.37%) than the dehulled sample (33.99%). Indeed, the undehulled watermelon seeds had more soluble fiber (53.45%) and total non-starch polysaccharide (57.56%) than the dehulled sample while the insoluble non-starch polysaccharide was higher in the dehulled seeds (10.28%). Certainly, the presence of soluble fiber which consist on non-cellulosic polysaccharides and oligosaccharides in high amounts is important. In fact, many health benefits are associated with the consumption of the dietary fibers including the improvement of the cardiovascular health, reduced postprandial glycemic response and increased insulin response, weight control and obesity prevention, improvement of gastrointestinal health, including prevention against colorectal cancer. In addition, the fibers act on the internal walls of the colon by dilating them, which facilitates the passage of waste, thus preventing constipation problems; they lower blood cholesterol levels and reduce the risk of various cancers [12, 58]. The richness of watermelon seeds, especially unshelled seeds, in soluble dietary fiber suggests their use as snacks for people with type II diabetes as reported by Ibeanu et al. [57].

Minerals and vitamins

It is well known that all fruits and vegetables are important sources of minerals and vitamins provided in quantities high enough to provide the body with its needs. Watermelon with all its parts (pulp, rind and seeds) are also a source of these micronutrients. According to the literature, minerals as total ash content of watermelon seeds varied between about 2% to more than 5% (Table 2). Most of the studies have shown that watermelon seeds have relatively high potassium content compared to other dietary minerals content, in particular sodium (Table 6) [12, 23, 26, 30]. This situation is very desirable for people suffering from high blood pressure problems. Egbuonu [30] reported levels of 614.30 and 524.00 mg/100 g in K and P, respectively, which were significantly ($p < 0.05$) higher than those found in the rind. Furthermore, Ibeanu et al. [57] found that, in dry weight basis per 100 g, magnesium (667.35 mg), iron (4.81 mg) and zinc (20.72 mg) were found to be more in the undehulled watermelon seeds sample than the dehulled. It has also been found that the seeds of watermelon constitute an important source of Mg and Ca. According to Falade et al. [5], the contents, in mg/kg, of these two minerals recorded on the seeds of two varieties of watermelon varied between 94.79 and 123.9 for Mg and between 125.9 and 233.5 for Ca. It is known that Mg is involved in the calcium metabolism in bones and in the prevention of circulatory diseases. It helps to regulate blood pressure and the release of insulin. While, Ca is an important mineral required for bone formation and

Table 6 Mineral content in watermelon seeds from different region of the world

Mineral	Reference					
	[22] **(%)**	[12] **(%)***	[23] **(g/100 g)**	[24] **(mg/100 g)**	[25] **(mg/100 g)**	[27] **(mg/100 g)**
Sodium (Na)	/	0.17 ± 0.02	7.1 ± 0.1	302.00 ± 29.64	90.35	99
Calcium (Ca)	0.83 ± 0.16	0.14 ± 0.03	758.2 ± 33.2	107.85 ± 9.64	86.75	54
Iron (Fe)	0.51 ± 0.01	4.60 ± 0.07	4.5 ± 0.7	5.17 ± 0.49	10.70	7.28
Magnesium (Mg)	2.66 ± 0.02	0.17 ± 0.02	125.6 ± 28.7	269.62 ± 28.39	1118.0	515
Potassium (K)	1.92 ± 0.04	3.85 ± 0.11	722.1 ± 243.1	750.50 ± 76.58	598.95	648
Phosphorus (P)	37.90 ± 0.15	0.18 ± 0.02	/	787.31 ± 79.58	1073.3	755
Zinc (Zn)	0.012 ± 0.00	0.66 ± 0.03	4.1 ± 0.8	6.80 ± 0.51	9.65	10.24
Copper (Cu)	0.013 ± 0.00	0.58 ± 0.03	12.1 ± 2.6	75.51 ± 6.58	1.66	0.686
Manganese (Mn)	0.008 ± 0.00	0.09 ± 0.01	2.6 ± 0.6	1.40 ± 0.15	10.20	1.614

* Results are expressed as percentage (%) except Fe, Zn and Cu which were expressed in mg/100 g

neurological function of the body [12]. The presence of iron is also reported in the seeds of watermelon. Milala et al. [22] reported an iron content of 0.61 µg/g and 0.51 µg/g in processed and unprocessed watermelon seeds, respectively. Iron is involved in the transport of oxygen to the tissues and its deficiency is very common especially in children and nursing mothers. For this, the consumption of watermelon seeds would be beneficial for the population at risk of anemia. Cu, Zn and Mn are among the trace elements reported in watermelon seeds but at lower concentrations compared to other minerals. Gwana et al. [26] obtained average Cu, Zn and Mn contents of 16.57, 35.33 and 23.5 mg/kg, respectively, low contents compared to other elements; Milala et al. [22] arrive to the same results. However, Alemika et al. [59] noted concentrations of Mn in watermelon seed pulp of 798.15 µg/g against 403.58 µg/g in seed shell, quite close to that of Ca. The authors concluded that watermelon seed is a rich source of both beneficial minerals, which can be used for nutritional and medicinal purposes. However, it should be noted that the presence of anti-nutritional factors, including mostly phytates beside to tannins, oxalate and cyanide, in the seeds of watermelon can decrease the bioavailability of minerals due to their action as chelating agent of cations such as Ca, Mg, Fe, Cu and Zn by inhibiting their absorption from the small intestine and can also negatively affect protein digestibility, solubility and functionality as found by Megat-Rusydi and Azrina [60] on soybean and peanut. However, Egbuonu [61] indicated in his study on anti-nutritional factors present in seeds and rind of Nigerian watermelon that the preponderance of antinutrients, namely saponin, alkaloid, tannins, phenol, flavonoid, cyanide, phytate and oxalate in comparatively lower amounts in samples suggests that the rind and seeds of Nigerian watermelon may provide pharmacological and dietary benefits with possibly lower toxic risk. Thus, the study encourages the use of watermelon rind and seeds as food and / or as a medicine in ethno-medication. Johnson et al. [62] arrived to the same results.

Table 7 Vitamin content of seeds of some Nigerian varieties of watermelon

Designation	Common name	Reference			
		[63] (mg/100 g)*	[26] (mg/kg)	[5] (mg/100 g)	[30] (mg/100 g)
Vitamin C	Ascorbic Acid	5.28 ± 0.00	0.91 ± 0.01	/	6.81 ± 0.03
Vitamin A	Carotene	0.00 ± 0.00	/	/	70.10 ± 1.04
Vitamin B1	Thiamine	0.13 ± 0.00	0.16 ± 0.01	1.1 ± 0.008	0.02 ± 0.00
Vitamin B2	Riboflavin	0.13 ± 0.00	0. 05 ± 0.01	/	0.15 ± 0.04
Vitamin B3	Niacin	3.22 ± 0.00	/	0.33 ± 0.01	3.32 ± 0.00
Vitamin B5	Pantothenic acid	/	0.27 ± 0.01	/	/
Vitamin B6	Pyridoxine	/	0.45 ± 0.01	1.7 ± 0.01	0.09 ± 0.01
Vitamine B9	Folic acid	/	0.11 0.01	0.3 ± 0.05	/

* Results are expressed as mg/100 g except for carotene which is expresses in µg/100 g

As with minerals, vitamins are detected at concentrations that vary over a wide range depending on the origin and variety of watermelon studied (Table 7). In fresh and dried *C. lanatus* samples from Nigeria, pro-vitamin A was not detected in the seeds, whereas thiamine showed a higher content in the seeds and rind than in the pulp. Likewise, the riboflavin levels of fresh and dried seeds of *C. lanatus* were significantly ($p < 0.05$) higher than the pulp. The same observation was made for niacin. Unlike ascorbic acid (vitamin C), this was found to be significantly ($p < 0.05$) lower in seeds compared to rind and pulp [63]. Falade et al. [5] did

not detect the vitamin C that was below the detection limit, While Ibeanu et al. [57] detected vitamin C at concentrations of 40.51 and 62.54 mg/100 g in dehulled and undehulled watermelon seeds, respectively. The presence of vitamin E (as total tocopherol) has also been discussed by Razis et al. [64] where they indicated that this vitamin is present in low quantities in the seeds of winter (3.85 mg/100 g) and summer (2.96 mg/100 g) watermelon without significant differences ($p > 0.05$) from the levels recorded in the seeds of melon, pumpkin and cantaloupe from Punjab (Pakistan). According to the literature, the main vitamins detected in the seeds of watermelon are those of group B alongside with fat-soluble vitamins provitamin, A and vitamin E.

Although the requirements in micronutrients (vitamins and minerals) are generally less than 100 milligrams per day for the man with an average weight of 70 kg, nevertheless, their role is primary and vital in the organism. Indeed, they are involved in the maintenance of tissues, mineral metabolism, the development of the skeleton and the health of the teeth. Further, vitamins serve as cofactors and coenzymes for various enzymatic systems, stimulate the immune system, facilitate the regulation and coordination of most bodily functions, and other biochemical and physiological functions in the body [65, 66].

Watermelon seeds phenolic compounds

The screening of watermelon seeds showed the presence of phytochemicals, in particular polyphenols, which are found abundantly in plants and known for their strong biological activities. Quantitatively, the seeds contain considerable amounts of these molecules. Commonly, the total phenolic tenor of plant material is determined using the Folin-Ciocalteu reagent assay. Indeed, the total phenolic compounds content was of 89.5 ± 0.06 mg GAE/100 g in *C. lanatus* variety seeds oil [46]. However, higher levels were recorded by Tabiri et al. [12] on watermelon seeds of three varieties ranging from 1494 to 5416 mg GAE/100 g and lower contents were obtained by Acar et al. [11] on Turkish seeds which varied from 0.13 mg GAE/100 mg to 0.30 mg GAE/100 mg. Whereas, an intermediate value (5.63 mg GAE/g) was indicated by Seidu and Otutu [67] on Nigerian seeds sample. Similarly to polyphenols, the seeds of the watermelon have interesting contents of flavonoids. Indeed, rates varying between 43.09 ± 0.11 and 113.53 ± 0.21 (mg/g quercetin equivalent) of various extracts of watermelon seeds of Indian origin were recorded by Rahman et al. [68]. However, a lower content of 7.76 ± 0.14 mg QE/g was noted by Seidu and Otutu [67]. In fact, flavonoids are a very important class of polyphenols; These secondary plant metabolites with important antioxidant and chelating properties exhibit numerous beneficial effects for health, namely anticancer action, antioxidant activity, ant-diabetic activity, inhibition of neuropathy, stroke prevention, anti-inflammatory activity, antiviral, antibacterial and antifungal activities. They also possess neuroprotective and cardio-protective effects [69]. There are few reports about the individual phenolic compounds' composition of watermelon seeds. The values of some phenolic acids in watermelon seeds [70] along with the bioactive properties of each polyphenol according to previous studies [71–78] are presented in Fig. 2.

Biological activities of watermelon seeds

Antioxidant activity

As expected, the seeds of watermelon have a high antioxidant capacity due to their content of phenolic compounds since phenols are known to possess high antioxidant activity as compared to other phytochemicals. The seed oil from Kinnaree variety grown in the Chonburi province (Thailand) showed strong antioxidant activity through the $DPPH^+$ radical scavenging capacity which was of 0.894 mg α-tocopherol equivalent/g of dried seeds [45]. Ouassor et al. [46] have found that all tested watermelon seed oils showed a significant amount of total phenolic compounds associated with a good antiradical activity against $DPPH^+$ radical ranging from 51.1 to 84.8%. Similarly, Tabiri et al. [12] reported a significant percentage of $DPPH^+$ radical scavenging capacity of seeds from three Ghanaian varieties of watermelon with a range of 59.88 − 94.66% with Trolox equivalent of 82.59-130.29 µM/g depending on the variety. Lower inhibition percentage against $DPPH^+$ radical was determined by Acar et al. [11] on Turkish watermelon seeds which were between 1.13 and 13.90%. There are several reports about the antioxidant activity of *C. lanatus* seeds extracts and it was noted that the potency of antioxidant power depends on the type of extract. A positive radical scavenging ability of polyphenols available in watermelon seeds against $ABTS^{\bullet+}$ and $DPPH^+$ free radicals ranging from 0.02 to 0.04 mg Trolox equivalent/g seed flour and from 39.89 to 61.11 mg ascorbic acid equivalent/g seed, respectively, has been proven in the work of Seidu and Otutu [67]. Significant ferric reducing power and higher capacity were observed in whole flour compared to shelled seeds and shells. These results suggest the use of watermelon seeds for therapeutic purposes.

Gastroprotective, hepatoprotective and antiulcerogenic activities

Rabiu and Muhummad [79] have demonstrated the gastroprotective and antiulcerogenic activities in ethanol induced gastric ulcer model in albino rats of Nigerian watermelon

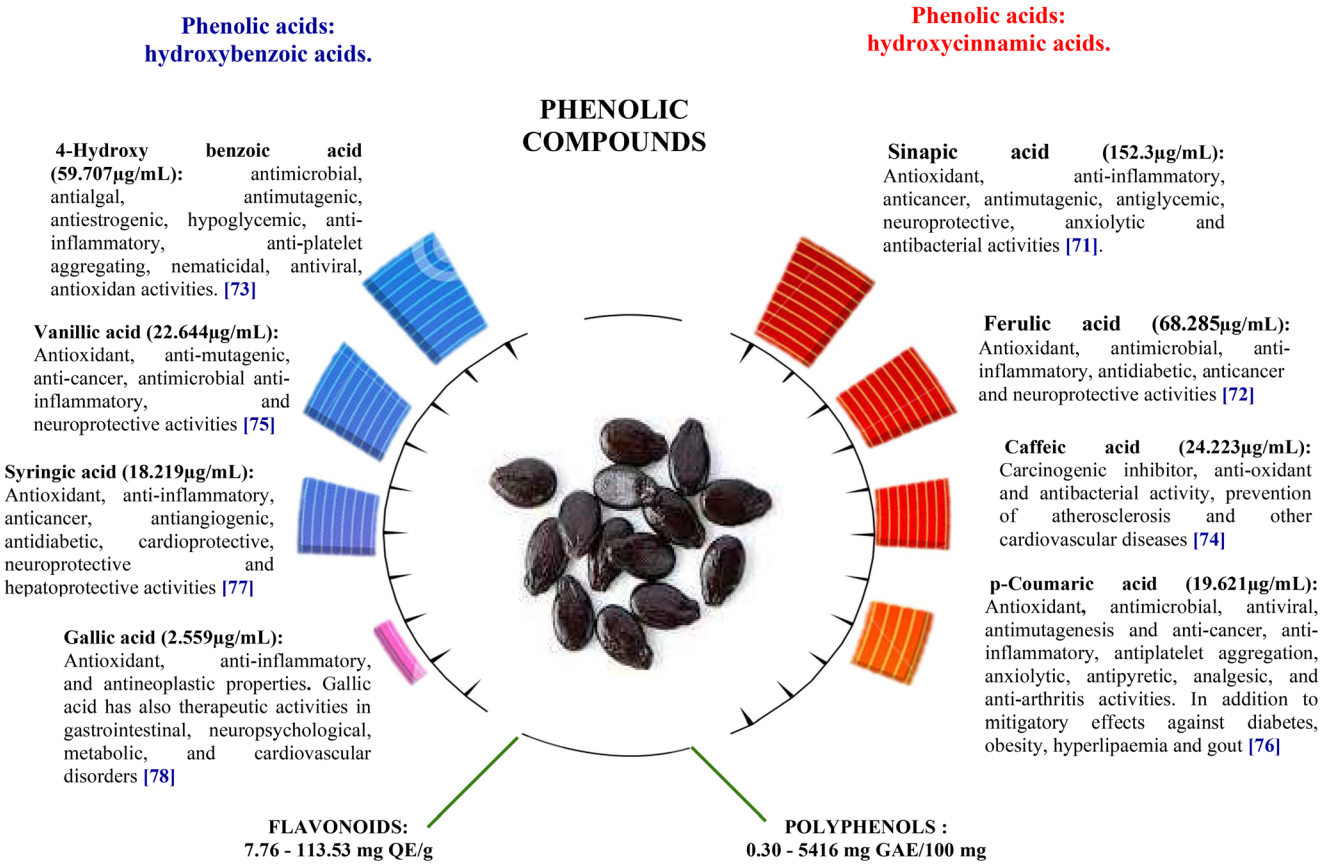


Fig. 2 Values of some phenolic acids in watermelon seed extracts and their potential health benefits

seeds. The authors stated that those effects are probably due to high citrulline and flavonoid contents of the extracts that have great influence on nitric oxide synthesis which has been reported to have antisecretory and antioxidant effects, respectively. An hepatoprotective effect of the aqueous extract of watermelon seeds was demonstrated in the work of Bazabang et al. [13] against ethanol-induced oxidative damage in rats, particularly at 400 mg/kg body weight. Authors explained this activity by various antioxidant phytochemicals content present in the extract. Furthermore, the antiulcer activity of watermelon seeds was previously demonstrated in the work of Bhardwaj et al. [80] in Wistar albino rats. Indeed, the methanolic extract of *C. lanatus* seeds administered at 300 mg/kg of body weight, orally and once a day for 7 days, has an anti-secretory activity as well as a proton pump inhibitory activity presuming its antiulcer therapeutic potential and can be used as an anti-ulcer remedy.

Antidiabetic and antihyperlipidemic effects

The antidiabetic and the antihyperlipidemic effects of watermelon seeds have been also reported. Deshmukh and Jain [81] concluded in their study that the methanolic seed extract of *C. lanatus* possesses remarkable antidiabetic and antihyperlipidemic effects in diabetic rats induced by streptozotocin and also prevents associated diabetic complications. Moreover, Messaoudi et al. [82] reported that the administration of the *C. lanatus* seed extract caused a decrease in the concentration of cholesterol, triglyceride, LDL- cholesterol and increased HDL- cholesterol concentration with associated reduction in the concentration of C-reactive protein, aspartate aminotransferase and alanine aminotransferase concentrations in male *M. musculus* mice. In vitro, the methanolic extract of *C. lanatus* seeds showed considerable inhibitory activity against α-glucosidase with IC_{50} values of 54.44 µg/mL and slight inhibitory activity against α-amylase with IC_{50} values of 76.68 µg/mL. Thus, this therapeutic potentiality could be exploited in the management of type II diabetes mellitus [83]. More recently, Jibril et al. [84] also demonstrated the antidiabetic action of the ethanolic extracts of seed, flesh, rind and leaf of yellow-fleshed seeded *C. lanatus*. The antidiabetic activity was evaluated through the inhibition of α-amylase and α-glucosidase enzymes activities by standard methods. In rats fed with a diet containing 9 g of watermelon seed kernel during 28 days, the serum glucose, triglyceride and very low-density lipoprotein were decreased significantly

($p < 0.01$, $p < 0.05$ and $p < 0.05$, respectively) compared to that of the control group. Liver glycogen, serum total cholesterol, low density lipoprotein and atherogenic index were decreased insignificantly whereas high density lipoprotein (HDL) increased insignificantly in the treated group [85]. The lipid profile, the markers of the hepatic and kidney functions were improved after administration of oil extracted from raw *C. lanatus* seeds by oral intubation to high fat diet induced hyperlipidemia rats during 28 days. Indeed, serum triglyceride, total cholesterol, LDL cholesterol, uric acid, serum transaminases, creatinine and urea were significantly reduced ($p < 0.05$), while, the serum HDL cholesterol level increased which reflects the oil hypolipidemic potential. Whereas, the oil extracted from cooked *C. lanatus* seeds significantly ($p < 0.05$) reduced some lipid profile and toxicity parameters (triglycerides and alanine aminotransferase) while increasing the serum HDL cholesterol [86]. Several other studies have also demonstrated the anti-diabetic and anti-hyperlipidemic action of *C. lanatus* seeds [87–90].

Anti-inflammatory activity

In vitro anti-inflammatory activity of *C. lanatus* seed aqueous and methanolic extracts were assessed by Iswariya and Uma [91] using human red blood cell membrane stabilization and inhibition of albumin denaturation. Results showed that both extracts were efficient in inhibiting thermally induced albumin denaturation at different concentrations. Methanolic extract exhibited a great percentage inhibition of 63.24% and aqueous extract showed 31.71%, while aspirin (used as standard drug) showed the maximum inhibition of 90.23% at the concentration of 100 µg/mL, respectively. The methanolic extract exhibited more significant anti-inflammatory activity as the membrane stabilization activity of both extracts (methanolic and aqueous) at a concentration of 250 µg/mL resulted in denaturation inhibition of 74.8% and 46.2% in a hypotonic solution, respectively, while standard drug aspirin (100 µg/mL) showed 79.2% inhibition of denaturation. Similarly, Jain et al. [92] previously demonstrated the significant anti-inflammatory activity of *C. lanatus* seeds methanolic extract at 200 mg/kg of extract for 30 min, 1 and 3 h. According to the analysis, this activity may be due to the individual or combined action of phytoconstituents such as alkaloids, steroids, tannins, phenolic acids and amino acids found in the extract. Likewise, Akinwunmi and Ayoola [93] have demonstrated, once more, the anti-inflammatory activities of methanolic *C. lanatus* seed extract using the membrane stability test, xanthine oxidase inhibition and inhibition of denaturation of albumin. Authors have linked this activity to the phytochemical contents of seed extract.

Cardiovascular, cerebral and hormonal benefits

Cardiovascular health was improved in hypercholesterolemic mice while receiving, in drinking water, an extract of *C. lanatus* from the skin, the pulp and the seeds contained 20 to 30 mg/g of citrulline. Indeed, it was observed a reduction in weight, a reduction in plasma levels of cholesterol with an improvement in the homeostasis of pro- and anti-inflammatory cytokines as well as an attenuated development of atherosclerosis without affecting the systolic arterial pressure, in favor of a better cardiovascular health [94]. The hexane extract of watermelon seed and vitamin E administered at doses of 200 and 500 mg/kg, respectively, demonstrated their neuroprotective activity in male rats. The degeneration of neurons of the frontal cerebral cortex induced by the administration of mercury chloride ($HgCl_2$) was attenuated. This result is very promising and may be beneficial for workers exposed to $HgCl_2$ in order to benefit from its neuroprotective capacity [95]. In addition, a consumption of *C. lanatus* seed oil has been shown to have a favorable impact on the endocrine environment and positively affects fertility. Indeed, the study undertaken by Agiang et al. [96] demonstrated that, in albino rats, supplementation with 5 and 10% seed oil resulted in a significant ($p < 0.05$) increase in prolactin levels (with a corresponding decrease in progesterone), luteinizing hormone, estradiol and testosterone compared to controls.

Antibacterial and antifungal activities

The main reported biological activities of watermelon seeds are antibacterial and antifungal activities. Ethanol and aqueous extracts from watermelon seeds proved to be effective against the growth of the tested pathogenic bacterial strains (*Esherichia coli*, *Klebsiella pneumonia*, *Pseudomonas aeruginos*a and *Bacillus subtilis*) and tested pathogenic fungal strain (*Candida albican*, *Aspergillus niger*, *Penicillium chrysogenum* and *Trichosporo bepelli*) at 100 mg/mL concentration. However, the ethanol extract showed higher antibacterial and antifungal activities than the aqueous extract [97]. These observations are different from those found by Łopusiewicz [1], where the author noted that melanin extracts (native and purified), from watermelon seeds, inhibited the growth of *Enterococcus faecalis* and *Pseudomonas aeruginosa* with a diameter of the inhibition zones ranging from 11 to 13 mm and that no inhibition on *Bacillus cereus*, *Esherichia coli* and *Staphylococcus aureus* was observed. Ibrahim et al. [29] demonstrated that free amino acids extracted from different parts of watermelon, including seeds, exhibit considerable antimicrobial and antifungal activity. Indeed, glutamate showed the highest antimicrobial activity against the fungus *Candida albican* with the

highest diameter of inhibition zone (28 mm) followed by *Staphylococcus aureus*, then *E. coli* and the lowest activity was against *Bacillus subtilis* which had the lowest inhibition zone diameter (13 mm). Nevertheless, Braide et al. [98] have noted low antimicrobial activities of Nigerian watermelon seeds extracts due, according to the same study, to the low phytochemicals content of seeds. More recently, Neglo et al. [99] have confirmed the susceptibility of all pathogenic microbe (both gram-positive and negative bacteria) used in their study to methanolic extract of watermelon seeds at 500 mg/mL with a diameter of the inhibition zone ranging from 8 to 18 mm. The results of Nwankwo et al. [100] support the application of watermelon seed extracts in ethno-medicine and their use as a good source in pharmaceutical productions due to their antibacterial activity against selected human pathogens. It has been established that among the isolated protein fractions, prolamin was found to be the most effective against *Acinetobacter baumannii* followed by albumin and globulin fractions. While the moiety globulin exhibited outstanding antioxidant activity [101]. Apeh et al. [102] demonstrated the antibacterial (against *Escherichia coli* and *Staphylococcus aureus*) and the antifungal activities (against *Candida albicans*) of both crude and degummed *C. lanatus* seeds oil at different concentrations (500.0 mg/mL, 250.0 mg/mL and 125.0 mg/mL) with variable inhibition zones. Authors have linked those capacities to the activity of palmitic acid and linoleic acid interaction with Secreted Aspartic Protein-5 known for its virulence. They concluded that linoleic and palmitic acid could be considered as a potential antifungal and antibacterial drug candidate with palmitic acid playing a significant role. The *C. lanatus* seeds oil fraction showed appreciable antimicrobial and antifungal activities against *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Candida albicans*, *Aspergillus niger* and *Penicillum notatum*. Inhibition zone diameters ranged from 7 to 20 mm and were compared to those of ciprofloxacin, which is used as a standard antibiotic. The extract showed the highest sensitivity to *C. albicans* followed by *P. notatum* and the lowest to *S. aureus* [103] Fig. 3.

Food applications of watermelon seeds

Watermelon seeds find different uses in the food industry, due to their interesting composition in terms of macro and micronutrients and several studies have already been conducted in this way.

Bakery products are the main uses for watermelon seeds. The results of the study conducted in 2015 by Wani et al. [16], showed the possible use of inexpensive watermelon seed protein for partial replacement of gluten in cookies and that the nutritional value of produced cookies was improved. Also, the authors reported that watermelon protein concentrates affected most of the dough handling properties as measured by the farinograph, fast visco-analyzer, and texture analyzer. In the same way, Kausar et al. [104] have concluded that watermelon seed flour can be used advantageously in the preparation of cookies with improved protein, fat, fiber and ash content without affecting the sensory acceptability of final product. Furthermore, a defatted watermelon seed flour was successfully used in bread making, where the protein content and the proportion of micronutrients such as phosphorus, potassium, iron and calcium increased with increasing amount of watermelon seed flour in the bread (15% and 25%). Calcium in particular proved to be the highest mineral in the bread samples, while iron levels improved significantly in the fortified samples. All types of bread were accepted by the panelists since the scores obtained were greater than 7 (7.08–7.92 like moderately) on a 9-point hedonic scale for all sensory attributes without significant differences ($p > 0.05$) with the control bread [105]. Incorporation of toasted watermelon seed and date palm fruit pulp as fat and sugar substitutes, respectively at 15%, produced cookies with improved physical properties such as cookies spread ratio, thickness, diameter and weight and an overall acceptability higher than 7 on 9-hedonic scale as concluded by Peter-Ikechukwu et al. [106]. Authors stated that production of these cookies could help to proffer solution to some health challenges. The study undertaken by Omobolanle et al. [107] on the evaluation of potentials of some selected seeds' flours, including watermelon seeds, as partial substitute for wheat in cookies production, showed that incorporation of defatted watermelon seeds flour in cookies making resulted into a significant improvement in fiber, ash, protein contents and virtually all the minerals examined (calcium, sodium, zinc, iron, potassium and magnesium). A significant decrease ($p < 0.05$) in anti-nutrient levels (oxalate, cyanide, saponin, alkaloid and phytic acid) has been also noted. In addition, cookies made with watermelon were accepted beside cookies from wheat flour. Three Indian products ("Biscuits", "Mathri" and "Laddoo") have been prepared by Virginia et al. [108] by incorporation of amaranth seeds, watermelon seeds and their flour, to find out the sensory acceptability and to determine the nutrient content of the prepared products. Results revealed that with regards to color and appearance, body and texture, taste and flavor and overall acceptability, products prepared from amaranth seed flour and watermelon seed flour in the ratio of 20:10 were the best. Further, the nutritive value in terms of protein, fat, carbohydrate, calcium and iron of the prepared products increased in enriched "Biscuits", "Mathri" and "Laddoo" as compared to control. Furthermore, watermelon seed flour proves an acceptable soup thickener with nutritional and functional properties that can fill food

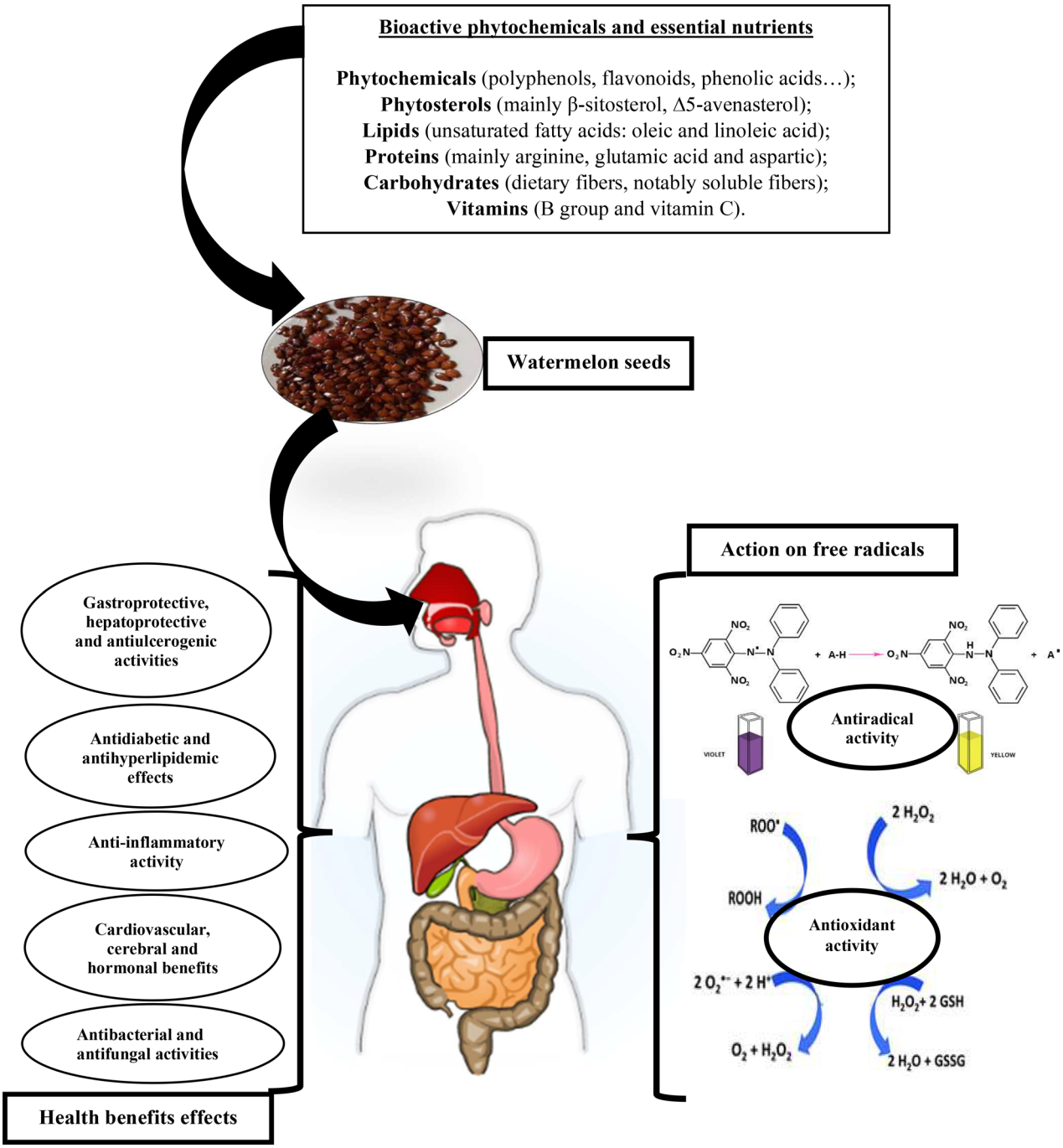


Fig. 3 Bioactive phytochemicals, essential nutrients and health benefits effects of watermelon seeds

diversity and economic gaps generally as stated by Nzeagwu and Raphael [109]. Likewise, Akusu and Kiin-Kabari [110] explained the possibility of replacement the melon grain flour by that of watermelon seeds up to 50% in the preparation of "egusi" soup which is traditional Nigerian soup made using ground dried melon seeds. Similarly, the thickness, nutritional quality and taste of Indian vegetable gravies have been ameliorated by adding the watermelon seeds powder at 5%, 8% and 10%. However, soups incorporated at a rate of 8% were the mostly preferred regarding to its overall acceptability with scores higher than 7 [111]. Odo et al. [112] have also successfully used watermelon seeds as soup thickener. Dehulled watermelon seed based extruded snacks have been developed by Raja et al. [113] by adding 15% of watermelon seeds flour to rice-corn blend. Results shown that the developed product had acceptable nutrition and sensory quality till 90 days of storage at ambient temperature compared with control extruded snacks based on rice-corn

flour blend. Also, in order to improve the use of watermelon seeds in the production of value-added products acceptable to consumers, Adeyeye et al. [114] discuss the possibility of producing "robo" a traditional Nigerian snack from watermelon seeds. Shahein et al. [115] developed yogurt enriched with watermelon seed milk by replacing cow's milk with different proportions of watermelon seed milk (0, 25, 50 and 75%) and they observed that yogurt enriched with 50% watermelon seed milk had shown to confer effective protection against hyperuricemia in albino rats. Ice creams made from soy milk, watermelon seed milk and guava pulp have been prepared by Bisla et al. [116]. The results showed that ice creams made from the mixture of 50% soy milk and 50% watermelon seed milk as well as guava pulp were the most acceptable on the 9-point hedonic scale. Lipid, protein, iron and vitamin C levels were improved compared to the control ice cream (100% cow's milk).

Conclusion

The development of societies with malnutrition problems, affecting various population groups with limited access to a healthy and balanced diet has favored the focus of efforts on the exploitation of all food resources. Therefore, the study of agricultural residues has been booming in recent years, as residues are considered an attractive source of nutrients, antioxidants and dietary fiber. In this sense, this review provides information on an agricultural residue, watermelon seeds. Watermelon seeds have nutritional and health benefits due to their unique biochemical composition. From a nutritional point of view, seeds are an important source of protein including bioactive peptides, a rich source of lipids making them a source of oil/fat for food and pharmaceutical industries. The seeds also constitute an important reservoir of micronutrients in terms of water-soluble vitamins (especially B group) and fat-soluble (pro vitamin A and vitamin E), in addition to major elements such as K, P and Ca and trace elements such as Cu, Zn and Mn. Due to their phytochemical content, the seeds of watermelon have many therapeutic virtues and show various beneficial effects for health namely antidiabetic, antimicrobial, antioxidant, gastroprotective and antiulcerogenic effects and many others. Several ways of valuing the seeds of watermelon in the form of food or ingredients have been proposed by several researchers which increases its economic importance while reducing food waste which could contribute to food diversity projects, in particular in developing countries to fight against food and nutritional insecurity. These review data contribute significantly to the knowledge of cultivated watermelon seeds across the world and support current recommendations to increase their consumption to promote overall health, wellness and longevity. Nevertheless, the possibility of exploiting watermelon seeds as a source of nutrients today, constitutes a great challenge for the future as researches concerning the characterization and application of *C. lanatus* seeds should be continued in order to identify the active principles responsible for the demonstrated therapeutic effects and to formulate seeds in suitable and easily administered pharmaceutical forms. This will pave the way to improve sustainability in the pharmaceutical industry. Research can also be directed towards the incorporation of *C. lanatus* seed into a wide range of food products, making it possible to mitigate the global nutrient deficiencies in nutrients on the one hand, and on the other hand, to ensure the sustainability of the food industry, while studying the fate of bioactive molecules and nutrients before and after cooking operations. All these future trends are in line with the current market demands related to "zero waste" goals and the so-called circular economy.

Acknowledgements The author would like to express its thanks to the Algerian Ministry of Higher Teaching and Scientific Research.

Funding (information that explains whether and by whom the research was supported): Algerian Ministry of Higher Teaching and Scientific Research.

Data Availability (Data transparency): Yes, the data are specific to this study.

Code Availability (Software application or custom code): Not applicable.

Declarations

Conflict of interest The authors declared no conflict of interest.

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