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BIOCHEMICAL COMPOSITION, NUTRITIONAL VALUES, AND CALORIE CONTENT OF *ALLIUM* SPECIES: A SYSTEMATIC REVIEW

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SUMMARY

The latest review discusses the chief metabolites of the genus *Allium* L., which characterize their nutritional qualities. The publications presented in the leading databases, such as Web of Science, Scopus, PubMed, Science Direct, and NCBI bore analysis. The vital active phytochemicals of *Allium* species include ascorbic acid, fatty acids, and carbohydrates. Many believe these biologically active compounds can prevent cancer development, coronary heart disease, and atherosclerosis.

Keywords: *Allium* L., biochemical composition, nutritional values, calorie content, onions, chives, garlic, leeks

Key findings: The analysis of the experimental data on metabolites of onion crops based on their nutritional values in light of the functional nutrition concept is currently relevant. The genus *Allium* L. species are an integral part of the human diet and a valuable source of biologically active substances.

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INTRODUCTION

The first introduction of the functional nutrition concept occurred in Japan around three decades ago. It refers to foods that contain components beneficial to one or more bodily functions relating to comfort and health and lessening the risk of different diseases (Roberfroid, 2000). Plant-derived compounds, defined as phytochemicals, produce various health-promoting effects when used. Presently, a primary aim of food researchers is to identify the evidence demonstrating the functionality of foods. Therefore, studies on the biological properties of putative phytochemicals and the biochemical composition of plant foods are highly appealing (Mamedov *et al*., 2017; Gins *et al*., 2020).

The genus *Allium* L., belonging to the family Amaryllidaceae, includes about 1200 species and has progressive replenishment (Herden *et al*., 2016). The most recent classification suggested 15 sub-genera and 56 sections for *Allium* (Brullo *et al*., 2019). The key centers of *Allium* diversity exist in Central Asia, the Mediterranean, and the Western part of North America (Friesen *et al*., 2006; Jabbes *et al*., 2011). The flora of Asia is abundant in onions. The regions abundant with more than 130 species appear in Western Asia (Turkey, Iran, and Afghanistan). However, Central Asia has more than 190 designated species. Non-Asian onion types account only for 38.2%. The natural growth and cultivation environment exists only in the South by the tropics and in the North by the 60th parallel. *Allium* species are mainly prevalent in temperate, semi-arid, and arid regions of the Northern Hemisphere (Fritsch and Friesen, 2002).

The genus *Allium* L. often attracts researchers' attention given its valuable medicinal, nutritional, and decorative properties, adaptive capabilities, resistance to pests and diseases, and ecological plasticity. These characteristics contribute to the competitiveness of species and the manifestation of a high degree of acclimatization outside natural areas and broad geographical allocation (Friesen *et al*., 2006). Humans consume more than 40 wild onion species, some of which serve to develop new types of cultivars and hybrids (Teshika *et al*., 2019).

Members of the genus *Allium* L. contain most of human nutrition's essential components. Ascorbic acid, chlorophylls, and secondary metabolites (carotenoids and phenolic compounds) mainly characterized the onion leaves' food and pharmacological values. The nutritional values comprise beneficial properties of a product that can satisfy the daily physiological needs of the human body with specific substances and the release of energy due to oxidation of the consumed components. The nutritional value directly depends on the biochemical composition of the products with deliberations concerning its consumption in accepted quantities of the chief organic substances, i.e., proteins, carbohydrates, fats, vitamins, and acids.

Detailed data on the daily human needs are available in Table 1. In onion family crops, the calorie content varies from 1.3% (tubular green leaves of the onions) to 9.71% (garlic bulbs) of the daily human needs. In this case, the protein contents also ranged from 1.2% (onion bulbs) to 7.07% (greens of garlic), carbohydrates without dietary fibers ranged from 1.36% (green chives) to 22.14% (garlic bulbs), and food fibers ranged from 4.0% (garlic greens) to 12.5% (green chives) of the daily human requirements. Fat content rated at 0.15%–1.04%, and water (2.16%–3.41%) of the daily human demands.

The nutritional structure of the genus *Allium* species is very complex and difficult to appraise. Plant metabolite levels principally depended upon the genetic and environmental factors and transport and storage conditions. Growth factors, such as light, temperature, humidity, soil type, fertilization, microbial and insect damage, UV stress, heavy metals, and pesticides amend the composition of plant metabolites (Orcutt and Nilsen, 2000).

Over the past decade, a considerable sum of data has accumulated on the identification, biochemical characterization, localization, and health benefits of *Allium* metabolites. The presented review is an attempt to summarize information on the

Table 1. Calorie content and nutritional values of onion crops (per 100 g FW) and percentage in the daily human need.

Allium species	Caloric content	Proteins	Fats	Carbohydrates	Dietary fiber	Water
A. fistulosum (leaves)	2.2	2.07	0.6	2.93	12	3.34
A. cepa (leaves)	1.3	1.41	0.15	2.29	6	3.41
A. cepa (bulb)	2.61	1.2	0.15	5.43	8.5	3.26
A. porrum (leaves)	2.35	2.17	0.3	4.5	11	3.23
A. schoenoprasum (leaves)	1.96	3.59	1.04	1.36	12.5	3.34
A. ascalonicum (bulb)	4.69	2.72	0.15	9.71	16	2.93
A. ursinum (leaves)	2.28	2.61	015	4.36	5	3.26
A. sativum (leaves)	3	7.07	0.15	3.71	4	2.93
A. sativum (cloves)	9.71	6.96	0.75	22.14	10.5	2.16

USDA National Nutrient Database for Standard Reference: https://data.nal.usda.gov/dataset/usda-national-nutrient-database-standard-reference-legacy-release.

metabolites that determine the nutritional values of the genus *Allium* and their vital role in the human daily diet. The primary content levels and ranges of variation of the foremost metabolites in onion crops attained analysis.

Inclusion criteria

This review solely focused on analyzing the biochemical composition of onion crops, including biologically active compounds of pharmacological significance. The review included the Web of Science, Scopus, PubMed, Science Direct, SciFinder, and Google Scholar databases. The online sources used were the Research Gate, National Center for Biotechnology Information (NCBI), Springer Nature Open Access, and Wiley Online Library.

Biochemical composition

Onions contain numerous phytochemicals, with organosulfur compounds as the most crucial. These compounds add the odor and taste characteristics and contain most of their biological possessions. Another essential group of biologically active compounds is polyphenols, which include phenolic acids and flavonoids, responsible for the bulbs' color trait. The edible parts of the onion are rich in carbohydrates, mainly glucose, and fructose, while the outer scales of the bulbs contain significant amounts of galactose and arabinose. Essential amino acids (arginine and glutamic acid), as relevant nitrogen stores, also contribute to the nutritional values of onion species. The onions also contain several other complex bioactive components, such as saponins, vitamins (A, C, B6, and B9), and minerals (P, K, Ca, Mg, Zn, Mn, Na, Fe, Br, I, Se, and Cu).

The organic compounds found in the species of genus *Allium* are a product of primary and secondary plant metabolism. Primary metabolites, i.e., carbohydrates, amino acids, fatty acids, and organic acids, contribute to the growth and development, respiration and photosynthesis, and hormone and protein synthesis. Primary metabolites are prevalent in all the species within extensive phylogenetic groups and proceed to form using the same biochemical pathways. Secondary metabolites, viz., flavonoids, carotenoids, sterols, phenolic acids, alkaloids, and glucosinolates, determine the color of vegetables, protect plants from herbivores and microorganisms, attract pollinators and seed dispersers, and act as indicator molecules under stress conditions (Crozier *et al*., 2006).

Carbohydrates

In vegetables, the carbohydrates come in the form of monosaccharides (glucose, fructose, arabinose, galactose, and rhamnose), disaccharides (sucrose, maltose, and trehalose), sugar alcohols (sorbitol, mannitol, and xylitol), oligosaccharides (raffinose, fructooligosaccharides, and galactooligosaccharides), and polysaccharides (starch, cellulose, hemicellulose, and pectin). On their physiological and nutritional role, the classification of carbohydrates is often available and unavailable. Available carbohydrates are those that enzymes hydrolyze in the human gastrointestinal system into monosaccharides, such as sucrose and digestible starch. Monosaccharides do not necessitate digestion and can continue direct absorption into the bloodstream and defend the cell's protein-lipid components, participating in the detoxification of free radicals (Siddiqui *et al*., 2020).

Unavailable carbohydrates (sugar alcohols, many oligosaccharides, and non-starch polysaccharides) are nonhydrolyzable by endogenous human enzymes, with microorganisms fermenting them in the large intestine before absorption (Asp, 1996). Fructooligosaccharides and non-starch polysaccharides are vital components of dietary fiber. Plant components described as dietary fiber typically include non-starch polysaccharides, resistant oligosaccharides, lignin, and related substances, such as resistant starch, waxes, cutin, and suberin (De-Vries, 2003). These materials pass through the gastrointestinal tract as fibers, where colonic microorganisms modify and digest them (Blaut, 2002). The high-fiber foods consumption has proven to reduce the symptoms of chronic constipation, diverticular disease, and several types of colitis (Stollman and Raskin, 2004). Therefore, a conclusion surfaced that a low-fiber diet may increase the risk of colon cancer, cardiovascular diseases, and obesity (Marlett, 2001; Slavin, 2005; Vernia *et al*., 2021).

Fructooligosaccharides (fructans) assemble in the species of *Allium* in different forms (Shiomi *et al*., 2005). Considerable information emerged about polysaccharides, including those based on fructose, in various species of the genus *Allium* (Shepherd and Gibson, 2006; Flores *et al*., 2016). This genus' most typical fructans are inulin, inulin neoseries, and levan neoseries (Livingston *et al*., 2009). In different species of *Allium*, the fructans content varies from 1.1 to 10.1 g/100 g, including in *A. sativum* L. (9 to 16 g/100 g), and the concentration of fructose and sucrose in different types of onions varies from 0.7% to 4.0% of fresh weight (Shepherd and Gibson, 2006). Levan-type fructans have a pronounced moisturizing effect on the skin, parallel to that of hyaluronic acid, as well as anti-inflammatory properties, and therefore, an endowing use in cosmetology (Kim *et al*., 2006).

In round *Allium* species (*A. aflatunense* B. Fedtsch., and *A. caeruleum* Pall.), the elevated molecular weight glucofructans (GFH) contents are significantly higher (22.22% to 41.40%) than in the group of bulbous-rhizomatous plants with large rhizomes and poorly developed bulbs (*A. ledebourianum* Schult. & Schult. F., *A. nutans* L., and *A. ramosum* L.). The group of bulbous-rhizomatous plants with large bulbs and poorly developed rhizomes (*A. obliguum* L., *A. altaicum* Pall., and *A. strictum* Schrad.) occupied an intermediate position between the two previous groups, which are similar significantly. In this group, the average high molecular weight glucofructans was 20.34% ± 3.64%. The varied accumulation of low molecular weight (GFL) and high molecular weight glucofructans in different plant organs is evident. In *A. altaicum and A. obliquum* (bulb-rhizomatous species with well-developed tubers), the bulb's GFL and GFH contents were 1.5–2.0 times higher than the rhizomes.

In *A. nutans* and *A. ramosum* with small bulbs, the differences in the content of GFL are low, and in *A. ramosum* rhizomes, the GFH content was 1.3 times higher than in bulbs. The glucofructans accumulation significantly varies during the growing season, showing an association with different intensities of plant growth and development. The maximum accumulation of GFH was prominent during the flowering period; however, their concentration noticeably decreased by the end of the growing season. In different species, the GFL content reaches its maximum in varied phenophases, as determined by the peculiarities of the seasonal development of the species (Shiomi *et al*., 2005).

Pectin is a part of the cell tissue's structural elements of higher plants and acts as a binding and strengthening component of the cell wall and regulates water metabolism (Minzanova *et al*., 2021). The onion pectin displayed a bimodal molar mass distribution, suggesting two polymer fractions with different molar masses, and it is vital in the observed promising emulsifying and emulsion stabilizing potential (Neckebroeck *et al*., 2021).

Amino acids

Amino acids, as transitional products, are the structural components of proteins, playing an influential role in the metabolism of plants and animals. Proteins perform crucial functions at the tissue level and act as enzymes, hormones, and antibodies. Dietary proteins are the chief source of amino acids. Most proteins have enzymes breaking them down into amino acids for absorption in the small intestine. Humans can synthesize several amino acids, including alanine, asparagine, aspartic acid, cysteine, cystine, glutamic acid, glutamine, glycine, proline, serine, and tyrosine. The nine amino acids called essential must come from the diet, including histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine (Hounsome *et al*., 2018). Vegetables contain all the essential amino acids; however, some may be in smaller quantities than the amount required for humans (Young and Pellett, 1994).

Arginine (Arg) is an amino acid that appears to be sufficient in onions, supporting the hypothesis that onions use Arg as a nitrogen reservoir, contributing to the nutritional value of the *Allium* species (Fredotovič *et al*., 2017, 2020). In addition to Arg, glutamic acid (Glu) and lysine (Lys) occur in large quantities. Garlic cloves also contain a high content of arginine (Lawson and Gardner, 2005). Moreover, the main free amino acids found in garlic are glutamine (Gln), asparagine (Asn), Glu, and Lys (Lee and Harnly, 2005). Interestingly, the proline content in onion seeds is a reliable indicator of cultivar tolerance to water stress (Golubkina *et al*., 2023).

In onions, the average data on the content of amino acids (mg/100 g FW) comprised, i.e., Arg - 104, Histidine - 14, Isoleucine - 14, Leucine - 25, Lys - 39, Methionine - 2, Phenylalanine - 25, Tryptophan - 14, and Valine - 21 (Hounsome *et al*., 2018). The analyzed 17 bound amino acids and 38 free amino acids from the leaves of *A. victorialis* L. revealed the total content of component amino acids and free amino acids at 2693.28 mg/100 g and 535.39 mg/100 g (Cho *et al*., 2011).

In *A. cornutum* Vis. and *A. cepa* L., the Arg content was 16.492 and 12.213 mg/g DW, respectively, while the Glu content was 14.964 and 11.238 mg/g DW, respectively (Table 2)

Table 2. Amino acid composition of *Allium* (Fredotovič, 2020).

Amino Acids	*A. cornutum* Vis. (mg/g DW)	*A. cepa* L. (mg/g DW)
Asp (Aspartic acid)	4.941 ± 0.043	6.100 ± 0.083
Ser (Serine)	2.921 ± 0.004	2.846 ± 0.031
Glu (Glutamic acid)	14.964 ± 0.008	11.238 ± 0.096
Gly (Glycine)	2.042 ± 0.013	2.217 ± 0.015
His (Histidine)	1.758 ± 0.015	1.667 ± 0.052
Arg (Arginine)	16.492 ± 0.256	12.213 ± 0.094
Thr (Threonine)	3.324 ± 0.013	4.003 ± 0.076
Ala (Alanine)	1.675 ± 0.002	2.027 ± 0.023
Pro (Proline)	1.434 ± 0.024	1.702 ± 0.128
Cys (Cysteine)	0.144 ± 0.002	0.023 ± 0.005
Tyr (Tyrosine)	1.719 ± 0.010	2.277 ± 0.049
Val (Valine)	2.005 ± 0.003	2.375 ± 0.072
Met (Methionine)	0.013 ± 0.005	0.010 ± 0.005
Lys (Lysine)	2.322 ± 0.010	2.328 ± 0.018
Ileu (Isoleucine)	1.426 ± 0.006	1.818 ± 0.007
Leu (Leucine)	2.284 ± 0.014	2.949 ± 0.026
Phe (Phenylalanine)	2.198 ± 0.014	2.378 ± 0.006

(Fredotovič *et al*., 2020). The amino acids Glu and Arg may be responsible for the color of onion seeds (Dini *et al*., 2008). In addition to its importance in human metabolism, free amino acids also affect the vegetable taste. Glycine and alanine are sweet; valine and leucine are bitter, and aspartic acid and glutamate taste sour and umami (Bachmanov *et al*., 2016; Wu, 2021). Prominently, in onions, these amino acids are potential fingerprints of geographical origin (Ianni *et al*. 2018).

Ascorbic acid

Ascorbic acid, as an antioxidant, performs the biological functions of a reducing agent and coenzyme of some metabolic processes. This compound protects against several reactive oxygen species types, i.e., free radicals and peroxides (Dzhos *et al*., 2023). It also synthesizes neurotransmitters, steroid hormones, and collagen, helps heal wounds and burns, prevents blood clotting and bruising, and strengthens the walls of human capillaries (Hounsome *et al*., 2018).

In onions, the growth conditions and nitrogen fertilization affect the ascorbic acid content (Kazimierczak *et al*., 2021). In the studied onion crops (33 species) in the Moscow Region, Russia, the ascorbic acid content in the leaves varied from 119.2 (*A. pskemense* B. Fedtsch.) to 133.5 (*A. suworowii* Regel) and, on average (126.0 ± 4.1 mg/100g fresh weight) (Ivanova *et al*., 2019).

Fatty acids

Fatty acids are the prime components of fats, consisting of a hydrophilic carboxylate group attached to a long hydrocarbon chain. An 80% of the total lipids of all *Allium* species consisted of four fatty acids, i.e., linoleic (46%–53%), palmitic (20%–23%), oleic (4%–13%), and α-linolenic acid (3%–7%). In *A. cepa*, 43 fatty acids are distinct, where 18 are more than 0.4%, and four are more than 2.5%. In *A. sativum*, 70 fatty acids are noteworthy, 14 at above 0.4%, and only four are above 2.5%. The *A. porrum* L. determined 50 fatty acids, having 12 being more than 0.4% and four being more than 2.5%. Phospholipids comprise a few specific fatty acids, while neutral lipids contain a wide range of fatty acids (Tsiaganis *et al*., 2006). *A. sativum* lipids amounted to 0.42% of raw plant tissue; the chief fatty acids are linoleic, palmitic, linolenic, and oleic acid (Tsiaganis *et al*., 2006).

In *A. fistulosum* L., the most common fatty acids in descending order of their content were linoleic (52.87%) > oleic (17.57%) > palmitic (9.80%) > stearic (8.81%) > linolenic (2.88%) > palmitoleic (2.84%) > myristic (1.28%) > behenic (1.23%). With a concentration of less than 1.00% are lauric, arachidonic, behenic, and lignoceric acids. Linoleic and oleic acids were the most abundant of all fatty acids, as well as the total unsaturated fatty acids, with the two making up 70.44% of the content of all fatty acids. Palmitic and stearic acids were the two most abundant saturated fatty acids, accounting for 18.61% of all fatty acids. Total unsaturated fatty acids (77.35%) dominate the total saturated fatty acids (22.63%), while the polyunsaturated fatty acids (56.34%) were much higher than that of monounsaturated (21.04%) (Adeyeye, 2020). The chief fatty acids detected in *A. sativum* were linoleic acid, which ranged from 32.54% to 58.97%, palmitic acid (ranging from 13.62% to 18.46%), and oleic acid (ranging from 6.21% to 14.74%) (Petropoulos *et al*., 2018).

In plant oil, the high level of essential fatty acids is an advantage in food consumption, and a better total unsaturated/saturated ratio makes this oil nutritionally applicable for domestic purposes. Linoleic acid, the most abundant fatty acid in oil, is also valuable as it prevents cardiovascular diseases (Singh *et al*., 2022). It helps relieve rough and flaky skin, maintaining smooth and silky skin (Adeyeye, 2020). Oleic acid also deters cardiovascular ailments (Arsic, 2020). Oleic acid can decrease plasma triacylglycerol and cholesterol concentrations without affecting plasma high-density lipoprotein cholesterol levels; linoleic and linolenic acids help reduce plasma concentrations of total cholesterol, low-density lipoprotein cholesterol, minute-density lipoprotein cholesterol, apolipoprotein B, and apolipoprotein A-1, lower the blood pressure, and protect against coronary heart diseases.

Linoleic acid can reduce the levels of inflammation-related factors and has a significant ameliorating effect on both acute and chronic inflammation; α-linolenic and γ-linolenic acids possess anti-inflammatory and anti-allergic properties to improve the immune system, also serving as a precursor of the prostaglandin and tissue hormones. Additionally, linoleic acid helps inhibit cancer growth in the human breast, colon, skin, stomach, and leukemia (Tian *et al*., 2023). Likewise, linolenic acid is crucial for nutrition, and it is an essential polyunsaturated fatty acid used in the biosynthesis of arachidonic acid. The available arachidonic acid also serves as a foundation for the biosynthesis of prostaglandin and thromboxane in humans (Majima *et al*., 2023). Myristic and stearic acids benefit as surfactants, emulsifiers, and thickeners in cosmetics (Adeyeye, 2020). The vegetable oil *A. fistulosum* has an acceptable polyunsaturated/saturated (P/S) ratio of 3.42 (Adeyeye, 2020). A high P/S ratio reduces serum cholesterol and atherosclerosis, preventing heart diseases (Xue *et al*., 2023).

Mineral elements

Mineral elements are structural components vital in enzyme activity, osmotic pressure control for cell turgor and growth, and acid-base and water-salt metabolism (Tetyannikov *et al*., 2022). The green onion leaves are an excellent source of mineral elements that enter the human body as ions in balanced concentrations. In onion leaves, the contents of the mineral elements follow the order of Zn > Fe > Si > Na > P > Cl > Mo > Mg > S > Ca > Cu > K (Nemtinov *et al*., 2020, 2021).

The *A. flavescens* Bess. accumulates five microelements (Cr, Ni, Cu, Zn, and Se) and contains high Fe, Co, and Mn concentrations. These features motivate the significant promise of this species to procure these microelements. The content of Cr in 100 g of leaves of this species equals 84% of the daily human need for this microelement. *A. fistulosum* L., *A. odorum* L., and the broad-leaved form of *A. nutans* specifically amass the Cu, Zn, and Se. *A. montanum* Schmidt comprised Zn accretion. *A. angulosum* L. and *A. schoenoprasum* L. cause the accrual of Se. The broad-leaved forms of *A. schoenoprasum* L., *A. nutans* L., and *A. odorum* L. accumulate higher amounts of Zn and Cu than their narrow-leaved counterparts (Golubev *et al*., 2003).

Garlic is a valuable source of macro- and microelements, especially potassium, calcium, magnesium, phosphorus, iron, manganese, selenium, vanadium, copper, and zinc. The garlic dry matter has about 4000 mg/kg of potassium (48.1% from the mass of all elements contained in cloves), 1500 mg/kg of phosphorus (18.3%), 1400 mg/kg of sulfur (17.2%), almost 900 mg/kg of calcium (10.7%), 300 mg/kg of magnesium (3.6%), 100 mg/kg of sodium (1.3%), 20 mg/kg (0.24%) of silicon, 16 mg/kg (0.20%) of iron, and 14 mg/kg (0.17%) of zinc. The content of manganese, aluminum, copper, and boron has the range of 1.8 mg/kg (0.02%)–6.9 mg/kg (0.084%); chromium, nickel, selenium, cadmium, cobalt, iodine, lithium, vanadium, germanium, and lead from 0.22 mg/kg (0.003%) to 0.013 mg/kg (0.0002%), and mercury - 0.0043 mg/kg (0.00005%).

Garlic cultivation in diverse climatic conditions leads to a significant change in the content of various elements. In this case, vanadium, boron, and cobalt contents can vary by 20 times, and the content of iron and germanium emerged more than 1000 times. In garlic, the variability of the elemental composition lessened based on the genotypes compared with the growing conditions. In general, the elemental composition depended upon cultivars (varies 1.1–4.7 times) while depending on growing conditions (2.1–57.4 times). Differences in iron content were according to cultivars (1.5 times) and on growing conditions (57.4 times), respectively, copper (1.4 and 54.0 times) and sodium (1.1 and 26.8 times). Garlic is a unique elemental complex, and according to indicators of sulfur, zinc, manganese, and copper, it corresponds to meat and fish (Polyakov *et al*., 2020).

Phytoremediation

Phytoremediation has contaminants removed from the soil using crop plants. Soil phytoremediation from organic and inorganic pollutants is evident based on plant-microbial interactions, and the presence of microorganisms resistant to pollutants promoted plant growth in the plant rhizosphere (Muratova *et al*., 2023). Garlic has the potential to absorb and hyper-accumulate heavy metals. It was apparent that the accumulation of Cd and Pb was much higher with inter-planting (Chatterjee and Chatterjee, 2021; Hussain *et al*., 2021). The enrichment of heavy metals in onion farmland may induce the accumulation of heavy metals in onion and cause food safety issues (Kharisu *et al*., 2019).

CONCLUSIONS

Given their distinctive aroma and rich nutritional content, onions and garlic are highly desirable edible plants widely used in cooking. Their regular utilization can prevent hyperlipidemia, diabetes, hypertension, cardiovascular diseases, and inflammatory conditions. Onions and their by-products provide many health benefits but require more research to identify the underlying molecular mechanisms and their interaction. *Allium* species (especially garlic) may also pose a safety risk due to elevated heavy metals accumulation.

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