Academy of Romanian Scientists *Volume 13, No. 2, 2024, pp. 19 - 37*
Annals Series on Biological Sciences Online ISSN 2285 – 4177

ORIGINAL PAPERS

NUTRITIONAL BENEFITS OF CHLOROPHYLL AND MINERAL ELEMENTS IN WHEATGRASS

Malina VISTERNICU [1,2], Viorica RARINCA [1,2,3], Ionel MIRON [4,5], Fatima Zahra KAMAL [6,7], Samson GUENNE [8], Alin CIOBICA [1,5,9]

[1] Department of Biology, Faculty of Biology, "Alexandru Ioan Cuza" University of Iași, Carol I Avenue, 20A, Iasi, Romania
[2] "Ioan Haulica" Institute, Apollonia University, Pacurari Street 11, Iasi, Romania;
[3] Doctoral School of Geosciences, Faculty of Geography and Geology, Alexandru Ioan Cuza University of Iasi, No 20A, Carol I Avenue, 700505 Iasi, Romania;
[4] Sange Verde Srl, Str. Viticultori 38, Iasi
[5] Academy of Romanian Scientists, Ilfov Street 3, Bucharest, Romania
[6] Higher Institute of Nursing Professions and Health Technical (ISPITS), Marrakech 40000, Morocco
[7] Laboratory of Physical Chemistry of Processes and Materials, Faculty of Sciences and Techniques, Hassan First University, Settat 26000, Morocco
[8] Department of Biochemistry and Microbiology, University Joseph KI-ZERBO, Ouagadougou BP 7021, Burkina Faso
[9] CENEMED Platform for Interdisciplinary Research, University of Medicine and Pharmacy "Grigore T. Popa", 700115 Iasi, Romania

Abstract. *Wheatgrass (WG) is a food derived from the plant Triticum aestivum and is considered a powerful health food with various benefits for human health. Due to its high concentration of essential nutrients, including chlorophyll and a wide range of minerals, it has become a superfood. This review explores the nutritional benefits of WG, focusing on its rich chlorophyll content, a green pigment with detoxifying and antioxidant properties, and its significant levels of minerals such as calcium (Ca), magnesium (Mg), cooper (Cu), zinc (Zn), phosphorus (P), manganese (Mn), selenium (Se), potassium (K), and iron (Fe). Chlorophyll is known for its ability to enhance oxygen transport in the body, support liver detoxification, and promote cellular health. The mineral composition of WG contributes to bone health, muscle function, and electrolyte balance. Moreover, WG is valued for its role in boosting immunity, increasing energy levels, and improving digestion. The synergy between chlorophyll and essential minerals makes WG a valuable nutritional supplement, supporting metabolic processes and overall well-being. This review highlights the potential health benefits of WG as a nutrient-dense natural food, with a promising role in disease prevention and health promotion.*

Keywords: wheatgrass, chlorophyll, nutritional benefits, minerals, mental health.

DOI 10.56082/annalsarscibio.2024.2.19

1. INTRODUCTION

Wheatgrass (*Triticum aestivum*) represents the young shoots of the wheat plant, being appreciated both for its nutritional value and its beneficial effects on health. Known for its rich composition of bioactive substances, including a wide range of minerals and vitamins, WG has been used as a traditional medicine and is highly valued for its therapeutic and nutritional properties [1–3]. The nutritional composition of WG is influenced by numerous factors, including production methods, growth period, pH, genetics, environmental conditions, cultivation methods, light intensity, temperature, type of light exposure, and minerals absorbed by the plant through its roots, which can affect the concentrations of nutrients and active compounds [4–6]. It has been found that WG contains approximately 297 proteins, most of which are involved in disease prevention, reducing oxidative stress (OS), energy storage, and primary metabolism [7]. Additionally, WG is an important source of chlorophyll, a pigment that contributes to its antioxidant and detoxifying effects [6]. Along with chlorophyll, flavonoids have been identified, known for their antioxidant role in preventing OS [8]. Due to its powerful combination of bioactive compounds, WG is considered a functional food, sometimes referred to as "green blood" due to the chemical similarity between chlorophyll and hemoglobin (Hgb) [9].

In recent years, more research has demonstrated the importance of WG consumption through its positive impact on human health [6,10]. WG can be consumed in the form of fresh juice, frozen juice, powder, or tablets [11]. Studies have shown that WG helps in treating various conditions such as periodontitis [12], aids in treating cancer patients [9,13], is effective in ulcerative colitis [10], bronchial disorders [14], and rheumatoid arthritis [15]. Juvenile WG has been effective in reducing blood glucose levels in diabetic rats [16,17]. Furthermore, due to its high antioxidant content, WG is considered an alternative medicine for cancer [18]. Phenolic compounds and flavonoids contribute to antioxidant activity, being known for their redox potential, which serve as hydrogen donors and reducing agents [2].

The body has several mechanisms to combat OS by producing antioxidants, either naturally in situ or through food. Plant-based antioxidants are known for their ability to reduce oxidative damage by neutralizing free radicals, thus offering increased protection against toxic effects, and preventing conditions such as cancer and coronary diseases. A deficiency of antioxidants is one of the many causes of chronic and degenerative pathologies. Dietary antioxidants assist endogenous antioxidants in neutralizing OS, with each nutrient being unique in its antioxidant structure and function [19–22]. WG extract can reduce cell death, inhibit metastasis in oral cancer, protect bone marrow function in chemotherapy patients, and improve enzymes regulating blood glucose and cholesterol levels [9,16,17,23]. Moreover, research indicates that the chlorophyll present in WG may

have cancer-preventive properties by binding to carcinogenic compounds and suppressing their metabolic function, and the detoxifying properties of chlorophyll help neutralize free radicals and reduce inflammation [24–26].

The aim of this review is to evaluate and synthesize existing scientific evidence regarding the nutritional benefits of chlorophyll and mineral elements in WG. Specifically, the review will explore the role of chlorophyll, analyzing its potential to offer health benefits. We will also correlate the effects of mineral elements on various physiological functions, providing a synthesis of existing research on the therapeutic benefits of WG for human health.

2. NUTRITIONAL COMPOSITION OF WHEATGRASS

Through germination, wheat grains significantly improve their nutritional value, increasing the content of phytochemical compounds and amplifying antioxidant activity. This process begins with exposing the grains to moisture for approximately 36 hours, which triggers germination [27]. Within 6 to 15 days, wheat sprouts appear, which are subsequently harvested and processed to obtain a green juice known for its low acidity and recognized for its multiple health benefits, including the ability to strengthen the immune system and provide a concentrated source of nutrients [27].

Moreover, WG accounts for nearly half of the global caloric intake, being rich in proteins, such as gluten, vitamins, minerals, and dietary fibers [28]. It also contains a considerable amount of reducing sugars, total sugars, carbohydrates, fats, and crude fibers [11]. Due to its complex composition rich in essential and bioactive nutrients (Figure 1), WG represents an important source of beneficial compounds for health. Specifically, it contains a wide range of minerals, vitamins, flavonoids, phenols, amino acids, and chlorophyll [5,9,11,25,29–32].

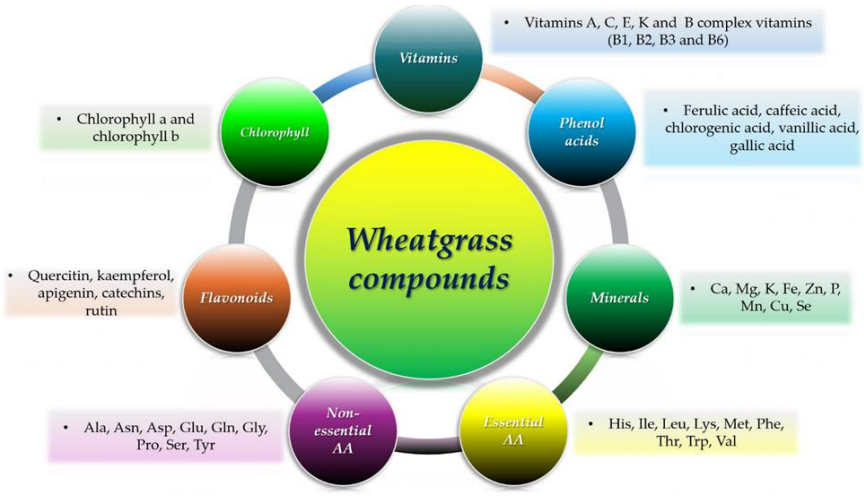

Figure 1. The main bioactive and nutritional components of wheatgrass

3.THE BENEFITS OF MINERAL ELEMENTS ON GENERAL HEALTH

WG has attracted attention for its potential health benefits, particularly in the areas of cancer prevention and general well-being. Rich in vitamins, minerals, and antioxidants, WG is increasingly recognized for its role in supporting immune function, promoting cellular health, and reducing OS by preventing oxidative DNA damage [33] (Table 1).

Minerals such as Cu, Mg, Zn, P, K, Ca, Mn, Se, and Fe are particularly important for the normal functioning of the body [25,34]. Cooper contributes to the formation of red blood cells and bone health, Mg engages in hundreds of biochemical reactions, including blood sugar and blood pressure regulation, while zinc supports immune function and wound healing [34]. Phosphorus is essential for the formation and maintenance of healthy bones and teeth, while Fe plays a crucial role in transporting oxygen in the body, helping to prevent anemia and supporting energy levels [34]. Ca provided by WG is beneficial for those who do not consume dairy products. Other vital minerals include Mg, which contributes to overall health, and Se, known for its antioxidant properties and importance in thyroid function [25,30,32,34,35].

Tabel 1. The main constituents of wheatgrass: antioxidants, minerals, amino acids, and chlorophyl

Types	Phytocompounds	Effects	References
Antioxidants	Vitamin A	Contributes to immune function and skin health, also acting as an antioxidant.	[25]
	Vitamin C	Helps protect cells from damage caused by free radicals and supports the immune system.	
	Vitamin E	Plays a role in protecting cell membranes and preventing OS.	
Minerals	Fe	Helping to prevent anemia and support overall energy levels.	[25,30–32]
	Ca	WG provides a source of Ca, beneficial for those who may not consume dairy.	
	Mg	WG contributes to Mg intake.	
	Se	An antioxidant that plays a role in protecting cells from oxidative damage. It is also important for thyroid function and immune system health.	
	Zn	Vital for immune function, wound healing, and DNA synthesis.	[25,30]

	P	Important for energy production and bone health, P works closely with Ca to maintain strong bones and teeth.	[32]
	K	Crucial for maintaining fluid balance, K helps regulate blood pressure and supports proper muscle and nerve function. WG offers a plant-based source of K.	[25,30,32]
	Mn	This mineral engages in bone formation, blood sugar control, and antioxidant defense systems.	
Essential Amino Acids	Histidine	Is crucial for the synthesis of histamine, a neurotransmitter involved in immune responses and regulating stomach acid. It also plays a role in maintaining the myelin sheath that protects nerve cells.	[30,36]
	Leucine	Is vital for protein synthesis and muscle repair. Leucine also helps regulate blood sugar levels by promoting insulin secretion and is important for energy production during exercise.	
	Lysine	Is essential for protein synthesis and plays a key role in Ca absorption and collagen formation. It also supports immune function and has been linked to improved recovery from stress and illness.	
	Methionine	Is important for the synthesis of proteins and other amino acids. It acts as an antioxidant by helping to detoxify harmful substances in the liver and supports the regeneration of kidney and liver cells.	[30,36,37]
	Phenylalanine	Is a precursor to neurotransmitters such as dopamine, norepinephrine, and epinephrine. It plays a significant role in mood regulation and cognitive function.	[30,36]

	Threonine	Is important for protein synthesis, immune function, and digestive health. It aids in the production of antibodies and supports gut health by maintaining the integrity of the intestinal lining.	[30,36,37]
	Valine	Is involved in muscle metabolism and tissue repair. It helps stimulate muscle growth and regeneration while also providing energy during physical activity.	
Non – Essential Amino acids	Alanine	Engages in energy production and the metabolism of glucose. It helps convert ammonia into urea for excretion, thereby aiding in detoxification.	[30,36]
	Arginine	Is crucial to produce NO, which helps improve blood flow and supports cardiovascular health. It also plays a role in immune function and hormone regulation.	[30,36,37]
	Aspartic acid	Is important for energy production and the synthesis of other amino acids. It helps in the urea cycle, which removes ammonia from the body.	[30,36]
	Cysteine	Is a precursor to glutathione, one of the body's most potent antioxidants. It plays a role in detoxification and supports immune function.	[36]
	Glutamic acid	It serves as a neurotransmitter in the brain and is involved in cognitive functions such as learning and memory. It also plays a role in protein synthesis and energy metabolism.	
	Glycine	Engages in the synthesis of proteins and collagen, supporting skin and joint health. It also acts as an inhibitory neurotransmitter in the CNS.	[30]

	Proline	Is essential for collagen production, which is important for skin elasticity and joint health. It also aids in wound healing and tissue repair.	
	Serine	Is important for protein synthesis and participates in the production of neurotransmitters. It also plays a role in metabolic processes related to fats and carbohydrates.	[30,36]
	Tyrosine	Is a precursor to several important neurotransmitters, including dopamine, norepinephrine, and epinephrine. It supports cognitive function and mood regulation.	
Chlorophyll	-	It detoxifies, neutralizes free radicals, reduces inflammation, and may help prevent cancer by suppressing carcinogenic compounds.	[24,25,32,38]
Flavonoids	Catechin	It plays several important roles in health and disease prevention due to its antioxidant properties and other biological activities.	[32,35,39–41]
	Rutin	Improves blood circulation, reduces inflammation, and may prevent blood clots. Neutralizes free radicals, lowering oxidative stress and protecting against neurodegenerative diseases like AD.	[32,42–44]
	Vitexin	It acts as a powerful antioxidant, neutralizing free radicals and reducing OS linked to aging and diseases. Vitexin has anti-inflammatory properties, supports cardiovascular health, and provides neuroprotective effects.	[32,39,42,43,45,46]
	Isovitexin	It offers antioxidant activity, neuroprotective and anti-	[32,45,47]

		inflammatory effects, potential anti-cancer benefits, and supports metabolic health.	
	Quercetin	Antioxidant activity and neuroprotective effects.	[32]
	Kaempferol	Antioxidant activity and neuroprotective effects.	
Phenolic acids	Ferulic acid	Antioxidant activity, anti-inflammatory effects, and cardiovascular protection	[32,48]
	Syringic acid	Antioxidant and anti-inflammatory properties	[32,48–50]

AD – Alzheimer disease; Ca – calcium; CNS - central nervous system; Fe – iron; K – potassium; Mg – magnesium; Mn – manganese; NO – nitric oxide; P – phosphorus; OS – oxidative stress; Se – selenium; WG – wheatgrass, Zn – zinc.

Vitamins A, C, E, K, and those from the B complex play a crucial role in maintaining overall health. Vitamin C, also known as ascorbic acid, is a powerful antioxidant that stimulates the immune system and contributes to the biosynthesis of collagen, neurotransmitters, and carnitine [51]. The positive effect of vitamin C on health includes a decrease in the incidence of stomach cancer, as well as the prevention of lung cancer. However, when consumed in excessive amounts, it can have pro-oxidant and anticancer properties [52]. Fresh fruits and vegetables are essential sources of vitamin C, as this labile molecule can be lost during cooking [53]. Vitamin A contributes to immune function and skin health, while also acting as an antioxidant [25], and vitamin K plays a significant role in blood coagulation [25,54]. Vitamin E is known for its protection against damage caused by free radicals, while the B complex (B1, B2, B3, B6, B12, folic acid) is vital for energy metabolism, nervous system health, and the production of red blood cells [25,54].

Flavonoids, such as quercetin, rutin, kaempferol, apigenin, and catechins, are antioxidant compounds that play a key role in protecting the body against OS [52]. Catechin is notable for its antioxidant properties and biological activities that help prevent diseases. Rutin, another flavonoid found in WG, improves blood circulation, and reduces inflammation, potentially benefiting conditions such as arthritis [42,44]. They contribute to the neutralization of free radicals, reducing inflammation and protecting cells from oxidative damage that can lead to premature aging or chronic diseases such as cardiovascular diseases and cancer [32,40,42]. Phenolic compounds, another group of antioxidant compounds, have anti-inflammatory and anticancer properties, contributing to the prevention of degenerative diseases. They act by neutralizing free radicals and reducing OS [32]. In WG, two types of phenolic compounds have been identified: free/soluble phenolic compounds that reduce the oxidation of low-density lipoproteins and

bound/insoluble phenolic compounds known for their potential to prevent colorectal cancer [27,32].

Moreover, WG is a rich source of amino acids that play critical roles in various bodily functions [11]. Essential amino acids, such as histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine, are vital for tissue development and repair, enzyme and hormone production, and proper immune system function. These amino acids cannot be synthesized by the body, so they must be obtained through diet. For example, lysine is essential for collagen synthesis, immune function, and calcium absorption [30,36], leucine is vital for protein synthesis and muscle repair, and tryptophan is a precursor of serotonin, the hormone that regulates mood and sleep [30,36]. Non-essential amino acids, such as alanine, asparagine, aspartic acid, glutamic acid, glutamine, glycine, proline, serine, and tyrosine, also play critical roles in various metabolic functions, even though the body can produce them naturally. Glutamine, for instance, is important for maintaining intestinal function and supporting the immune system [30,36], while arginine contributes to cardiovascular health by improving blood flow through nitric oxide production [30,36,37]).

Chlorophyll and Carotenoids

An especially important aspect of WG is its pigments, which are known for their powerful antioxidant properties [27,55]. Among these, chlorophyll plays a significant role [56], and the leaves of WG are considered one of the richest natural sources of chlorophyll [27,55]. Chlorophylls are the most abundant pigments on Earth that play a crucial role in photosynthesis and are found abundantly in green fruits and vegetables that are an integral part of our diet. These bioactive molecules exhibit a wide range of beneficial effects, including antioxidant, antigenotoxic, antimutagenic, antiobesity, and anticancer activities [56]. Chlorophyll is a complex molecule consisting of a porphyrin ring, a Mg ion, and a hydrocarbon part. The porphyrin ring functions to absorb light energy, while Mg acts as an electron acceptor [57]. Chlorophyll, both in its a and b forms, plays a significant role in detoxifying the body and supporting overall health. Chlorophyll acts as a powerful antioxidant and helps eliminate toxins while also contributing to cell regeneration and maintaining blood health [24,25,32,38]. Chlorophyll a is the most common form of chlorophyll found in plants, playing a role in light absorption [58]. Chlorophyll b also has an important role in photosynthesis, but its main function is to protect chlorophyll a from excess light [58]. The ratio of these predominant pigments varies significantly depending on environmental conditions, species, and maturity stage [59,60].

Wheatgrass juice (WGJ) is recognized for its high chlorophyll content [27,55], which has a chemical structure like that of Hgb in human blood, explaining why it is believed to help increase Hgb levels in the body [55]. The

central atom of Hgb is Fe, while in chlorophyll, it is Mg [61]. Both pure chlorophyll and its metal-chlorophyll derivatives exhibit antioxidant properties, protecting the body against OS and cellular damage, as well as anti-inflammatory, antimutagenic, and mutagenic activities [8]. These properties make it a valuable supplement for maintaining overall health.

Another important class of natural pigments are carotenoids, which are recognized for their powerful antioxidant properties and potential benefits in preventing certain types of cancer. These compounds, which include β-carotene, lutein, lycopene, and zeaxanthin, are responsible for the red, yellow, and orange coloring of many fruits and vegetables [27]. β-carotene is a powerful, fat-soluble antioxidant known for its ability to neutralize singlet oxygen, a reactive form of oxygen that can cause cellular damage [52]. This carotenoid plays a key role in protecting cells against OS, thus contributing to overall health. However, studies have highlighted that high-dose β-carotene supplementation can have negative health effects. For example, supplementation with 20 mg of β-carotene daily for 5 to 8 years has been associated with an increased risk of developing prostate and lung cancer in certain groups of people. These adverse effects have been observed particularly among smokers, where doses of 20-30 mg of β-carotene per day have been correlated with increased cardiovascular mortality. This suggests that, in the context of artificial supplementation, β-carotene may have a paradoxical effect, promoting the development of diseases instead of protecting the body [19,52].

However, it is important to emphasize that these risks do not apply to individuals who obtain β-carotene from natural food sources rich in this carotenoid. Consuming fruits and vegetables, such as carrots, as well as leafy green plants, provides β-carotene in a more balanced and safe form, along with other nutrients that can counteract negative effects. Thus, in the context of a balanced diet rich in natural foods, β-carotene maintains its beneficial effects without presenting health risks [19,52].

Chlorophyll and carotenoids are intricately linked to phenolic compounds and the antioxidant capacity of plants, thereby contributing to numerous health benefits. These pigments not only play an essential role in photosynthesis but also in protecting the human body against clinical conditions and chronic diseases, such as hemolytic anemia, cancer, cardiovascular diseases, and skin diseases [62]. These colored compounds perform vital functions in photosynthesis and also in protecting cells against OS. Chlorophylls, along with other porphyrins (tetrapyrroles), such as cytochromes, participate in redox reactions in various biological systems. These redox reactions are essential for energy production processes and cellular metabolism. Thus, chlorophyll and carotenoids not only contribute to plant health but also to human health through their potent antioxidant and anti-inflammatory properties [63].

It is noteworthy that phenolic compounds, including plant flavonoids, play a key role in neutralizing free radicals. These compounds exhibit various antioxidant properties, which are responsible for their therapeutic uses in treating various conditions [64]. During the germination process, WG becomes a rich source of bioactive substances, such as amino acids, minerals, vitamins, and chlorophyll. Among these, gamma-aminobutyric acid, an essential indicator, and alpha-linolenic acid have been analyzed based on previous study results [65].

WG extracts can be used as dietary supplements due to their high content of antioxidants, such as polyphenols and flavonoids, which are extracted either in water or in ethanol [64]. The antioxidant activity of these extracts has been demonstrated by their ability to neutralize primary and secondary free radicals, as well as by the protection they offer to cell membranes against oxidative damage caused by these radicals.

Table 2 highlights a wide range of studies investigating the pharmacological effects of WG in various forms and doses on health. This research suggests that WG has significant therapeutic potential in managing conditions such as hyperlipidemia, ulcerative colitis, cancer, and diabetes. Additionally, the consumption of WGJ may contribute to meeting the daily mineral requirements, with 100 ml providing 5-7% of the Mg requirement, 10% of the sodium requirement, and over 60% of the Ca requirement [66].

Table 2. Pharmacological effects of wheatgrass: experimental studies

Form of WG	Experimental model	Pharmacological effect	Administrated	Time	Effects	References
WG	cell	Cytotoxic and anti-proliferative effect	17.5 ± 1.1, 12.5 ± 0.3, and 16 ± 0.5 µg/ml	24, 48 and 72 hours	The optimal effect occurred after 48 hours, with WG reducing viable cells by 13.5% at 24 hours, 47.1% at 48 hours, and 64.9% at 72 hours.	[67]
WGJ	rats	Hypolipidemic effect	5 and 10 ml/kg	14 days	Significant decline in TC, TG, LDL-C and VLDL-C	[68]
	patients	Treatment of UC	100 cc	1 month	Significant reductions were observed in the overall disease activity index and in the severity of rectal bleeding.	[10]

		Anticancerigen effect	60 cc	orally daily during the first three cycles of chemotherapy	WGJ taken during FAC chemotherapy may reduce myelotoxicity.	[30]
		Anticancer activity	60 cc WGJ daily	5-6 month	WG has the potential to mitigate various chemotherapy-induced damages and does not cause adverse effects like chemical drugs.	[69]
WG powder	rabbits	Hypolipidemic effect	2 g/day	10 weeks	WG supplementation with a high-fat diet improved lipid levels, reduced MDA, and increased GSH and vitamin C, indicating its beneficial role in managing hyperlipidemia and OS.	[70]
WG powder + fluoxetine	rats	Neuroprotective effect	fluoxetine (10 mg/kg) and WG (100 mg/kg).	5 weeks	Fluoxetine and WG improve aluminum-induced AD in rats, with their combination showing greater efficacy than fluoxetine alone.	[71]
ethanolic extract and commercial powder WG	cells	Anticancer activity	156 µg/ml	48 hours	WG exhibited dose-dependent anticancer activity on KB cells, indicating its anticarcinogenic potential in animals.	[13]
ethanolic extracts WG	rats	Antidiabetic activity	100 mg/kg body weight	30 days	The ethanol extract of WG can control blood glucose levels in diabetes.	[16]
WG-derived polysaccharide	mice	Antiinflammatory, anti-oxidative and anti-apoptotic effects	100 or 200 mg/kg daily	2 days	WG-derived polysaccharide inhibited LPS induced pro-inflammatory cytokines and improved liver oxidative status.	[72]

cc - cubic centimeters; FAC - fluorouracil, doxorubicin, and cyclophosphamide; GSH - glutathione; LDL-C - low density lipoprotein-cholesterol; LPS – lipopolysaccharide; MDA – malondialdehyde; OS – oxidative stress; TC - total cholesterol; TG - triglycerides; UC - ulcerative colitis; VLDL-C - very low-density lipoprotein-cholesterol; WG – wheatgrass; WGJ – wheatgrass juice; WGP - wheatgrass-derived polysaccharide.

A study shows that green wheat has cytotoxic and anti-proliferative effects on cells. Doses of 17.5, 12.5, and 16 µg/ml were evaluated over periods of 24, 48, and 72 hours, with the optimal effect observed after 48 hours. At this point, the number of viable cells was reduced by 47.1%, indicating that green wheat may play a role in inhibiting the growth of cancer cells [67]. Green WGJ form has also been studied for its hypolipidemic effects on rats [68]. Administered at doses of 5 ml/kg and 10 ml/kg for 14 days, the juice significantly reduced levels of total cholesterol, triglycerides, low-density lipoproteins, and very low-density lipoproteins in hyperlipidemic rats, suggesting important potential in reducing the risk of cardiovascular diseases [68].

In another study, WGJ was administered to patients with ulcerative colitis. They received 100 cc of juice daily for one month, and the results showed a significant reduction in the overall disease activity index and the severity of rectal bleeding. This study suggests that WGJ may have a beneficial effect in treating inflammatory bowel diseases [10]. WGJ has also been investigated for its anticancer effects, particularly in patients undergoing chemotherapy. Administered daily, 60 cc of WGJ during the first three cycles of chemotherapy reduced myelotoxicity, meaning a decrease in toxicity to the bone marrow. This suggests that green wheat may have a protective role during aggressive cancer treatments [30].

Avisar et al. (2020) demonstrated that long-term administration of 60 cc of juice daily over a period of 5-6 months showed that WGJ could mitigate the negative effects of chemotherapy, without adverse effects comparable to those of chemical drugs. This underscores the potential of green wheat as a natural adjunct in cancer treatment [69]. In animal studies, green wheat in powder form showed hypolipidemic effects in rabbits [70]. Administered at a dose of 2 g/day for 10 weeks, it improved cholesterol levels, increased HDL-C (good cholesterol), and significantly reduced OS. These results suggest a protective effect against hypercholesterolemia and OS. In another study, WG and fluoxetine were administered together to evaluate the neuroprotective effect on aluminum-induced Alzheimer's disease (AD) rats [71]. It was observed that the combination of fluoxetine and green wheat had a stronger effect than fluoxetine alone, suggesting a potential synergistic treatment for AD [71].

Several studies have also shown the anticancer effects of ethanolic extracts and commercial powder of green wheat. These demonstrated dose-dependent anticancer activity on KB cells [13], and another study [16] highlighted the antidiabetic

potential of ethanolic extracts of green wheat in diabetic rats, suggesting that green wheat may contribute to glycemic control. Furthermore, Nepali et al. (2017) highlighted the anti-inflammatory, antioxidant, and anti-apoptotic effects of polysaccharides derived from green wheat, administered to mice. These inhibited the production of pro-inflammatory cytokines and improved the oxidative status of liver tissues, indicating significant therapeutic potential in acute inflammations [72].

3.1. Impact on bone health and muscle function

WG has attracted attention for its potential benefits on bone health and muscle function. It is rich in vitamins A, C, E, and several B vitamins, which are essential for various body functions. Among the main minerals it contains, we list Ca, Mg, K, and P, all of which are important for the health of bones and muscles. It is also a complete source of protein, including essential amino acids necessary for muscle repair and growth. Thus, WG is a rich source of Ca and Mg, both vital for maintaining bone density and preventing osteoporosis [31]. Adequate intake of these minerals is particularly important for older adults. On the other hand, the high chlorophyll content in WG may support bone health by reducing inflammation and OS, which can lead to bone degradation [8]. Additionally, with its antioxidant properties, WG contains antioxidants that help combat free radicals, potentially protecting bones from oxidative damage. This is crucial for maintaining bone integrity over time [38].

Some studies suggest that WG may improve bone marrow function, which is essential to produce blood cells and supporting the overall health of the skeleton [31,38]. Furthermore, WG provides a significant number of proteins and essential amino acids that are crucial for muscle growth and repair. This makes it beneficial for athletes and those engaged in regular physical activity. The presence of minerals such as Mg and K aids in the contraction and relaxation of muscles, improving muscle performance during exercise [31]. Due to its high B vitamin content, which is known to boost energy levels, it can enhance athletic performance by providing the necessary vigor for training. The anti-inflammatory properties of WG may help reduce muscle soreness after physical exercise by minimizing inflammation in muscle tissues [8].

However, WG appears to offer multiple benefits for both bone health and muscle function due to its rich nutritional profile, including essential vitamins, minerals, proteins, and antioxidants. While preliminary research supports these benefits, further studies are needed to fully understand its effects on humans. Incorporating WG into a balanced diet can provide valuable nutrients that support overall health, especially for bones and muscles.

3.2. Wheatgrass and mental health

WG has promising potential in supporting mental health due to its antioxidant, anti-inflammatory, and neuroprotective properties. Although specific research on its direct effects on mental health is limited, there are several mechanisms through which WG may contribute to improving psychological health. Research confirms the benefits of WG on nervous system disorders, owing

to fewer side effects [71,73]. WGJ is often consumed for its numerous health benefits, being known for its ability to nourish cells and detoxify the body due to its content of bioactive ingredients. It contains gamma-aminobutyric acid, flavonoids, superoxide dismutase, vitamins, tryptophan, chlorophyll, bioflavonoids, minerals, and amino acids, making it useful in treating various conditions [65].

Depression, a neuropsychiatric disorder affecting millions of people, is influenced by environmental factors such as stress and life events that can trigger major depressive disorder (MDD) [74]. A key factor in the development of depression is OS, caused by an imbalance in the generation of free radicals and reactive oxygen species (ROS). The accumulation of these ROS can damage lipids, proteins, and nucleic acids, leading to cell death and impaired neuronal function [70,73].

AD is a neurodegenerative condition that causes cognitive decline, primarily due to neuronal death [71,75]. WG has neuroprotective potential, contributing to the restoration of cognitive functions, increasing acetylcholinesterase enzyme activity and monoamine levels. It also prevents neuronal degeneration, reduces OS and inflammation, and may alleviate disorders associated with liver and kidney function, which can enhance vulnerability to Alzheimer's. Results also suggest that WG may be useful in treating respiratory diseases by inhibiting hypersecretion of mucus in the epithelial lining of the respiratory tract [76].

CONCLUSIONS

WG represents a promising natural resource for improving health, due to its rich nutritional profile. Its components, including vitamins, minerals, antioxidants, and amino acids, contribute to strengthening the immune system, reducing OS, and potentially preventing cancer. Continued research on the specific mechanisms of these compounds will further clarify their role in promoting health. In various forms, WG demonstrates a wide range of therapeutic effects, from cardiovascular protection and anticancer activity to neuroprotective and antidiabetic effects, offering significant potential in preventive and complementary medicine.

ACKNOWLEDGMENTS

Ciobica Alin is funded through The Operational Program for Competitiveness 2014-2020, Axis 1, under POC/448/1/1 Research infrastructure projects for public R&D institutions/universities, project "Multidisciplinary platform for medical research-development in N-E region, CENEMED", grant agreement no. 127606.

REFERENCES

[1] Padalia S, Drabu S, Raheja I, Gupta A, Dhamija M. Multitude Potential of Wheatgrass Juice (Green Blood): An Overview. Chronicles of Young Scientists. 2010;1.

[2] Al-Awaida W, Al-Ameer HJ, Sharab A, Akasheh RT. Modulation of wheatgrass (Triticum aestivum Linn) toxicity against breast cancer cell lines by simulated microgravity. Curr Res Toxicol. 2023;5.

[3] Chakraborty R, Kashyap P, Gadhave RK, Jindal N, Kumar S, Guiné RPF, et al. Fluidized Bed Drying of Wheatgrass: Effect of Temperature on Drying Kinetics, Proximate Composition, Functional Properties, and Antioxidant Activity. Foods. 2023;12.
[4] Benincasa P, Falcinelli B, Lutts S, Stagnari F, Galieni A. Sprouted grains: A comprehensive review. Nutrients. 2019;11.
[5] Mishra N, Tripathi R, Pandey D, Shah K, Chauhan NS. Wheatgrass (Triticum aestivum): a miraculous microgreen: an overview. Journal of Future Foods. 2025; 5:239–47.
[6] Bar-Sela G, Cohen M, Ben-Arye E, Epelbaum R. The Medical Use of Wheatgrass: Review of the Gap Between Basic and Clinical Applications. Mini-Reviews in Medicinal Chemistry. 2015;15.
[7] Parit SB, Dawkar V V., Tanpure RS, Pai SR, Chougale AD. Nutritional Quality and Antioxidant Activity of Wheatgrass (Triticum aestivum) Unwrap by Proteome Profiling and DPPH and FRAP assays. J Food Sci. 2018;83.
[8] Banerjee S, Katiyar P, Kumar V, Waghmode B, Nathani S, Krishnan V, et al. Wheatgrass inhibits the lipopolysaccharide-stimulated inflammatory effect in RAW 264.7 macrophages. Curr Res Toxicol. 2021;2.
[9] Gore RD, Palaskar SJ, Bartake AR. Wheatgrass: Green blood can help to fight cancer. Journal of Clinical and Diagnostic Research. 2017;11.
[10] Ben-Arye E, Goldin E, Wengrower D, Stamper A, Kohn R, Berry E. Wheat grass juice in the treatment of active distal ulcerative colitis: A randomized double-blind placebo-controlled trial. Scand J Gastroenterol. 2002;37.
[11] Sharma A, Yadav M, Sharma N, Kumari A, Kaur S, Meenu M, et al. Comparison of wheatgrass juices from colored wheat (white, black, blue, and purple) for health promoting phytochemicals. Food Research International. 2022;161.
[12] Awulachew MT. The Role of Wheat in Human Nutrition and Its Medicinal Value. Citation: Melaku Tafese Awulachew. 2020;2.
[13] Hattarki SA, Bogar C, Bhat K. Triticum aestivum (wheat grass) Exhibited Anticancer Activity on Oral Cancer (KB) Cell Line. International Journal of Pharma Research and Health Sciences. 2020;8.
[14] Fedoseev GB, Smirnov Ai, Zukheir A, Ivanova OA, Smirnova OI, Alekseeva EF, et al. [Absolute diet therapy and antibiotic tolerance in bronchial asthma patients]. Ter Arkh. 1996;68.
[15] Nenonen MT, Helve TA, Rauma AL, Hänninen OO. Uncooked, lactobacilli-rich, vegan food and rheumatoid arthritis. Br J Rheumatol. 1998;37.
[16] Mohan Y, Jesuthankaraj GN, Ramasamy Thangavelu N. Antidiabetic and antioxidant properties of triticum aestivum in streptozotocin-induced diabetic rats. Adv Pharmacol Sci. 2013;2013.
[17] Shakya G, Randhi PK, Pajaniradje S, Mohankumar K, Rajagopalan R. Hypoglycaemic role of wheatgrass and its effect on carbohydrate metabolic enzymes in type II diabetic rats. Toxicol Ind Health. 2016;32.
[18] Minocha N, Pandey P, Sharma N, Saini S. Wheatgrass (Triticum Aestivum) Extract Loaded Chitosan Solid Lipid Nanoparticles: Formulation, Physicochemical Characterisation and Cytotoxic Potential. Recent Pat Nanotechnol. 2024;18.
[19] Willcox JK, Ash SL, Catignani GL. Antioxidants and prevention of chronic disease. Crit Rev Food Sci Nutr. 2004;44.
[20] Donaldson MS. Nutrition and cancer: A review of the evidence for an anti-cancer diet. Nutr J [Internet]. 2004 [cited 2024 Oct 15]; 3:19. Available from: /pmc/articles/PMC526387/
[21] Yıldırım K, Kaya Z. Gene regulation network behind drought escape, avoidance and tolerance strategies in black poplar (Populus nigra L.). Plant Physiology and Biochemistry. 2017;115.

[22] Nunes C dos R, Arantes MB, de Faria Pereira SM, da Cruz LL, de Souza Passos M, de Moraes LP, et al. Plants as Sources of Anti-Inflammatory Agents. Molecules. 2020.
[23] Cho K, Lee CW, Ohm JB. In vitro study on effect of germinated wheat on human breast cancer cells. Cereal Chem. 2016;93.
[24] Mutha AS, Shah KU, Kinikar AA, Ghongane BB. Efficacy and Safety of Wheat Grass in Thalassemic Children on Regular Blood Transfusion. Cureus. 2018;
[25] Cores Rodríguez F, Gallagher E, Rai DK, Burgess CM. Nutritional and physiochemical properties of wheatgrass juice and preservation strategies. Food Chemistry Advances. 2022;1.
[26] Minocha N, Sharma N, Pandey P. Wheatgrass: An Epitome of Nutritional Value. Curr Nutr Food Sci. 2021;18.
[27] Tamraz M, Al Ghossaini N, Temraz S. The Role of Wheatgrass in Colorectal Cancer: A Review of the Current Evidence. Int J Mol Sci [Internet]. 2024 [cited 2024 Oct 16];25. Available from: https://pubmed.ncbi.nlm.nih.gov/38791211/
[28] Khalid A, Hameed A, Tahir MF. Wheat quality: A review on chemical composition, nutritional attributes, grain anatomy, types, classification, and function of seed storage proteins in bread making quality. Front Nutr. 2023.
[29] Khan MS, Parveen R, Mishra K, Tulsawani R, Ahmad S. Chromatographic analysis of wheatgrass extracts. J Pharm Bioallied Sci. 2015.
[30] Bar-Sela G, Tsalic M, Fried G, Goldberg H. Wheat grass juice may improve hematological toxicity related to chemotherapy in breast cancer patients: A pilot study. Nutr Cancer. 2007;58.
[31] Kour B. Wheat Grass Benefits. Int J Complement Altern Med. 2016;3.
[32] Kaur N, Singh B, Kaur A, Yadav MP, Singh N, Ahlawat AK, et al. Effect of growing conditions on proximate, mineral, amino acid, phenolic composition and antioxidant properties of wheatgrass from different wheat (Triticum aestivum L.) varieties. Food Chem. 2021;341.
[33] Benincasa P, Tosti G, Farneselli M, Maranghi S, Bravi E, Marconi O, et al. Phenolic content and antioxidant activity of einkorn and emmer sprouts and wheatgrass obtained under different radiation wavelengths. Annals of Agricultural Sciences. 2020;65.
[34] Weyh C, Krüger K, Peeling P, Castell L. The Role of Minerals in the Optimal Functioning of the Immune System. Nutrients. 2022.
[35] Wen L, Wu D, Tan X, Zhong M, Xing J, Li W, et al. The Role of Catechins in Regulating Diabetes: An Update Review. Nutrients. 2022.
[36] Thakur N, Singh PA. Amino Acid and Vitamin Content of Wheatgrass (Triticum Aestivum) Powder [Internet]. 2012. Available from: www.ijfans.org
[37] Runjala S, Murthy Y. Product Development with Wheat Grass and Nutrient Analysis [Internet]. International Journal of Science and Research. 2013. Available from: www.ijsr.net
[38] Minocha N, Saini S, Pandey P. Nutritional prospects of wheatgrass (Triticum aestivum) and its effects in treatment and chemoprevention. Explor Med. 2022.
[39] Bernatoniene J, Kopustinskiene DM. The Role of Catechins in Cellular Responses to Oxidative Stress. Molecules. 2018.
[40] Sheng Y, Sun Y, Tang Y, Yu Y, Wang J, Zheng F, et al. Catechins: Protective mechanism of antioxidant stress in atherosclerosis. Front Pharmacol. 2023.
[41] Sutherland BA, Rahman RMA, Appleton I. Mechanisms of action of green tea catechins, with a focus on ischemia-induced neurodegeneration. Journal of Nutritional Biochemistry. 2006.
[42] Bazyar H, Zare Javid A, Ahangarpour A, Zaman F, Hosseini SA, Zohoori V, et al. The effects of rutin supplement on blood pressure markers, some serum antioxidant enzymes, and quality of life in patients with type 2 diabetes mellitus compared with placebo. Front Nutr. 2023;10.

[43] Ganeshpurkar A, Saluja AK. The Pharmacological Potential of Rutin. Saudi Pharmaceutical Journal. 2017.
[44] Tripathi R, Agarwal S, Rizvi SI, Mishra N. The antioxidant efficacy of wheatgrass (Triticum aestivum) on mercuric chloride (hgcl2)-induced oxidative stress in rat model. Current Research in Nutrition and Food Science. 2021;9.
[45] Babaei F, Moafizad A, Darvishvand Z, Mirzababaei M, Hosseinzadeh H, Nassiri-Asl M. Review of the effects of vitexin in oxidative stress-related diseases. Food Sci Nutr. 2020.
[46] de Oliveira DD, da Silva CP, Iglesias BB, Beleboni RO. Vitexin Possesses Anticonvulsant and Anxiolytic-Like Effects in Murine Animal Models. Front Pharmacol. 2020;11.
[47] Ghanbari-Movahed M, Shafiee S, Burcher JT, Lagoa R, Farzaei MH, Bishayee A. Anticancer Potential of Apigenin and Isovitexin with Focus on Oncogenic Metabolism in Cancer Stem Cells. Metabolites. 2023.
[48] Alam MA. Anti-hypertensive Effect of Cereal Antioxidant Ferulic Acid and Its Mechanism of Action. Front Nutr. 2019.
[49] Chen S, Wang X, Wang X, Zheng W, He S, Song M, et al. The Influence of Syringic Acid and Erucic Acid on the Antioxidant Properties of Natural Rubber: Experimental and Molecular Simulation Investigations. Polymers (Basel). 2022;14.
[50] Bartel I, Mandryk I, Horbańczuk JO, Wierzbicka A, Koszarska M. Nutraceutical Properties of Syringic Acid in Civilization Diseases—Review. Nutrients 2024, Vol 16, Page 10 [Internet]. 2023 [cited 2024 Oct 16]; 16:10. Available from: https://www.mdpi.com/2072-6643/16/1/10/htm
[51] Li Y, Schellhorn HE. The Journal of Nutrition Critical Review New Developments and Novel Therapeutic Perspectives for Vitamin C 1,2. J. Nutr. 2007.
[52] Pham-Huy LA, He H, Pham-Huy C. Free radicals, antioxidants in disease and health. International Journal of Biomedical Science. 2008.
[53] Naidu KA. Vitamin C in human health and disease is still a mystery? An overview. Nutr J. 2003.
[54] Tardy AL, Pouteau E, Marquez D, Yilmaz C, Scholey A. Vitamins and minerals for energy, fatigue and cognition: A narrative review of the biochemical and clinical evidence. Nutrients. 2020.
[55] Ghumman A, Singh N, Kaur A. Chemical, nutritional and phenolic composition of wheatgrass and pulse shoots. Int J Food Sci Technol. 2017;52.
[56] Martins T, Barros AN, Rosa E, Antunes L. Enhancing Health Benefits through Chlorophylls and Chlorophyll-Rich Agro-Food: A Comprehensive Review. Molecules. 2023.
[57] Björn LO, Papageorgiou GC, Blankenship RE, Govindjee. A viewpoint: Why chlorophyll a? Photosynth Res. 2009.
[58] Durrett TP, Welti R. The tail of chlorophyll: Fates for phytol. Journal of Biological Chemistry. 2021.
[59] Roca M, Chen K, Pérez-Gálvez A. Chlorophylls. Handbook on Natural Pigments in Food and Beverages: Industrial Applications for Improving Food Color, Second Edition. 2024;193–226.
[60] Yilmaz C, Gökmen V. Chlorophyll. Encyclopedia of Food and Health. 2015;37–41.
[61] Grubišić S, Kristić M, Lisjak M, Špoljarić KM, Petrović S, Vila S, et al. Effect of Wheatgrass Juice on Nutritional Quality of Apple, Carrot, Beet, Orange and Lemon Juice. Foods. 2022;11.
[62] Niroula A, Khatri S, Timilsina R, Khadka D, Khadka A, Ojha P. Profile of chlorophylls and carotenoids of wheat (Triticum aestivum L.) and barley (Hordeum vulgare L.) microgreens. J Food Sci Technol. 2019;56.

[63] Fahey JW, Stephenson KK, Dinkova-Kostova AT, Egner PA, Kensler TW, Talalay P. Chlorophyll, chlorophyllin and related tetrapyrroles are significant inducers of mammalian phase 2 cytoprotective genes. Carcinogenesis. 2005;26.
[64] Kulkarni SD, Tilak JC, Acharya R, Rajurkar NS, Devasagayam TPA, Reddy AVR. Evaluation of the antioxidant activity of wheatgrass (Triticum aestivum L.) as a function of growth under different conditions. Phytotherapy Research. 2006;20.
[65] Lim JY, Yun DH, Lee JH, Kwon YB, Lee YM, Lee DH, et al. Extract of triticum aestivum sprouts suppresses acetaminophen-induced hepatotoxicity in mice by inhibiting oxidative stress. Molecules. 2021;26.
[66] Fortună ME, Vasilache V, Ignat M, Silion M, Vicol T, Patraş X, et al. Elemental and macromolecular modifications in Triticum aestivum L. plantlets under different cultivation conditions. PLoS One. 2018;13.
[67] Alitheen NB, Oon CL, Keong YS, Chuan TK, Li HK, Yong HW. Cytotoxic effects of commercial wheatgrass and fiber towards human acute promyelocytic leukemia cells (HL60). Pak J Pharm Sci. 2011;24.
[68] Kothari S, Jain AK, Mehta SC, Tonpay SD. Hypolipidemic effect of fresh Triticum aestivum (wheat) grass juice in hypercholesterolemic rats. Acta Poloniae Pharmaceutica - Drug Research. 2011;68.
[69] Avisar A, Cohen M, Katz R, Kutiel TS, Aharon A, Bar-Sela G. Wheatgrass juice administration and immune measures during adjuvant chemotherapy in colon cancer patients: Preliminary results. Pharmaceuticals. 2020;13.
[70] Sethi J, Yadav M, Dahiya K, Sood S, Singh V, Bhattacharya SB. Antioxidant effect of triticum aestivium (wheat grass) in high-fat diet-induced oxidative stress in rabbits. Methods Find Exp Clin Pharmacol. 2010;32.
[71] Abu-Elfotuh K, Ragab GM, Salahuddin A, Jamil L, Abd Al Haleem EN. Attenuative effects of fluoxetine and triticum aestivum against aluminum-induced alzheimer's disease in rats: The possible consequences on hepatotoxicity and nephrotoxicity. Molecules. 2021;26.
[72] Nepali S, Ki HH, Lee JH, Lee HY, Kim DK, Lee YM. Wheatgrass-Derived Polysaccharide Has Antiinflammatory, Anti-Oxidative and Anti-Apoptotic Effects on LPS-Induced Hepatic Injury in Mice. Phytotherapy Research. 2017;31.
[73] Shrivastava AK, Magar PT, Shrestha L. Effect of aqueous extract of barley and wheat grass in stress induced depression in Swiss mice. J Ayurveda Integr Med. 2022;13.
[74] Berger T, Lee H, Young AH, Aarsland D, Thuret S. Adult Hippocampal Neurogenesis in Major Depressive Disorder and Alzheimer's Disease. Trends Mol Med. 2020.
[75] Soria Lopez JA, González HM, Léger GC. Alzheimer's disease. Handb Clin Neurol. 2019; 167:231–55.
[76] Sim J, Choi MH, Shin HJ, Lee JE. Wheatgrass extract ameliorates hypoxia-induced mucin gene expression in A549 cells. Pharmacogn Mag. 2017;13.