Cruciferous Sprouts as Sources of Bioactive Compounds

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Edible sprouts with germinating seeds of a few days of age are naturally rich in nutrients and other bioactive compounds. Among them, the cruciferous (Brassicaceae) sprouts stand out due to their high contents of glucosinolates (GLSs) and phenolic compounds.

Keywords: Brassicaceae ; elicitation ; growing conditions ; broccoli ; radish ; kale pak choi ; isothiocyanates

1. Introduction

In the last decades, a growing interest concerning the implications of diet and physical activity on health has occurred in society. This interest lies in the expansion of life expectancy as well as in the improvement in quality of life, and this has led to interventions based on the incorporation of new healthy foods in the human diet. These new foods are envisaged to constitute a valuable source of bioactive healthy nutrients and non-nutrients that would contribute to delaying the onset of a number of chronic and disabling diseases as well as reducing their incidence and severity. In this sense, consumers are demanding a diversified range of foods that provide health benefits and contribute to well-being. For the consecution of this objective, a wide range of plants, crops, and foods have been studied and characterized throughout the recent decades regarding their potential to exert effects on health, according to their nutritional content and bioactive phytochemical composition. Also, many works have paid attention to the bioaccessibility, bioavailability, and bioactivity which will allow, in the near future, validation of their use in the design of new functional ingredients and foods [1].

In this regard, edible sprouts represent a valuable source of diverse micronutrients (vitamins, minerals, and amino acids), macronutrients (proteins, low in carbohydrates, and a high content of dietary fiber), and plant secondary metabolites (mainly phenolic compounds and glucosinolates (GLSs)). Due to this composition, edible sprouts are a valuable vehicle and opportunity to impact health, delivering beneficial bioactive compounds once incorporated in the diet on a regular basis.

From a commercial point of view, a broad spectrum of sprouts and sprouting seeds is available including, but not limited to, soybean, alfalfa, broccoli, radishes, kale, watercress, and peas. This type of fresh product is gaining interest, not only in the field of gourmet and elite cooking or in dedicated nutrition (e.g., vegetarians and health conscious consumers), but also (and consequently) in the food industry, boosted by interest in sprouts as a source of nutrients and healthy secondary metabolites with a really short production time (5–10 days, depending on species or varieties) [2].

Within the current diversity of sprouts and germinates, cruciferous types (which includes sprouts of Brassicaceae, like broccoli, radish, kale, mustards, radishes, or wasabi) are noticed because of their high content of micronutrients, nitrogen–sulfur compounds (glucosinolates (GLSs) and their derivatives, isothiocyanates (ITCs), and indoles) and phenolic compounds (mainly phenolic acids, flavonols, and anthocyanins) [3][4][5].

2. Bioactive Secondary Metabolites in Edible Cruciferous Sprouts

As mentioned above, cruciferous sprouts contain non-nutrient/health-promoting compounds, such as diverse types of glucosinolates and phenolic compounds [5]. The biological activity developed by these compounds is mainly due to their antioxidant capacity, which could lower the deleterious consequences of excessively high levels of reactive oxygen species (ROS) in cells and, thus, decrease oxidative stress (OS) by providing cells with molecular tools to combat the imbalance between the production of ROS and the capacity to modulate the redox balance. These properties have direct effects on a number of cellular processes triggered by ROS, which are related to inflammation and oxidative reactions on

DNA, proteins, and cell lipids [6]. In addition, to provide further molecular tools to cells to lower OS, many bioactive phytochemicals present in edible sprouts display biological functions that are crucial for the prevention of carcinogenesis processes and other chronic diseases [1] (**Table 1**).

Table 1. The main bioactive phytochemicals and health promoting activities of diverse raw edible sprouts.

Edible Sprout	Main Bioactive Compounds	Main Bioactivities Associated with Sprout Consumption	References
Broccoli (*Brassica oleracea* var. *Italica*)	**Flavonoids** Quercetin, kaempferol, and flavonol glycosides	Cancer risk (↓) Degenerative diseases (↓) Obesity-related metabolic disorders (↓) Allergic nasal symptoms (↓) Inflammation (↓) Pain (↓) Antioxidant capacity (↑)	[5][7]
	Phenolic acids Chlorogenic, sinapic, and ferulic acid derivatives		
	Glucosinolates Glucoraphanin, glucoiberin, glucoraphenin, glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin, and neoglucobrassicin		
	Isothiocyanates Sulphoraphane, iberin, and indole-3-carbinol		
Radish (*Raphanus sativus L.*)	**Flavonoids** Quercetin	Risk of cancer (↓) Heart disease (↓) Diabetes (↓) Antioxidant capacity (↑)	[8]
	Phenolic acids Ferulic, caffeic and *p*-coumaric acids, and derivatives		
	Glucosinolates Glucoraphenin, dehydroerucin, glucobrassicin, and 4-methoxyglucobrassicin		
	Isothiocyanates Sulforaphene, sulforaphane, and indole-3-carbinol		

Edible Sprout	Main Bioactive Compounds	Main Bioactivities Associated with Sprout Consumption	References
Kale (*Brassica oleracea* var. *acephala*)	**Flavonoids** Quercetin and cyanidin **Phenolic acids** Chlorogenic and ferulic acids **Glucosinolates** Glucoraphanin, glucoiberin, gluconapin, gluconasturtin, progoitrin, gluconapin, gluconapoleiferin, sinigrin, glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin, and neoglucobrassicin	Risk of cancer (↓) Heart disease (↓) Diabetes (↓) Antioxidant capacity (↑)	[9]
Pak choi (*Brassica rapa* var. *chinensis*)	**Flavonoids** Kaempferol, quercetin, and isorhamnetin glucosides **Phenolic acids** Ferulic, sinapic, caffeic, and *p*-coumaric acids, and derivatives **Glucosinolates** Gluconapin, glucoalyssin, gluconasturtin, progoitrin, glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin, and neoglucobrassicin	Risk of cancer (↓) Heart disease (↓) Diabetes (↓) Antioxidant capacity (↑)	[9][10]

3. Elicitation of Brassicaceae Sprouts to Enhance the Content of Bioactive (Poly)phenols and Glucosinolates

The production of edible sprouts allows the modification of certain pre- and post-harvest conditions to try to improve the production of secondary metabolites, such as GLSs or phenolic acids. Indeed, nowadays, elicitation has been employed in agronomic production to increase the expression of specific genes of interest in plants [11]. The elicitation alternatives that could induce stress in the plants vary from the modification of the abiotic factors affecting sprout growth in the chamber, such as temperature, humidity, and the light intensity/period, to the use of specific biotic elicitors, like plant hormones (methyl-jasmonate and ethylene, among others) or amino acids (methionine) [12]. In this context, elicitors can be classified as biotics (plant hormones, proteins, natural toxins, oligosaccharides, lipopolysaccharides, polysaccharides, or extracts with essential oils) and abiotics (minerals, chemical elements, physical damage, or benzothiadiazole) [13]. Moreover, seed priming before the exogenous elicitation has also been described as modulating the response of the sprouts [13]. Nowadays, these elicitation practices are extensively used to implement the production of edible sprouts, while new emergent agro-technologies, like the use of light-emitting diode (LED) lights to elicit secondary metabolites ((poly)phenols and GLSs) in edible sprouts, has been less explored. In this regard, Baenas et al. (2014) [13] clustered many techniques and their effects on the content of bioactive (poly)phenols and GLSs or the transcription of specific genes in diverse raw edible sprouts, and updated information is presented in **Table 2**.

Table 2. Compounds of interest in edible sprouts through different elicitors (update from original table of Baenas et al., 2014 [13]).

Raw Edible Sprout	Elicitor Treatment	Elicitor Classification	Application	Target Compound and Increase	Reference
Broccoli sprouts (*Brassica oleracea*) (7 days of growth)	Sucrose, fructose, and glucose (146 mM)	Biotic elicitor	In 0.5% agar media for 5 days after sowing seeds	Total anthocyanins (10.0%)	[14]
Broccoli sprouts (*Brassica oleracea*) (7 days of growth)	Sucrose and mannitol (176 mM)	Biotic elicitor	Hydroponic system for 5 days after sowing seeds	Total anthocyanins (40.0%) and phenolics (60.0%) Total glucosinolates (50.0%)	[14]
Broccoli (*Brassica oleracea*) (7 days of growth)	Met (5 mM) Trp (10 mM) SA (100 μM) MeJA (25 μM)	Biotic elicitors (Met, Trp, and plant hormones—SA and MeJA)	Daily exogenous spraying during 3, 5, and 7 days	Met: glucoiberin, glucoraphanin, and glucoerucin (30.0%) Trp: 4-hydroxyglucobrassicin, glucobrassicin, 4-Methoxyglucobrassicin, and neoglucobrassicin (80.0%) SA: 4-hydroxyglucobrassicin, glucobrassicin, 4-Methoxyglucobrassicin, and neoglucobrassicin (30.0%) MeJA: 4-hydroxyglucobrassicin, glucobrassicin, 4-Methoxyglucobrassicin, neoglucobrassicin (50.0%)	[15]
Broccoli sprouts (*Brassica oleracea*)	Sucrose (146 mM)	Biotic elicitor	In 0.5% agar media for 5 days after sowing	Total GLS (2.0-fold)	[14]

Raw Edible Sprout	Elicitor Treatment	Elicitor Classification	Application	Target Compound and Increase	Reference
Broccoli sprouts (*Brassica oleracea*) (7 days of growth)	Mg (300 mg L^{-1})	Abiotic elicitor	Suplementation with $MgSO_4$	Increase of total ascorbic acid contain (29.1–44.5%)	[16]
Radish sprouts (*raphanistrum subsp. sativus*) (12 days of growth)	MeJA (100 μM)	Biotic elicitor (plant hormones—MeJA)	Treatment with MeJA in growth chamber under dark conditions	Glucoalyssin (1.4-fold) Glucoerucin (2.0-fold) Glucotropaeolin (1.8-fold) Glucoraphasatin (1.4-fold)	[17]
Radish sprouts (*raphanistrum subsp. sativus*) (12 days of growth)	MeJA (100 μM) Light	Biotic elicitor (plant hormones—MeJA-) Abiotic elicitor	Treatment with MeJA in growth chamber under light	Glucoraphanin (1.5-fold) Glucoerucin (1.6-fold) Glucotropaeolin (1.3-fold) 4-hydroxyglucobrassicin (4.4-fold) Pergonidin (1.7-fold) Cyanidin (2.0-fold)	[17]
Radish sprouts (*raphanistrum subsp. sativus*) (7 days of growth)	Mg (300 mg L^{-1})	Abiotic elicitor	Supplementation with $MgSO_4$	Phenolic compounds (13.9–21.7%)	[16]
Radish sprouts (*raphanistrum subsp. sativus)*	NaCl (100 mM)	Abiotic elicitor	In 0.5% agar media for 3.5 and 7.0 days after sowing	Total phenolics (30 and 50% in 5 and 7 day-old sprouts, respectively) Total GLS (50% and 120% in 5 and 7 day-old sprouts, respectively)	[18]
Pak Choi sprouts (*rapa subsp. chinensis*)	Application of different wavelengths of LED light (white, blue, and red)	Abiotic elicitor	Medium of perlite for 5 days in darkness and 18 h at the different wavelengths	Total carotenoid content (12.1% and 9.2% with white light (respect to blue and red light, respectively)	[11]

Raw Edible Sprout	Elicitor Treatment	Elicitor Classification	Application	Target Compound and Increase	Reference
Pak Choi sprouts (*rapa subsp. chinensis*)	Application of different wavelengths of LED light (white, blue, and red)	Abiotic elicitor	Medium of perlite for 5 days in darkness and 18 h at the different wavelengths	Enhanced transcription of genes involved in carotenoid biosynthesis (*CYP97A3, CYP97C1, βLCY, εLCY, β-OHASE1, PDS, PSY, VDE, ZEP*)	[11]
Kale Sprouts (*oleracea var. sabellica*)	Application of different light wavelengths (470, 660, and 730 nm)	Abiotic elicitor	Seeds stratified for 2 days, exposed to light for 1 h, exposed to darkness for between 1 and 3 days and later, the specific light treatment	Total GLS content (31.7%)	[19]
Radish, Chinese kale and pak choi sprouts (3 days of growth)	Glucose (5 g 100 mL^{-1})	Biotic elicitor	Hydroponic system for 3 days after sowing seeds	Total phenolics (20.0%), gluconapin (150.0% and 60.0% in Chinese kale and pak choi, respectively), glucobrassicanapin (110-fold in pak choi)	[20]
Different Brassica sprouts (broccoli, turnip, and rutabaga)	MeJA (25 μM) JA (150 μM) Sucrose (146 mM)	Biotic elicitors (Sucrose and plant hormones—MeJA and JA)	Sprayed for 5 days before harvest	Total GLS (>50%, broccoli; >20.0% turnip; >100.0% rutabaga)	[21]
Radish sprouts (*raphanistrum subsp. sativus*) (8 days of growth)	MeJA (25 μM) SA (100 μM) Glucose (277 mM)	Biotic elicitors (glucose and plant hormones—MeJA and JA)	Sprayed for 5 days before harvest	Total GLS (20.0%)	[21]

Genes: *CYP97A3*: *cytochrome P450 97A3*; *CYP97C1*: *cytochrome P450 97C1*; *βLCY*: *β-cyclase*; *εLCY*: *ε-cyclase*; *β-OHASE1*: *β-carotene hydroxylase 1*; *PDS*: *phytoene desaturase*; *PSY*: *phytoene synthase*; *VDE*: *violaxanthin de-epoxidase*; *ZEP*: *zeaxanthin epoxidase*. GLS: glucosinolates; JA: jasmonate or jasmonic acid; LED: diode electric light; MeJA: methyl jasmonate; Met, methionine; Mg, magnesium; SA, salicylic acid; Trp, tryptophan.

The elicitation with Mg (50–300 mg/L) enhanced the production and concentration of total phenolics in radish sprouts when applied at a concentration of 300 mg/L, although regarding broccoli sprouts, it reduced the content of total phenolics when applied at 50 mg/L [16] (**Table 2**). Besides, the cited study analyzed the influence of different Mg dosages on the defense capacities of broccoli and radish against OS, and significant modifications of the antioxidant capacity were demonstrated with augmented activity of the major antioxidant enzymes (catalase (CAT), gluatathione reductase (GR), and ascorbate peroxidase (APX)). Specifically, the activity of CAT in Mg-enriched sprouts increased in broccoli (up to 46.7% higher), but decreased in radish sprouts (by 1.5–20.0%). On the other hand, the activity of GR increased in radish sprouts (32.0–96.0% higher), while it decreased in broccoli (14.8–40.7% lower). The APX activity increased in broccoli sprouts, but just at intermediate concentrations (50 and 100 mg/L), while in radish sprouts, it significantly decreased (7.6–24.1%). These enzymes are key to the antioxidant capacity of the plants. However, currently, it is not clear how the improvement in the reduction of ROS, as a consequence of the elicitation of Mg, is a positive effect for plants, and further research is required (**Table 2**).

It is also important to mention that the elicitation with plant hormones can be effective to modify the secondary metabolism of higher plants. In this regard, methyl jasmonate (MeJA) and the free acid associated jasmonic acid (JA) are regulators with key influences on the diverse steps of cellular pathways involved in the development of Brassicaceae sprouts in the stages of seed germination, root growth, fertility, and senescense, among others. However, the succes of the elicitation with MeJA and its influence on the secondary metabolism depends on an array of factors like the presence of induced light [22] or the combination with other elicitors, like polysaccharides [21]. In this sense, Al-Dabhy et al., 2015 demonstrated that light has a decisive influence on the production of GLSs and anthocyanins in radish sprouts at different developmental stages. In fact, when grown under light absence conditions with and without MeJA elicitation, a less intense augmentation of anthocyanins and most GLSs was observed relative to that produced with exposition to light. Besides, the application of MeJA to radish sprouts with induced light showed significant increases mainly represented by glucoraphanin (1.5-fold), glucoerucin (1.6-fold), glucotropaeolin (1.3-fold), 4-hydroxyglucobrassicin (4.4-fold), pelargonidin (1.7-fold), and cyanidin (2.0-fold) (**Table 2**). Finally, some GLSs (glucoalyssin, glucoerucin, glucotropaeolin, glucoraphasatin, and glucobrassicin) increased their concentration in radish sprouts grown in darkness when the presence of MeJA was not higher than 100 µM [17].

Light, in addition to being a vital element required for plant survival, constitutes a factor with the capacity to critically influence a range of variations regarding the composition and metabolism observed during sprout growth. In connection to this role, light generates stress in plants and thus, activates specific enzymatic pathways of interest for the production of health-promoting bioactive compounds [11]. In this sense, the wavelength of the spectra applied during the development of seedlings has shown interesting changes. Nowadays, the use of LED lights allows us to apply and characterize the effects on plant growth and composition of all of the spectra, including far-red light (>700 nm). Far-red light has been proven to be a powerful booster that enhances the occurrence of glucosinolates and phenolic compounds in kale sprouts (**Figure 1**) [19].

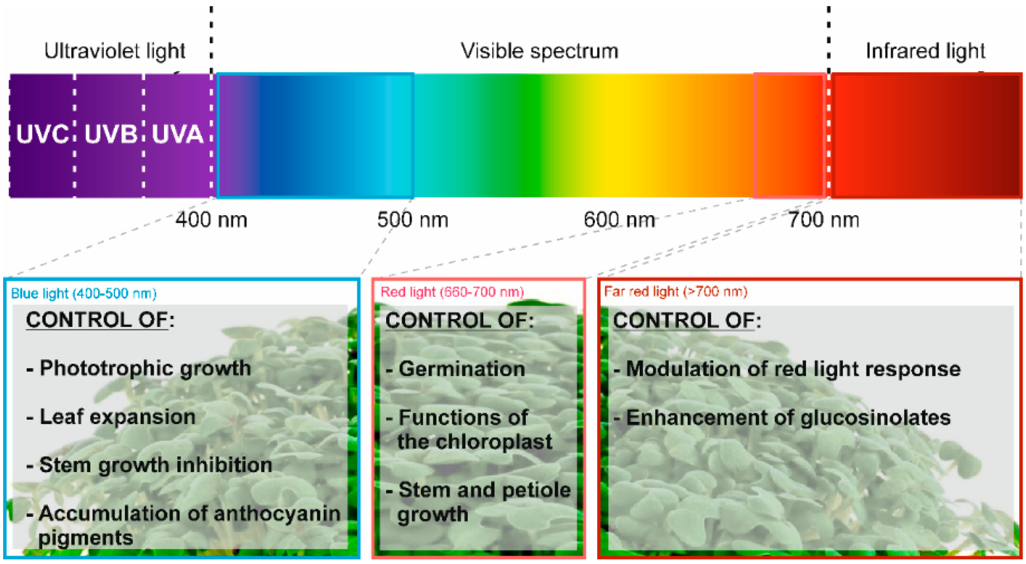

Figure 1. Light spectra influence on the development of kale sprouts.

Carvalho et al. observed that the application of different light wavelengths (470, 660, and 730 nm) modifies diverse molecular pathways routes in cells, affecting the concentration of bioactive phytochemicals (**Table 2**), with the most remarkable combination being the use of far-red light with other colors like blue (responsible for the regulation of phenolic compounds) and white, and having the appropriate amount of time in darkness (enhanced the total GLSs by 20.0%), throwing off interesting results compared to the regular application of white light and darkness (**Table 2**).

4. The Challenges of Including Cruciferous Sprouts in Balanced Diets and Personalized Nutrition

Balanced diets are critical for the provision of energy and nutrients essential to human health and well-being. Besides, a balanced nutritional supply should be considered carefully in diverse pathophysiological situations. Under a specific physiological status, a given nutrient supply could constitute a preventive or a risk factor. Anyway, to date, a consensus on the most appropriate dietary patterns has been set up, featuring a high proportion of plant foods to lower the incidence and severity of a number of degenerative pathologies, namely cardiovascular diseases, metabolic disturbances, and tumoral processes. This is of special relevance regarding the specific molecules prone to developing biological functions in humans. Indeed, (poly)phenols and GLSs, in addition to bioactive nutrients, are able to produce diverse effects that go beyond basic nutrition, being active on diverse pathophysiological processes and capable of selectively affecting cell proliferation, apoptosis, inflammation, cell differentiation, angiogenesis, DNA repair, and detoxification [23].

Nowadays, it is well accepted that the consumption of cruciferous sprouts is positive for the prevention of health problems, based on the presence of a number of bioactive secondary metabolites (phytochemicals) that naturally occur in plant foods, which have the capacity to act on diverse molecular targets into cells. This range of molecular mechanisms, which is susceptible to activation or inhibition by the GLSs, ITCs, and (poly)phenols present in cruciferous sprouts triggers diverse pathways governed by the expression of a broad variety of genes. Among them, to date, the following pathways have been identified: the inhibition of the DNA binding of carcinogens, the stimulation of detoxification of potentially damaging compounds, DNA repair, the repression of cell proliferation and angiogenesis (directly related to tumor growth and metastasis), the induction of apoptosis of malignant cells [24][25], and the ability to enhance the antioxidant tools of cells and promote free radical scavenging [26][27]. Regarding this biological activity, the modulation of the inflammatory cascade, and more specifically, the transcription factor NF-κB by GLSs, ITCs, and (poly)phenols, are also involved in the anticancer activity [28]. Hence, hereafter, the evidence on the value of incorporating cruciferous sprouts to regular diets to prevent a number of clinical situations is reviewed (**Table 3**), and the molecular mechanisms involved are also discussed.

Table 3. Demonstrated health benefits of cruciferous sprouts under a range of pathophysiological conditions.

Matrix	Pathophysiological Condition	Effect	Model	Action Mechanism Z	Ref.
Broccoli sprouts	Metabolic profile	No specific effect monitored	Humans	FA 14:1, FA 16:1, FA 18:1, FA 14:0, FA 16:0, FA 18:0, dehydroepiandrosterone, glutathione, cysteine, and glutamine (↑) Deoxy-uridin monophosohate (↓)	[29]
Radish sprouts	Energy metabolism	Decrease glucose level	*Drosophila melanogaster*	Expression of *spargel* (↑)	[30]
Broccoli sprouts	Pregnancy	Prevention of brain injury in newborns	Rats	Not determined	[31]
Broccoli sprouts	Inflammation and oxidative stress	Modulation of inflammation and vascular events	Humans	Not determined	[32]
Broccoli sprouts	Inflammation in overweight population	Anti-inflammatory activity	Humans	IL-6 and C-reactive protein (↓)	[33]

Matrix	Pathophysiological Condition	Effect	Model	Action Mechanism [Z]	Ref.
Broccoli sprout powder	Diabetes	Anti-inflammatory effect	Humans	C-reactive protein (↓)	[34]
Broccoli sprouts	Hypertension	Does not improve endothelial function of hypertension in humans	Humans	Not determined	[35]
Broccoli sprouts	Hypertension	Attenuation of oxidative stress, hypertension, and inflammation	Rats	Not determined	[36]
Rutabaga sprouts	Thyroid function and iodine deficiency. Role as goitrogenic foods	Protective effect against thyroid damage Goitrogenic activity not discarded	Male rats	Dietary source of iodine GPX1, GPX3, and FRAP (↓)	[37]
Broccoli sprouts	Hepatic and renal toxicity	Antioxidant activity	Female rats	Phase-II enzymes (↑) Lipid peroxidation and apoptosis (↓)	[38]
Broccoli sprouts	Bowel habits	Decrease in the constipation scoring system Decrease of *Bifidobacterium*	Humans	Not determined	[39]
Broccoli sprouts	Pain assessment and analgesia	Dose-dependent nociceptive activity	Rats	Agonists of central and peripheral opioid receptors	[40]
Tuscan black cabbage sprout extract	Xenobiotic metabolism and antioxidant defense	Improvement of the detoxification of xenebiotics	Rats	Induction of phase-II enzymes and boosting of the enzymatic activity of catalase, NAD(P)H:quinone reductase, glutathione reductase, and glutathione peroxidase	[41]
Japanese Radish Sprout	Diabetes	Decrease in plasma fructosamine, glucose, and insulin in diabetic rats	Rats	Not determined	[27]

Matrix	Pathophysiological Condition	Effect	Model	Action Mechanism [Z]	Ref.
Radish sprouts	Diabetes	Increase in blood glucose, triglycerides, total cholesterol, low-density lipoproteins, and very low density lipoproteins	Rats	Not determined	[42]
Broccoli sprout extracts	Skin disorders	Induction of phase-II response	Mice and humans	NQO1 enzyme activity (↑)	[43]
Broccoli sprout extracts	Skin disorders	Protection against inflammation, edema, and carcinogens in humans	Humans	Phase-II enzymes (↑) NQO1 enzyme activity (↑)	[44]
Broccoli sprout homogenate	Physiological upper airway	No specific effect monitored	Humans	Phase-II enzymes (↑)	[45]
Broccoli sprouts	Physiological upper airway	No specific effect monitored	Humans	Nrf2 activity (↑) Secretory leukocyte protease inhibitor (↑)	[46]
Broccoli sprout extract	Asthma	Blocking the bronchoconstrictor hyperresponsiveness of some asthmatic phenotypes	Humans	Activity of Nrf2 regulated antioxidant and anti-inflammatory genes (↓)	[47]
Broccoli sprout extract	Hepatic disturbances	Improvement of liver functions and reduction of oxidative stress	Rats	Not determined	[48]
Broccoli sprout-based supplements	General carcinogenic processes	Chemopreventive effect	Humans	Not determined	[49]
Broccoli sprout extract	Head and neck squamous cell carcinoma	Chemopreventive activity of sulforaphane against carcinogen-induced oral cancer	Mice	Time and dose dependent induction of Nrf2 and Nrf2 target genes (*NQO1* and *GCLC*) Dephosphorilation of pSTAT3	[50]
Broccoli sprouts homogenate	Sickle cell disease (hemoglobinopathy)	Change in the gene expression levels	Humans	Expression of Nrf2 targets (*HMOX1* and *HBG1*) (↑)	[51]

Matrix	Pathophysiological Condition	Effect	Model	Action Mechanism [Z]	Ref.
Broccoli sprouts	Oxidative stress	Improvement in cholesterol metabolism and decrease in oxidative stress	Humans	Not determined	[52]
Broccoli sprouts	General carcinogenic processes	Chemopreventive agent	Humans	Histone deacetylase activity (↓)	[53]
Broccoli sprouts	Unspecific frame	Not determined	Humans	Histone deacetylase activity (↓)	[54]
Broccoli sprouts	Antimicrobial activity against *Helicobacter pylori*	Reduction of *Helicobacter pylori* colonization in mice Enhancement of sequelae of *Helicobacter pylori* infection in mice and humans	Mice and humans	Not determined	[55]
Broccoli sprout extract	Allergic response	Broccoli sprouts reduce the impact of particulate pollution of allergic disease and asthma	Humans	Not determined	[56]
Broccoli sprout extract	Prostate cancer	Inconclusive	Humans	Not determined	[57]
Broccoli sprout and myrosinase-treated broccoli sprout extracts	Chemoprevention of carcinogenesis processes	Inconclusive	Humans	No dose response was observed for molecular targets	[58]
Broccoli sprout extract	Psychiatric disorders	Improvement of the cognitive function in patients affected by schizophrenia	Humans	Not determined	[59]
Broccoli sprout extract	Type II diabetes	Reduction of fasting blood glucose and glycated hemoglobin	Mice	(↑) Nuclear translocation of Nrf2 (↓) Glucose production and intolerance	[60]

Matrix	Pathophysiological Condition	Effect	Model	Action Mechanism [Z]	Ref.
Broccoli sprout extract	Neurological disorder	Inconclusive improvement of Autism symptoms	Humans	(↑) Gene transcription in multiple cell signaling pathways	[61]
Broccoli sprout homogenate	Viral infections	Enhancement of antiviral defense response	Humans	Modulation of natural killer cell activation Production of granzyme B by natural killer cells (↑)	[62]

[Z] FA, fatty acids; FRAP, ferric reducing activity of plasma; GCLC, glutamate-cysteine ligase catalytic subunit; GPX1, cytosolic glutathione peroxidase-1; GPX3, cytosolic glutathione peroxidase-3; HBG1, Hemoglobin subunit gamma 1; HMOX1, heme oxygenase (decycling) 1; IL-6, interleukina 6; NAD(P)H, nicotinamide adenine dinucleotide phosphate; NQO1, NAD(P)H:quinone oxidoreductase 1; TNF-α, tumor necrosis factor-alpha; Nrf2, nuclear factor erythroid 2–related factor 2; pSTAT3, signal transducer and activator of transcription-3; TSH, thyroid stimulating hormone. (↓↑) Non-significant variation, (↓) decrease, and (↑) increase.

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