

# Broccoli: An Underexploited Exotic Vegetable In Nutraceutical Development: A Review

## Abstract

In 2024, health and wellness trends are set to redefine how we approach personal care, focusing on technology, sustainability, and a holistic mindset. As we become more attuned to the intricate connection between physical, mental, and environmental health, innovations like AI-powered health tools, personalized nutrition, and longevity science are gaining ground. People are increasingly drawn to mental wellness practices, eco-conscious living, and biohacking methods to optimize every aspect of their well-being. From the rise of telemedicine to sustainable beauty, these trends reflect a growing demand for personalized, accessible, and inclusive wellness solutions that support a balanced, health-centered lifestyle.

An essential part of this wellness movement is the focus on cruciferous vegetables, particularly broccoli, for their powerful health benefits. Rich in vitamins, fiber, and antioxidants, broccoli is celebrated for its potential to reduce inflammation, support digestive health, and even provide anti-cancer properties due to compounds like sulforaphane. As awareness of plant-based, nutrient-dense foods grows, cruciferous crops like broccoli are increasingly valued not just as staples of a healthy diet but as natural allies in long-term disease prevention and metabolic health. This renewed focus on cruciferous vegetables highlights a trend toward using whole, natural foods to support wellness from within.

Various factors affect broccoli's nutraceutical composition, including genetics, environmental conditions, and cultivation practices. Genetic variation determines the levels of glucosinolates and other beneficial compounds, while environmental factors such as soil quality, temperature, and light exposure further influence these concentrations. Organic farming practices, for instance, are known to enhance glucosinolate content compared to conventional farming. Post-harvest processing methods also play a key role in preserving or degrading these nutrients, with practices like blanching and freezing impacting the stability of bioactive compounds.

In addition, advanced extraction methods such as ultrasound-assisted, microwave-assisted, and supercritical fluid extraction are used to increase the yield and bioavailability of broccoli's beneficial components. These techniques offer sustainable ways to harness broccoli's nutraceutical potential, making it a valuable food for disease prevention and health promotion.

**Keywords:** Nutraceuticals, cruciferous crops, broccoli, sulforaphane, glucosinolates, health care, bioactive compounds, extraction, flavanoids, phytochemicals

## Introduction

Natural foods are in greater demand as a result of sedentary lifestyles, changing eating patterns, and a growing interest in nutrient-rich, protective meals. A daily mainstay, vegetables are rich in vital vitamins, minerals, antioxidants, and a variety of bioactive phytochemicals. When it comes to their rich functional bioactive profiles, cruciferous vegetables such as broccoli, cabbage, cauliflower, arugula, horseradish, mustard greens, bok

choy, and Brussels sprouts stand out among them (Satish *et al.*, 2022). These vegetables are valuable not only for their culinary applications but also for their potential as nutraceuticals because they contain sulfur-rich compounds (like methyl cysteine sulfoxide and glucosinolates), pigments (like carotenoids and anthocyanins), minerals (selenium, iron, potassium, and calcium), vitamins (B complex and C), dietary fiber, and other bioactive compounds (like phytoalexins, etc.). (Satish and others, 2022). The presence of sulfur-rich compounds (like methyl cysteine sulfoxide and glucosinolates), pigments (like carotenoids and anthocyanins), minerals (selenium, iron, potassium, and calcium), vitamins (B complex and C), dietary fiber, and other bioactive compounds (like phytoalexins, terpenes, tocopherols, hydroxycinnamic acid, chlorogenic acid, ferulic acid, synapic acid, and flavonols) make these vegetables valuable not only for their culinary uses but also for their potential as nutraceuticals. These substances provide cruciferous (Gonçalves *et al.*, 2013).

Understanding the effects of these bioactive substances on health, figuring out their minimum effective concentrations, improving their distribution to target organs, and increasing their bioavailability have all been major study topics in the last ten years. Despite the strong *in vitro* and *in vivo* evidence for their health advantages, more research is required to examine any potential negative consequences as well as other positive activities. In order to support public health and the demands of customers who are health-conscious, future research should focus on improving the functional value of these vegetables, whether by genetic alteration or the modulation of biochemical pathways (Dhruv *et al.*, 2019).

Broccoli (*Brassica oleracea* var. *italica* L.) also referred to as winter broccoli, heading broccoli, Italian broccoli and Italian Calabrese is a nutritious exotic vegetable belonging to the Cruciferae family. Broccoli (*Brassica oleracea* var. *italica*) and cauliflower (*B. oleracea* var. *botrytis*) are the most extensively cultivated brassica vegetable crops worldwide, covering a combined production area of 1.4 million hectares (FAO, 2020). With the growing emphasis on health, broccoli is becoming increasingly popular and in demand. It is well-known for its numerous health benefits, such as anti-cancer, anti-diabetic, antimicrobial, antioxidant, and antiaging properties.

Despite being known for its remarkable nutritional profile and health-promoting qualities, broccoli is still not widely used in the creation of nutraceuticals. Broccoli, which belongs to the Brassicaceae family, is rich in vitamins, minerals, fiber, and a special variety of phytochemicals like glucosinolates and sulforaphane, which have been connected to a number of health advantages, such as anti-inflammatory, antioxidant, and anticancer properties (Lu *et al.*, 2024). Broccoli's bioactive properties are influenced by genetic variations, cultivation practices, and environmental conditions. Climate change challenges broccoli cultivation, but breeding programs are developing heat-tolerant genotypes. Broccoli's potential as a nutraceutical ingredient is underutilized, but this review aims to explore its bioactive compounds and potential applications in health-focused products. Addressing research gaps can help improve health outcomes.

### **Nutritional and bioactive profile of broccoli**

Broccoli is a nutrient-dense vegetable that has gained significant attention for its role in a well-balanced and healthy diet. Composed of approximately 90% water, 7% carbohydrates, and 3% protein with no fat, a cup of fresh broccoli (about 91g) provides 34 Kcal, 2.5g of protein, 6g of carbohydrates, 1.5g of sugar, 2.4g of fiber, and 0.4g of fat, all while being

cholesterol-free(Syed *et al.*, 2020). It is a low-calorie vegetable (34 kcal per 100g fresh weight) and serves as a rich dietary source of essential minerals such as calcium, phosphorus, potassium, and sodium(Samec, 2019). Broccoli is also packed with vitamins B, C, E, and K, fibers, and numerous health-promoting compounds, including carotenoids ( $\beta$ -carotene and lutein), flavonoids (like kaempferol), hydroxycinnamic acids (such as sinapic and caffeoyl-quinic acid derivatives), and, distinctively, glucosinolates(Mukherjee *et al.*, 2012). Broccoli heads are particularly high in vitamin C (188 mg per 100g) and contain a substantial amount of polyphenols (64.9 mg per 100g) compared to other plant parts like the main stalk, leaves, and roots. These nutrients contribute to broccoli's positive effects in managing overall health and chronic diseases (Ilahyet *al.*, 2020).The major classes of bioactive compounds in broccoli includes fatty acids,aliphaticglucosinolates,indolic glucosinolates, hydroxycinnamic acids and flavonoids.Aliphatic glucosinolates contain the important isothiocyanates called sulforaphane.(Hernandez *et al* 2023).

### **Health benefits of bioactive components**

Broccoli, specifically rich in the bioactive compound sulforaphane, has garnered attention for its role in managing diabetes and improving cardiovascular health. Sulforaphane, a sulfur-rich isothiocyanate, acts as a powerful antioxidant that targets oxidative stress and inflammation, which are critical drivers in the development of chronic diseases such as type 2 diabetes and cardiovascular conditions. (AminuandMuhammed,2023). Sulforaphane has been found to enhance the body's antioxidant defenses by activating the Nrf2 pathway, a key regulator of cellular defense mechanisms. Activation of Nrf2 leads to the production of protective enzymes, such as heme oxygenase-1 and glutathione S-transferase, that reduce oxidative damage and promote detoxification. This process is particularly significant in diabetes management, where oxidative stress and inflammation are major contributors to insulin resistance and pancreatic  $\beta$ -cell dysfunction.

Clinical studies have shown that sulforaphane can mitigate the harmful effects of hyperglycemia by reducing the production of reactive oxygen species (ROS) in type 2 diabetics, ultimately preventing oxidative stress-induced damage to blood vessels and organs. A study highlighted that sulforaphane supplementation improves insulin secretion and enhances glucose tolerance in individuals with type 2 diabetes. In animal models, sulforaphane has been found to restore insulin sensitivity and reduce blood glucose levels, demonstrating its potential as a natural therapeutic agent for diabetes control. Beyond its benefits for diabetes, sulforaphane is also integral in supporting cardiovascular health. It has been shown to inhibit the inflammatory processes that underlie many cardiovascular diseases, such as atherosclerosis, which is driven by chronic inflammation and oxidative stress. Sulforaphane lowers LDL (bad) cholesterol while promoting the increase of HDL (good) cholesterol, which plays a protective role in heart health.

One study demonstrated that regular consumption of broccoli sprouts (100 grams per day) significantly decreased LDL cholesterol and improved HDL levels, particularly in women, highlighting its heart-protective benefits. The reduction in LDL cholesterol is crucial as it helps prevent the accumulation of plaque in the arteries, a leading cause of hypertension and atherosclerosis. Additionally, sulforaphane has been shown to improve vascular function, reduce arterial stiffness, and enhance blood flow, which collectively lower the risk of hypertension and ischemic heart disease.

### **List 1 :Mechanisms of Action**

Bioactive compounds		Health benefits
Flavonoids	Quercetin, kaempferol, and flavonol glycosides	<ul style="list-style-type: none"> <li>- Lowers risk of degenerative diseases</li> <li>- Reduces obesity-related metabolic disorders</li> <li>- Eases allergic nasal symptoms</li> </ul>
Phenolic Acids	Chlorogenic acid, sinapic acid, and ferulic acid derivatives	<ul style="list-style-type: none"> <li>- Reduces inflammation</li> <li>- Alleviates pain</li> <li>- Boosts antioxidant capacity</li> </ul>
Glucosinolates	Glucoraphanin, glucoiberin, glucoraphenin, glucobrassicin, 4-hydroxyglucobrassicin, 4-methoxyglucobrassicin, and neoglucobrassicin	Same as above
Isothiocyanates	Sulforaphane, iberin, and indole-3-carbinol	-Reduces cancer risk

Source :Angelet *al.*, 2019

### **Sulforaphane key nutraceutical compound**

Sulforaphane is one of the most widely studied bioactive compounds in broccoli, primarily recognized for its potent anti-cancer, anti-inflammatory, and antioxidant properties. Initially identified as an antibiotic, sulforaphane was first detected in red cabbage and hoary cress before its cancer-protective benefits were confirmed in broccoli (Tříska *et al.*, 2021). The precursor to sulforaphane, glucoraphanin, is a stable compound found in significant concentrations in broccoli. When broccoli tissues are damaged, such as during chewing or cutting, glucoraphanin is converted into sulforaphane through the action of the enzyme myrosinase, which is released in response to this damage (Miraj, 2016). Notably, mammals lack this enzyme, but the conversion can still occur in the human body thanks to the bacterial microflora in the gut, which contains similar enzymes capable of facilitating this transformation (Yagishita *et al.*, 2019).

This microbial conversion in the gut is particularly important because it enhances the bioavailability of sulforaphane in the colon, making it a valuable focus in understanding glucoraphanin biosynthesis in plants and its potential as a functional compound in human health. Research into sulforaphane has revealed its ability to intervene in various biochemical pathways involved in disease processes, particularly cancer development (Andrea *et al.*,

2022). One of the most significant findings is its dual role in both inhibiting and promoting the activity of certain enzymes. Sulforaphane inhibits Phase I enzymes, which are responsible for the conversion of procarcinogens into carcinogens, while inducing Phase II enzymes, which are involved in detoxifying and eliminating carcinogens from the body (Topcu *et al.*, 2018). This balance helps to prevent the formation and accumulation of cancerous cells.

The compound has shown specific efficacy against breast cancer, where it has been found to down-regulate cell multiplication and self-renewal pathways that are typically active in cancerous tissues. Daily injections of sulforaphane in studies involving immunodeficient xenograft tumors demonstrated that a dose of 50 mg per kg for two weeks reduced aldehyde dehydrogenase-positive cells by more than 50%, a clear indication of its ability to inhibit the proliferation of cancerous cells and induce apoptosis, or programmed cell death, in breast cancer cells (Li *et al.*, 2010). This highlights sulforaphane's potential as an effective treatment option for targeting breast cancer stem cells, which are often resistant to traditional therapies and are a major cause of cancer recurrence.

Beyond cancer, sulforaphane has also shown promising effects in metabolic diseases. Axelsson *et al.* (2017) explored its impact on glucose production, focusing on H4IIE cells, a rat hepatoma cell line. Their research revealed that preincubation with sulforaphane at concentrations ranging from 0.5 to 10  $\mu\text{M}$  over a 24-hour period resulted in a dose-dependent decrease in glucose production. This suggests that sulforaphane could play a role in managing glucose levels and possibly preventing or treating conditions such as type 2 diabetes by reducing the production of glucose in the liver.

In addition to these findings, sulforaphane has gained attention in recent years for its potential to reduce the severity of viral infections, including SARS-CoV-2, the virus responsible for the COVID-19 pandemic. In one study, participants who took capsules containing glucoraphanin, the precursor to sulforaphane, before the onset of COVID-19 symptoms and continued taking them throughout their infection, reported a rapid reduction in symptoms lasting between six and twelve hours after repeated doses. This suggests that sulforaphane may help to alleviate some of the clinical symptoms associated with COVID-19, though further research is needed to fully understand the mechanisms behind this effect (Bosquet *et al.*, 2021).

### **Varietal Influence on Nutraceutical Content**

Different varieties of broccoli have been found to exhibit variations in the types and amounts of bioactive compounds they contain. For instance, a study by Moreno *et al.* (2007) assessed the glucosinolate content of different broccoli cultivars and identified 4-methyl sulphinyl butyl glucosinolate (glucoraphanin) and indol-3-methyl glucosinolate (glucobrassicin) as the primary glucosinolates in all samples. However, cultivars grown in different regions, particularly in Germany, demonstrated higher levels of glucoraphanin (6.6–39.7 mg per 100g fresh weight) and total aliphatic glucosinolates (10.3–42.4 mg per 100g fresh weight). (Aseeya *et al.*, 2023)

Research conducted by Renaud *et al.* (2014) categorized 23 broccoli cultivars into early, mid, and late maturity classes, revealing that late-maturing cultivars had significantly higher glucoraphanin content, while early-maturing cultivars had higher carotenoid concentrations. Porter (2012) compared green and purple sprouting broccoli and found that the latter contained significantly more phenolic and anthocyanin compounds, with anthocyanin levels being six times higher in purple sprouting broccoli.

## **Growth Stages and Nutrient Composition**

The phytochemical content of broccoli also varies with its growth stage. Sprouts, microgreens, and babygreens are stages of growth that influence the concentration of bioactive compounds. Sprouts, harvested within 2–7 days of germination, and microgreens, typically harvested 7–21 days after sowing, both offer high levels of nutrients, but their compositions differ. Microgreens, for example, contain significantly higher levels of ascorbic acid, chlorophyll, and phenolic compounds compared to mature leaves and sprouts (Bhatt *et al.*, 2023). A study by Le *et al.* (2020) found that glucosinolates were more abundant in broccoli sprouts (35.4%) compared to mature plants, while microgreens exhibited a rich profile of essential nutrients and phenolic compounds.

## **Environmental Factors and Cultivation Practices**

Environmental factors, such as temperature and light exposure, profoundly impact the bioactive properties of broccoli. High temperatures during cultivation can reduce glucosinolate content by up to 40%, as demonstrated by Elmogyet *al.* (2019), who observed that broccoli grown at 30°C had significantly lower glucosinolate levels than those grown at 20°C. Other studies, like those from Siomose *et al.* (2022), also highlight that elevated temperatures during growth can lead to undesirable changes in broccoli head characteristics, including reduced head diameter and overall quality.

Light intensity has been shown to influence the growth and phytochemical content of broccoli microgreens. Gao *et al.* (2021) found that microgreens grown under a photosynthetic photon flux density of 50  $\mu\text{mol per m}^2 \text{ per s}$  had the highest fresh weight, but their phytochemical content was lower compared to those grown under higher light intensities. Specifically, the content of chlorophyll, soluble proteins, flavonoids, and glucosinolates increased with higher light intensities.

## **Soil and Hydroponic Systems**

Soil composition and growing conditions also play critical roles in determining the nutrient content of broccoli. For instance, irrigation with saline water (NaCl) has been shown to reduce the levels of both aliphatic and indole glucosinolates in broccoli, as demonstrated by experiments in greenhouse conditions (Nadia *et al.*, 2020). Additionally, the type of cultivation system—such as organic hydroponics, inorganic hydroponics, or aquaponics—affects both the yield and nutrient composition of broccoli. Broccoli grown in inorganic hydroponics showed the highest yields and nutrient content, followed by aquaponics, with organic systems yielding the least (Nadia *et al.*, 2020).

Foliar application of minerals, such as calcium, zinc, manganese, and iron, can also enhance the nutrient content of broccoli, particularly during postharvest storage. A study by El Mogyet *al.* (2019) demonstrated that foliar treatments increased the concentration of essential nutrients in broccoli heads and reduced yellowing and weight loss during storage, thus extending shelf life and maintaining higher levels of bioactive compounds.

## **Breeding and Nutraceutical Enhancement**

Advances in breeding have led to the development of broccoli varieties with enhanced nutraceutical properties. The Cornell Eastern Broccoli Project focused on breeding a heat-tolerant variety suitable for East Coast summers. This resulted in the development of new hybrids with improved yields and resilience under hot conditions (Bjorkman and Pearson, 1998). Moreover, breeding efforts have focused on increasing the glucoraphanin content, a compound linked to cancer prevention. Beneforte, a high-glucoraphanin variety developed through selective breeding programs in the US, Netherlands, and the UK, has been commercialized for its superior health benefits (Traka *et al.*, 2013).

### **Extraction Techniques for Bioactive Compounds**

The extraction of bioactive compounds from broccoli has evolved with advancements in technology. Traditional extraction methods, such as maceration and Soxhlet extraction, require large amounts of organic solvents and long processing times, which are neither cost-effective nor environmentally friendly. Newer methods, such as Ultrasound-Assisted Extraction (UAE) and Microwave-Assisted Extraction (MAE), offer more sustainable and efficient alternatives. UAE, for example, utilizes acoustic cavitation to break down plant cell walls, facilitating the release of bioactive compounds with minimal solvent use (Liu *et al.*, 2022). MAE, on the other hand, uses microwave energy to accelerate the extraction of phenolic compounds from broccoli by-products, yielding higher concentrations of antioxidants and phenolics compared to traditional methods (Garcia and Raghavan, 2022).

Supercritical fluid extraction (SFE) using carbon dioxide is another method gaining popularity due to its efficiency and environmental benefits. Unlike conventional solvent-based methods, SFE reduces the need for toxic solvents and shortens extraction times, making it a viable option for obtaining high-purity extracts from broccoli (Martinez *et al.*, 2020).

### **Conclusion**

Broccoli plant represents a highly promising but underexploited nutraceutical resource. Its a potential powerhouse of bioactive compounds, such as glucosinolates, flavonoids, carotenes, and vitamins that promoting human health. This helps in preventing various chronic diseases, including cancer, cardiovascular conditions, and more. Many more nutraceutical properties hidden in broccoli , to unlock its full potential more exploitation is needed.

Exploring innovative techniques for the extraction and utilization of these compounds, such as nanotechnology and targeted delivery systems, holds great promise. Additionally, understanding the interactions between these phytochemicals and the human body, as well as their optimal dosages, will be vital for harnessing the full nutraceutical potential of broccoli.

As we delve deeper into the era of personalized nutrition and natural remedies, the underexploited nutraceutical potential of broccoli presents an exciting avenue for future research and development. Unlocking the hidden treasures within this common vegetable has the potential to revolutionize preventive and therapeutic strategies in healthcare, leading to a brighter and healthier future for all

To fully exploit broccoli's potential, innovative extraction techniques and technologies, such as nanotechnology and targeted delivery systems, should be further explored. These advanced methods can enhance the bioavailability and efficacy of broccoli's phytochemicals, ensuring that they reach the targeted areas in the human body effectively. Additionally, understanding

the molecular interactions between these compounds and human cells, along with determining their optimal dosages, is crucial for maximizing health benefits

Broccoli's role in the evolving field of personalized nutrition and natural remedies underscores its importance as a functional food. The development of heat-tolerant and nutrient-rich cultivars through advanced breeding techniques will further enhance its nutraceutical potential, especially in the face of climate change.

Research into sustainable and efficient extraction methods, coupled with deeper insights into how these compounds interact with human biology, can unlock its full potential, leading to innovative preventive and therapeutic healthcare strategies.

The future of broccoli as a nutraceutical is bright, with advancements in breeding, cultivation techniques, and extraction methods promising to unlock even greater health benefits. As research continues to explore the complexities of broccoli's bioactive compounds, its role in preventive health strategies will likely expand, particularly in the areas of cancer prevention, anti-inflammatory therapies, and cardiovascular health. The growing consumer demand for functional foods and natural supplements, combined with innovations in personalized nutrition, positions broccoli as a key player in the nutraceutical market.

Looking ahead, further integration of broccoli into functional foods and supplements, along with continued research into its bioactive properties, will likely enhance its role as a health-promoting superfood. Broccoli's potential to combat chronic diseases, coupled with sustainable and innovative production methods, ensures that this humble vegetable will remain at the forefront of nutraceutical research and development in the coming decades.

## References

- Aminu, M. and H. A. Mohammed, (2023). Beneficial role of broccoli and its active ingredient, sulforaphane in the treatment of diabetes. *Phytomedicine Plus*, 3(2), 100431.
- Andrea, M., C. E. Pérez, V. Zambrano and H. Barrientos, (2022). Maximization of Sulforaphane Content in Broccoli Sprouts by Blanching. *Foods*, 11(13), 1906.
- Ángel, A., R. Domínguez-Perles, D. A. Moreno, and C. García-Viguera, (2019). Sorting out the Value of Cruciferous Sprouts as Sources of Bioactive Compounds for Nutrition and Health. *Nutr.* 10(50):77-85.
- Aseeya, W., S. K. Giri, A. Kate, M. K. Tripathi, and M. Kumar, (2023). Enhancing phytochemical parameters in broccoli through vacuum impregnation and their prediction with comparative ANN and RSM models. *Scientific Reports*, 13(1).
- Axelsson, A. S., E. Tubbs, B. Mecham, S. Chacko, H. A. Nenonen, Y. Tang, J. W. Fahey, J. M. Derry, C. B. Wollheim, N. Wierup, M. W. Haymond, S. H. Friend, H. Mulder, and A. H. Rosengren, 2017. Sulforaphane reduces hepatic glucose production and improves glucose control in patients with type 2 diabetes. *Sci. Translational Med.* 9(394): 44-77.
- Bjorkman, T., and K.J. Pearson, 1998. High temperature arrest of inflorescence development in broccoli (*Brassica oleracea* var. *italica*) *J. Exp. Bot.* 49(1):101-106.
- Bella, M. C., S. Toscano, D. Arena, D. A. Moreno, D. Romano, and F. Branca, 2021. Effects of growing cycle and genotype on the morphometric properties and glucosinolates amount and profile of sprouts, microgreens and baby leaves of broccoli and Kale. *Agron.* 11(9): 1685-1689.

- Bhatt, P., S.Sharma,K.Grover, S. Sharma, K. Dharni, and A. S. Dhatt, 2023. Optimization of nutritional composition, bioactive compounds and antioxidant activity in broccoli microgreen Sprinkler using alternate drying techniques. *J. Dairy. Foods Home Sciences* 5(16): 60-65.
- Bousquet, V., H.Blain, W.Czarlewski, T. Zuberbier, R.Torre, N.Pizarro,J.Reynes, A. Bedbrook, J.P. Cristol, A. A. Cruz, A. Fiocchi, T.Haahtela, G. Iaccarino, L.Klimek, P. Kuna, E. Melen, J. Mullol, B. Samolinski, and A.Valiulis, 2021. Efficacy of broccoli and glucoraphanin in COVID-19: From hypothesis to proof-of-concept with three experimental clinical cases. *World Allergy Organ. J.* 14(1): 100-498.
- Cervantes, J., L. G. Noriega, D. I Machado, O. N Baypoli,E. U.Soto, and J. A. Gastelum, 2013. Biochemical composition of broccoli seeds and sprouts at different stages of seedling development. *Int. J.Food Sci. Technol.* 11(11): 88-90.
- Dhruv, J. J, N. J. Patel and S. Parmar, (2019). Nutraceutical Importance of Vegetables and Their Use for Human Health: A Review. *Indian J.Agr.Biochem.* 32(2), 132-142.
- Dogra , R. 2003. Biochemical evaluation of some broccoli (*Brassica oleracea* var. *italica*) cultivars. M. Sc. (Hort.) Diss, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya Palampur - 176 062 (H.P) India , 102p.
- Elmogly, M. M., M. A Wahab, M. B. I Elsayy, and A. Parmar, 2019. Pre-harvest foliar application of mineral nutrients to retard chlorophyll degradation and preserve bioactive compounds in broccoli. *Agron.* 9(11): 7-11.
- FAOSTAT [Food And Agricultural Organisation of United Nations] <https://www.fao.org/faostat/en/#home> [12 JUNE 2020].
- Ferguson, L. R., and R. C. Schlothauer, (2011). The potential role of nutritional genomics tools in validating high health foods for cancer control: Broccoli as example. *Molecular Nutr. Food Res.*56(1), 126–146.
- Gao, M., S. R.Zhang, Y,S. Song, and H. Liu, 2021. Differential effects of low light intensity on broccoli microgreens growth and phytochemicals. *Agron.* 11(3): 537-550.
- Garcia, S. L., and Raghavan, V. 2022 . Microwave assisted extraction of phenolic compounds from broccoli stems, leaves, and florets: Optimization, characterization, and comparison with maceration extraction. *Recent Prog. in Nutr.* 2(2): 1-20.
- Gmizic, D., M.Pinteric,M.Lazarusand,I. Sola, 2023. High growing temperature changes nutritional value of broccoli (*Brassica oleracea* var. *italica*) Seedlings. *Foods*, 12(3): 51- 82.
- Gonçalves, E. M., C. Alegria, and Abreu, M. (2013). Benefits of brassica nutraceutical compounds on human health. *Brassicaceae—Characterization, Functional Genomics and Health Benefits; Lang, M., Ed*, 19-65.
- Hernandez, A., M.Francisco, and L.Zamora,2023. Genus brassica by products revalorization with green technologies to fortify innovative foods: A scoping review. *Foods*. 12(1): 5-6.

- Ilahy, R., I. Z.Tlili, Pek, A. Montefusco, M. W.Siddiqui, F. Homa, C. Hider, T. Him, H.Lajos, and M. S.Lenucci,. 2020. Pre and Post harvest factors affecting glucosinolate content in broccoli. *Frontiers Nutr.* 7(8): 11-22.
- Jain, M., K. K.Mishra, A.Anand, and B. Samarendra, 2023. Impact of organic manures and biofertilizers on yield and quality attributes of broccoli (*Brassica oleracea* var. *italica*) cv-N.S.-50. *Ecol. Environ. Conserv.* 29(02): 904–908.
- Jin, P., D. Yao,F. Xu, H.Wang, and Y. Zheng, 2015. Effect of light on quality and bioactive compounds in postharvest broccoli florets. *Food Chem.* 172(172): 705–709.
- Le, T. N., C. H Chiu., and P.C. Hsieh, 2020. Bioactive compounds and bioactivities of *Brassica oleracea* var. *italica* sprouts and microgreens: An updated overview from a nutraceutical perspective. *Plants* 9(8): 40-46.
- Li, Y., T.Zhang, H. Korkaya, S. Liu, H. F.Lee, B.Newman, Y. Yu, S. G.Clouthier, S. J.Schwartz, M. S. Wicha, and D. Sun, 2010. Sulforaphane, a dietary component of broccoli/broccoli sprouts, inhibits breast cancer stem cells. *Clin. Cancer Res.* 16(9): 2580–2590.
- Liu, Y., D.Zhang, X. Li, J.Xiao, and L.Guo,2022. Enhancement of ultrasound assisted extraction of sulforaphane from broccoli seeds via the application of microwave pretreatment. *Ultrasonics Sonochemistry* 87(5): 10-61.
- Lu, S., Li, Y., Lin, M., Liang, Y. and Zhang, Z. (2024). Profiling the Bioactive Compounds in Broccoli Heads with Varying Organ Sizes and Growing Seasons. *Plants*, 13(10), pp.1329–1329.
- Madhu, A., and A. Kochhar, 2013. Role of nutraceutical enriched broccoli in the management of lifestyle diseases - A review *Int. J. Med. Sci.* 6(2): 69–76.
- Manchali, S., M. K. N. Chidambara and B. S. Patil, (2012). Crucial facts about health benefits of popular cruciferous vegetables. *J. Functional Foods*, 4(1), 94–106.
- Martinez, M., J. Sanchez, I.Linares, M. A.Pedreno, and A. B.Jara,2020. Revalorization of broccoli by products for cosmetic uses using supercritical fluid extraction. *Antioxidants* 9(12): 11-95.
- Miraj, S. 2016. Broccoli (*Brassica oleracea* var. *italica*): Potential candidate in the health management. *Food Chem.* 8(7): 61-65.
- Moreno, D. A., M. Carvajal, C.Berenguer, and , C. Viguera2007. Chemical and biological characterisation of nutraceutical compounds of broccoli. *J. pharma. biomedical analysis* 41(5): 1508-1522.
- Mukherjee, V., M.Voomika, and P. Kumar, 2012. Broccoli an underexploited nutraceutical. *Sci. res. reporter* 2(3): 291-294.

- Nadia, Z., P. Prosun, and M. Salam, 2020. Production potential of broccoli (*Brassica oleracea* var. *italica*) in hydroponics and tilapia based aquaponics. *J.Bangladesh Agric. Univ.* 18(3): 1-12.
- Natella, F., M.Mariateresa, M. Nardini, E. Azzini, F. Maria, and C. Scaccini, 2016. Improvement of the nutraceutical quality of broccoli sprouts by elicitation. *Food Chem.* 201(11): 101–109.
- Porter, Y. 2012. Antioxidant properties of green broccoli and purple-sprouting broccoli under different cooking conditions. *Bioscience Horizons* 5(1): 15-20.
- Ruud, V., Schreiner, M., Krumbein, A., Ciska, E., Holst, B., Rowland, I., De Schrijver, R., Hansen, M., Gerhäuser, C., Mithen, R. and Dekker, M. (2008). Glucosinolates in Brassica vegetables: The influence of the food supply chain on intake, bioavailability and human health. *Mol.Nutr.and Fd. Res.*, 53(S2), pp.
- Renaud, E. N., E. T.Lammerts, M. J.Paulo, F. A. Eeuwijk, J. A. Juvik, M. G.Hutton, and J. R. Myers, 2014. Broccoli cultivar performance under organic and conventional management systems and implications for crop improvement. *Crop Sci.* 54(4): 1539-1554.
- Samec, D., and B. Sondi, 2019. Cruciferous (Brassicaceae) Vegetables. Nonvitamin and Nonmineral Nutritional Supplements 10(4): 195–202.
- Satish, K., S. Sharma, V. Kumar, R. Sharma, A. Minhas, and R. Boddu, (2022). Cruciferous vegetables: a mine of phytonutrients for functional and nutraceutical enrichment. *Current Advances for Development of Functional Foods Modulating Inflammation and Oxidative Stress*, 20(6), 401–426.
- Sarikamiş, G. 2017. Influence of salinity on aliphatic and indole glucosinolates in broccoli (*Brassica oleracea* var. *italica*). *Applied Ecol. Environ. Res.* 15(3): 1781–1788.
- Serrano, M., D. Martinez, F.Guillen, S.Castillo, and D. Valero, 2006. Maintenance of broccoli quality and functional properties during cold storage as affected by modified atmosphere packaging. *Postharvest Biol. Technol.* 39(1): 61–68.
- Siomos, A. S., K. Koularmanis, and P. Tsouvaltzis, 2022. The impacts of the emerging climate change on broccoli (*Brassica oleracea* var. *italica* ) *Crop. Hortic.* 8(11): 10-32.
- Siomos A.S., P.P.Papadopoulou, C.C.Dogras, 2004. Compositional differences of stem and floral portions of Broccoli heads. *J. Veg. Crop Product.* 10(2):107-118.
- Syed, U.R., S.Sivakumar, K. M.Moni, M. A. Weam, 2023. Broccoli: A multi-faceted vegetable for health: An in depth review of its nutritional attributes, antimicrobial abilities, and anti inflammatory properties. *Antibiot.* 12(7): 1157–1157.

- Topcu, Y., A. Dogan, H. Sahin, E. Polat, Z. Kasimoglu, and M. Erkan, 2018. Morphological and biochemical responses of broccoli florets to supplemental ultraviolet-B illumination. *Agric. Ecosyst. and Environ.* 259(10): 1-10.
- Torres, N., T. Talavera, H. Andrews, A. Contreras, and N. Pacheco, 2017. Ultrasound assisted extraction for the recovery of phenolic compounds from vegetable sources. *Agron.* 7(3): 47.
- Traka, M. H., S. Saha, S. Huseby, S. Kopriva, P. G. Walley, G. C. Barker, and R. F. Mithen, 2013. Genetic regulation of glucoraphanin accumulation in Beneforte broccoli. *New Phytologist* 198(4): 1085-1095.
- Tříska, J., J. Balík, M. Houška, P. Novotná, M. Magner, N. Vrchotová, P. Hic, L. Jílek, K. Thorová, P. Šnurkovič, and I. Sural, (2021). Factors Influencing Sulforaphane Content in Broccoli Sprouts and Subsequent Sulforaphane Extraction. *Foods*, 10(8)
- Yagishita, Y., W. Jed, A. T. Fahey and W. K. Thomas 2019. Broccoli or sulforaphane: is it the source or dose that matters. *Molecules* 24(19): 35-93.
- Yuan, G. F., B. Sun, J. Yuan, and Q. M. Wang, 2009. Effects of different cooking methods on health promoting compounds of broccoli. *J. Zhejiang Univ. Sci.* 10(8): 580-588.