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Exploring broccoli's valuable bioactive phytochemicals and their biological activities

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Abstract

Currently, consumers prefer nutrient-rich foods for health benefits. In this context, Broccoli, a cruciferous plant, in particular, is consumed worldwide as sprouts, and vegetables. The high bioactive ingredients like vitamins, vital minerals, phenolic compounds, glucosinolates, and others—have made it popular. Broccoli's nutritional value and pharmacological benefits are driving up its appeal day by day. Due to its many biologically active metabolites, broccoli's phytochemical makeup has been widely studied recently. There is a well-known positive correlation between secondary metabolites and their health benefits. Scientists recommend it for obesity, type-2 diabetes, cardiovascular disease (CVD), cancer, and osteoporosis. Many in vitro and in vivo researches on Broccoli showed a variety of noteworthy biological qualities, like anti-obesity, antioxidant, anti-inflammatory, anticancer, antimicrobial, anti-inflammatory, and antidiabetic effects. All these bioactive characteristics of Broccoli make it more valuable in the treatment of man. This review addresses an updated summary of bioactive components, bioactivities, and pertinent mechanisms of action of broccoli derivatives. By evaluating broccoli's wide range of nutrients, this review paper sought to determine its potential health advantages. Furthermore, it will also aid consumer food choices and nutraceutical and functional food applications.

Keywords: Broccoli, Bioactive compounds, Biological activities, Glucosinolates

1. Introduction

Over the past 20 years, population growth and environmental degradation have highlighted critical need of sustainable agricultural output for human nutrition (Godfray and Garnett, 2014). Due to rising food and agricultural output, water, soil occupation, herbicides, chemical fertilizers, pesticides, and food waste disposal have cost the economy, ecosystem, and human health (Weber, 2017). Thus, the agriculture and food businesses must overcome a significant obstacle to reach the sustainable development goals of providing food demand while minimizing adverse environmental impacts (Aschemann-Witzel and Peschel, 2019). Additionally, new food sources with high nutrient content and health benefits are sought due to growing public awareness of healthy lifestyles (Butkutė et al., 2018).

Consequently, nutritional foods and nutraceuticals are gaining popularity since they provide basic nutrition and reduce risk of chronic diseases (Gupta et al., 2013). Nutrition and health are closely connected. Maintaining good health and lowering the chances of many diseases require eating a balanced diet. Health and nutrition experts have long recommended a diet rich in fruits and vegetables. Hence, it is crucial for human society to consume particular fruits and vegetables in order to prevent certain diseases (Murphy et al., 2014). Numerous studies suggest eating natural vegetables may help maintain heart health. Consuming lycopene and beta-carotene, for instance, reduce risk of heart disease (Jacques et al., 2013).

In this context, Broccoli (*Brassica oleracea* L. var. *italica*), an annual, herbaceous vegetable belonging to the family Cruciferae is a nutritious food source and commonly grown for its rigid, terminating crowns of green flower buds at the tips of firm palatable stalks (Siomos et al., 2022). In addition, it is low in calories, high in fiber, and abundant in vitamins, minerals, and other vital compounds (Hu et al., 2004). Broccoli's antibacterial, antioxidant, immunomodulatory, anticancer, liver-protective, cardioprotective, and anti-amnesic properties are widely known in the medical community (Pacheco-Cano et al., 2018; Hu et al., 2004; Hwang and Lim, 2015; Mahn and Reyes, 2012; Park et al., 2016; Vinha et al., 2015; Owis, 2015).

2. Bioactive Compounds

2.1 Glucosinolates (GSLs) and Sulforaphane (SFN)

GSLs are crucial secondary metabolites classified by amino acid precursors into aromatic, aliphatic, and indole groups (Blažević et al., 2020; Wittstock and Halkier, 2002). Although GSLs are chemically stable, post-myrosinase isothiocyanates have varied biological actions (Rask et al., 2000). GSLs make broccoli anti-cancer. GSLs also affect flavor, disease resistance, and insect resistance (Bell et al., 2018). Strong and nontoxic anti-cancer compounds from broccoli are glucoraphanin (GRA), an aliphatic GSL, and its decomposition product, is SFN (Soundararajan et al., 2018). **Figure 1** displays generalized Glucosinolate hydrolysis.

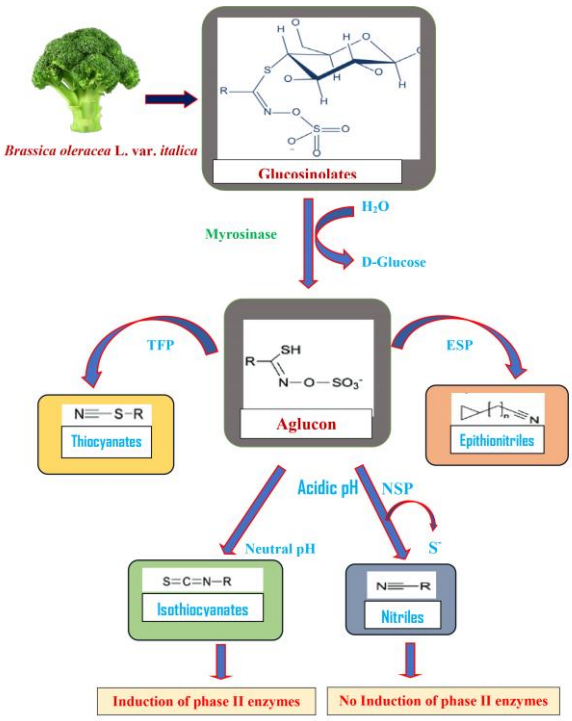

Figure 1: General hydrolysis of Glucosinolates. Myrosinase hydrolyzes glucoseolates to produce unstable aglycones. Depending on the presence of specifier proteins [thiocyanate-forming proteins (TFP), epithiospecifier proteins (ESP), and nitrile-specifier proteins (NSP), these aglycones can spontaneously generate isothiocyanates or other hydrolysis products].

The 22 GLS compounds found in broccoli sprouts and microgreens are shown in **Table 1**.

Table 1: List of glucosinalates identified in broccoli.

Sl no.	Trivial name	Chemical name	Molecular formula	Molecular weight (g/mol)	Reference
		Aliphatic glucosinolates			
01.	Glucoiberin	3-Methylsulfinylpropyl	$C_{11}H_{21}NO_{10}S_3$	423.5	Baenas et al., 2012; Baenas et al., 2017a; Moreira-Rodríguez et al., 2017.
02.	Sinigrin	2-Propenyl	$C_{10}H_{17}NO_9S_2$	397.5	Baenas et al., 2012; Kestwal et al., 2011; Rychlik et al., 2015; Guo et al., 2018.
03.	Glucoraphenin	4-Methylsulfinylbutyl	$C_{12}H_{21}NO_{10}S_3$	437.5	Baenas et al., 2017a.

04,	Glucoiberverin	3-Methylthiopropyl	$C_{11}H_{21}NO_9S_3$	406.5	Baenas et al., 2012.
05.	Progoitrin	(2R)-2-hydroxy-3-butenyl	$C_{11}H_{19}NO_{10}S_2$	389.4	Baenas et al., 2012; Moreira-Rodríguez etal., 2017; Rychlik et al., 2015; Guo et al., 2018.
06.	Glucoerucin	4-Methylthiobutyl	$C_{12}H_{23}NO_9S_3$	421.5	
07.	Gluconapin	3-Butenyl	$C_{11}H_{19}NO_9S_2$	373.4	
08.	Epiprogoitrin	(2S)-2-hydroxy-3-butenyl	$C_{12}H_{15}NOS_2$	389.4	El Sayed et al., 1996.
09.	Gluconapoleiferin	2-Hydroxy-4-pentenyl	$C_{12}H_{21}NO_{10}S_2$	403.4	
10.	Glucoalyssin	5-Methylsulfinylpentyl	$C_{13}H_{25}NO_{10}S_3$	451.5	Baenas et al., 2012; Guo et al., 2011.
11.	Glucobrassicanapin	4-Pentenyl	$C_{12}H_{21}NO_9S_2$	386.4	Yamada-Kato et al., 2012.
12.	Glucococchlearin	1-methylpropyl glucosinolate	$C_{11}H_{21}NO_9S_2$	375.4	
13.	Glucosativin	[(Z)-(5-sulfanyl-1-{[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl) oxan-2-yl] sulfanyl}pentylidene)amino]oxy}sulfonic acid	$C_{11}H_{21}NO_9S_3$	407.4	Lelario et al., 2012.
14.	Glucoconringianin	3-hydroxy-3-methyl- N - sulfooxybutanimidothioate	$C_{11}H_{21}NO_9S_2$	391.4	
15.	Glucohirsutin	8-Methylsulfinyloctyl glucosinolate	$C_{16}H_{31}NO_{10}S_3$	492.6	Kestwal et al., 2011.
16.	Glucojiaputin	1- Methyylethyl glucosinolate	$C_{12}H_{23}NO_9S_2$	361.4	Lelario et al., 2012.
		Aromatic glucosinolates			
17.	Gluconasturtiin	2-Phenylethyl	$C_{15}H_{21}NO_9S_2$	423.45	Baenas et al., 2012.
18.	Glucosinalbin	[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-(hydroxymethyl)oxan-2-yl] (1E)-2-(4-hydroxyphenyl)-N-sulooxyethanimidothioate	$C_{14}H_{19}NO_{10}S_2$	425.4	

Indolic glucosinolates					
19.	4-Hydroxy glucobrassicin	4-Hydroxy-3-indolylmethyl	$C_{16}H_{20}N_2O_{10}S_2$	464.5	Baenas et al., 2012; Baenas et al., 2017a; Moreira-Rodríguez et al., 2017; Clarke et al., 2011; Guo et al., 2011
20.	Glucobrassicin	3-Indolylmethyl	$C_{16}H_{20}N_2O_9S$	448.5	
21.	Neoglucobrassicin	*N*-methoxy-3-indolylmethyl	$C_{17}H_{22}N_2O_{10}S_2$	478.5	
22.	4-Methoxy glucobrassicin	4-Methoxy-3-indolylmethyl	$C_{17}H_{22}N_2O_{10}S_2$	478.5	

Glucoraphanin, glucoiberin, glucoerucin, glucobrassicin, and neoglucobrassicin are the most prevalent GLSs among these substances (Pérez-Balibrea et al., 2010). Specifically, glucoraphanin comprised more than half of the total GLSs content, measured at 605–1172 mg/100 g of fresh weight (Guo et al., 2014; Yang et al., 2016a). According to Clarke et al. (2011), the bioactive molecules in cruciferous vegetables are not GLSs but the byproducts of their hydrolysis (Clarke et al., 2011). Making this distinction is crucial. GLSs have the potential to be hydrolyzed by the enzyme myrosinase into a wide range of breakdown products in the event that plant tissues are subjected to mechanical injury. These degradation products include isothiocyanates (ITCs), thiocyanates, nitriles, epithionitriles, along with oxazolidines. ITCs have powerful anticarcinogenic effects (Guo et al., 2014). Different compounds were produced under different enzymatic conditions. Epithiospecifier proteins and a pH of less than 6.5 encourage the synthesis of nitrile while preventing the production of SFN. Nitrile is promoted when $2 < pH < 5$ when Fe^{2+} and nitrile-specifier proteins are present. Isothiocyanate synthesis is promoted when pH is greater than 8 and thiocyanate-forming protein is present. The formation of SFN is only promoted when pH is kept within the neutral range (Shokri et al., 2021; Sikorska-Zimny and Beneduce, 2021). As was indicated before, the most common GLSs found in broccoli seedlings are glucoraphanin, glucoerucin, and glucobrassicin. These GLSs are changed into SFN, erucin, and iberin, respectively, by the process of enzymatic conversion (Clarke et al., 2011). SFN naturally activates the phase 2 enzymes that detoxify carcinogens in humans and animals. This means that it may reduce the risk of getting a number of cancers, especially those of the bladder, colon, and lungs (Baenas et al., 2015). According to the findings, the total amount of ITC that was found in broccoli seedlings was around 11 mg/100 g of Fresh weight. Moreover, it was stated that these seedlings have 90% SFN (Baenas et al., 2017a; Guo et al., 2013). A proposed role for SFN in tumor suppression is depicted in Figure 2, along with its conversion from glucoraphanin.

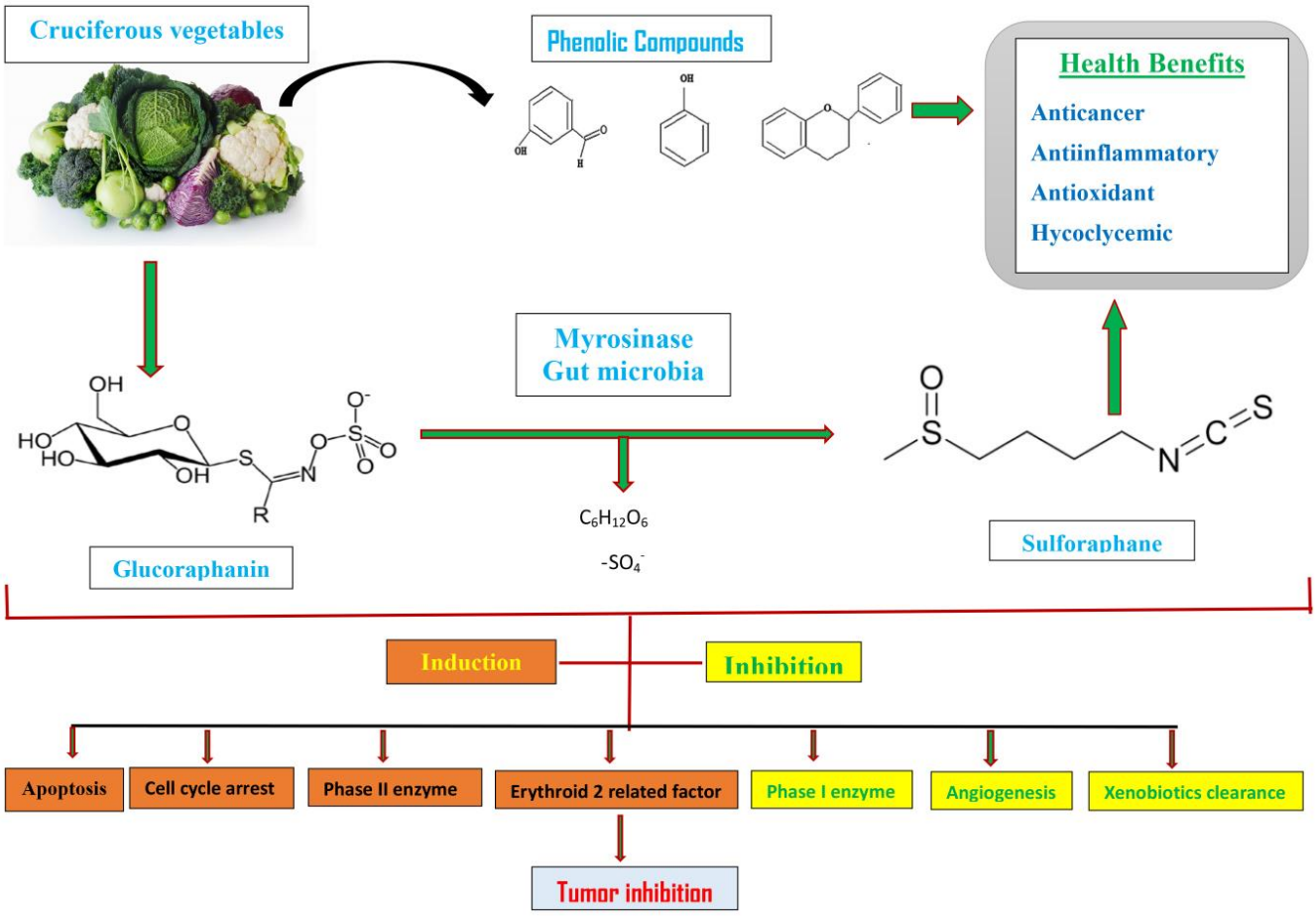

Figure 2: The transformation of Glucoraphanin into Sulforaphane and its potential involvement in inhibiting tumor growth

2.2 Phenolic compounds

Besides GLSs and ITCs, cruciferous vegetables such as, broccoli, include phenolic compounds (**Table 2**).

Table 2: List of phenolic compounds in broccoli sprouts.

Sl no.	Chemical name	Molecular formula	Molecular weight	Ref.
		Phenolic acid		
01	Ferulic acid	$C_{10}H_{10}O_4$	194.18	Le et al., 2019; Pasko et al., 2018a; Gawlik-Dziki et al., 2012a; Pająk et al., 2014

02	Benzoic acid	$C_7H_6O_2$	122.12	Gawlik-Dziki et al., 2012a.
03	Sinapic acid	$C_{11}H_{12}O_5$	224.21	Baenas et al., 2012; Moreira-Rodríguez et al., 2017; Paśko et al., 2018a.
04	Salicylic acid	$C_7H_6O_3$	138.12	Gawlik-Dziki et al., 2012a.
05	Sinapoyl malate	$C_{15}H_{16}O_9$	340.28	Moreira-Rodríguez et al., 2017.
06	Protocatechuic acid	$C_7H_6O_4$	154.12	Pająk et al., 2014.
07	Chlorogenic acid	$C_{16}H_{18}O_9$	354.31	Baenas et al., 2012; Paśko et al., 2018a; Pasko et al., 2018b.
08	Gentisic acid	$C_7H_6O_4$	117.14	Paśko et al., 2018a; Pasko et al., 2018b.
09	Caffeoyl-quinic acid	$C_{16}H_{18}O_9$	354.31	Moreira-Rodríguez et al., 2017.
10	Digalloyl hexoside	$C_{20}H_{20}O_{14}$	484.4	
11	1,2-Diferuloylgentiobiose	$C_{32}H_{38}O_{19}$	694.6	
12	Gallotannic acid	$C_{76}H_{52}O_{46}$	1701.19	
13	1,2-Disinapoylgentiobiose	$C_{34}H_{42}O_{19}$	754.7	
14	2-Feruloyl-1,2'-disinapoylgentiobiose	$C_{44}H_{50}O_{22}$	754.7	
15	Gallic acid hexoside	$C_{13}H_{16}O_{10}$	170.12	
16	1,2-Disinapoyl-1-ferulolylgentiobiose	$C_{44}H_{50}O_{23}$	754.7	
17	Caffeic acid	$C_9H_8O_4$	180.16	Le et al., 2019; Pasko et al., 2018b; Di Bella et al., 2020.

18	Esculetin	$C_9H_6O_4$	178.14	Le et al., 2019
19	Vanillic acid	C_8H_8O	168.15	Pająk et al., 2014
		Flavonoids		
20	Robinin	$C_{33}H_{40}O_{19}$	740.66	Baenas et al., 2012; Moreira-Rodríguez et al., 2017; Le et al., 2019; Pasko et al., 2018b; Pająk et al., 2014; Di Bella et al., 2020.
21	Apigenin	$C_{15}H_{10}O_5$	270.24	
22	Myricetin	$C_{15}H_{10}O_8$	318.23	
23	Kaempferol	$C_{15}H_{10}O_6$	286.24	
24	Astragalin	$C_{21}H_{20}O_{11}$	448.38	
25	Luteolin	$C_{15}H_{10}O_6$	286.24	
26	Quercetin	$C_{15}H_{10}O_7$	302.23	
27	Rutin	$C_{27}H_{30}O_{16}$	610.51	Rychlik et al., 2015.

Polyphenols help plants resist diseases and UV radiation. These secondary metabolites are produced by plants via the shikimate and phenylpropanoid pathways (Abellán et al., 2019). Major phenolic compounds found in broccoli seedlings include flavonoid glycosides and hydroxycinnamic acids (Moreira-Rodríguez et al. 2017; Gawlik-Dziki et al. 2012a).

2.3 Selenium (Se)

Se, a crucial trace element included in the DNA code, shows its biological significance (Rayman, 2000). Like other plants, broccoli accumulates Se (Ellis and Salt, 2003). This trait is linked to better health and fewer cancers (Finley et al., 2000). Se directly or indirectly acts as antioxidant. Witte et al. (2001) found that decreased Se metabolism increased CVD and cancer risk. Some chemical versions of Se minimize cancer risk (Rayman et al., 2008).

Ip et al. (2000) and Finley and Davis (2001) found that organic Se compounds, especially SMSeC, are more powerful chemoprotective agent than sodium selenite and selenomethionine at doses of 1 to 3 mg Se/kg in humans (Abdulah et al., 2005). SMSeC's monomethylated Se molecules may explain its chemoprotective effects. SMSeC, a nonproteinogenic amino acid, protects against cancer chemotherapy fully (Wachowicz et al., 2001). As a powerful antioxidant, Se boosts immunity and lowers CVD risk (Alissa et al., 2008). Prenatal Se supplementation decreases blood pressure, according to Franco et al. (2009). Lubos et al. (2010) found that heart patients with low Se levels had a greater risk of acute coronary syndrome death.

2.4 Other compounds

Broccoli sprouts and microgreens, are rich in vital nutrients which are essential for body's regular processes like DNA synthesis, energy production and biochemical pathways (Turne et al., 2020; Jahangir et al., 2009). However, compared to glucosinolate and phenolic chemical studies, broccoli

seedling nutritional makeup and germination changes have been studied less. Studies (Moreira-Rodríguez et al., 2017; Vicas et al., 2019; Guo et at., 2011; Yanaka, 2018) have shown that broccoli sprouts are especially high in minerals (potassium, magnesium, calcium, and Se), pigments (carotenoids and chlorophylls), vitamins (Vit-A, C, K, and folic acid), and other vital nutrients (dietary fiber, amino acids, and fatty acids). It has been found that conjugated double bonds in long polyene chains can block reactive oxygen species (ROS) and minimize oxidative damage, making them immunomodulatory and lipophilic antioxidants. Carotenoids may protect degenerative diseases such as diabetes, skin damage, CVD, and cancer. Broccoli contains three primary carotenoids: lutein, zeaxanthin, violaxanthin, and neoxanthin (Moreira-Rodríguez et al. 2017). Beta-carotene is the carotenoid most investigated in broccoli sprouts and microgreens for medical benefits (Mewis et al., 2012).

3. Biological Activities

Over the years, researchers have extensively studied the positive effects of Broccoli's bioactive components, such as its ability to act as an antioxidant, anticarcinogenic, antibacterial, and anti-inflammatory agent. Laboratory studies and clinical trials in animals have evaluated these capacities (Le et al., 2019; Yang et al., 2016b; Bahadoran et al., 2013).

3.1 Anti-cancer activity

Glutathione (GSH) levels in cancer cells are higher than in healthy cells. In cancer cells, GSH concentrations are four times greater than in healthy cells and over 1,000 times higher than in extracellular fluid. Tenfold higher amount is found in cancer cells (Kalinina and Gavriliuk, 2020). Glutathione S-transferase uses SFN and GSH in cancer cells to produce SFN-GSH. SFN-GSH uses g-glutamyltranspeptidase, cysteine glycinase, and N-acetyltransferase to produce SFN-Cys-Gly, SFN-Cys, and SFN-NAC. Upon entering the cell, SFN quickly combines with GSH to generate SFN-GSH, which the cell accumulates. The high GSH level of carcinoma cells boosted SFN production and increased its anti-cancer activity (Gu et al., 2022). SFN's primary mechanism of action against cancer is the inhibition of histone deacetylase (HDAC). Multiple research (Chen et al., 2014; Jiang et al., 2016; Bär et al., 2022) have demonstrated that SFN hinders HDAC activity, hence impeding cell growth and promoting programmed cell death. This process results in the suppression of E2F3 and Ki-67, as well as the activation of p21, bax, and caspase-3 in cancerous cells. When SFN (20-40 mM) disrupts the mitochondrial membrane, it may cause apoptosis in different cancer cell types by releasing cytochrome c, Smac/DIABLO, and AIF from the mitochondria. Protein kinase B (PKB, Akt) and ERK1/2 are activated by SFN (40 mM), which results at an end to the cell cycle and apoptosis and induces apoptosis (Choi and Singh, 2005). Additional research (Rudolf et al., 2009) has demonstrated that SFN may induce apoptosis through JNK and p38. Additionally, it has been shown that SFN can damage the endoplasmic reticulum, which in turn can activate the effector proteins calapsin, caspase-12, caspase-9, and caspase-3 in that order (De Gianni and Fimognari, 2015). The mechanism of anti-cancer activity of SFN is diagrammatically shown in **Figure 3**.

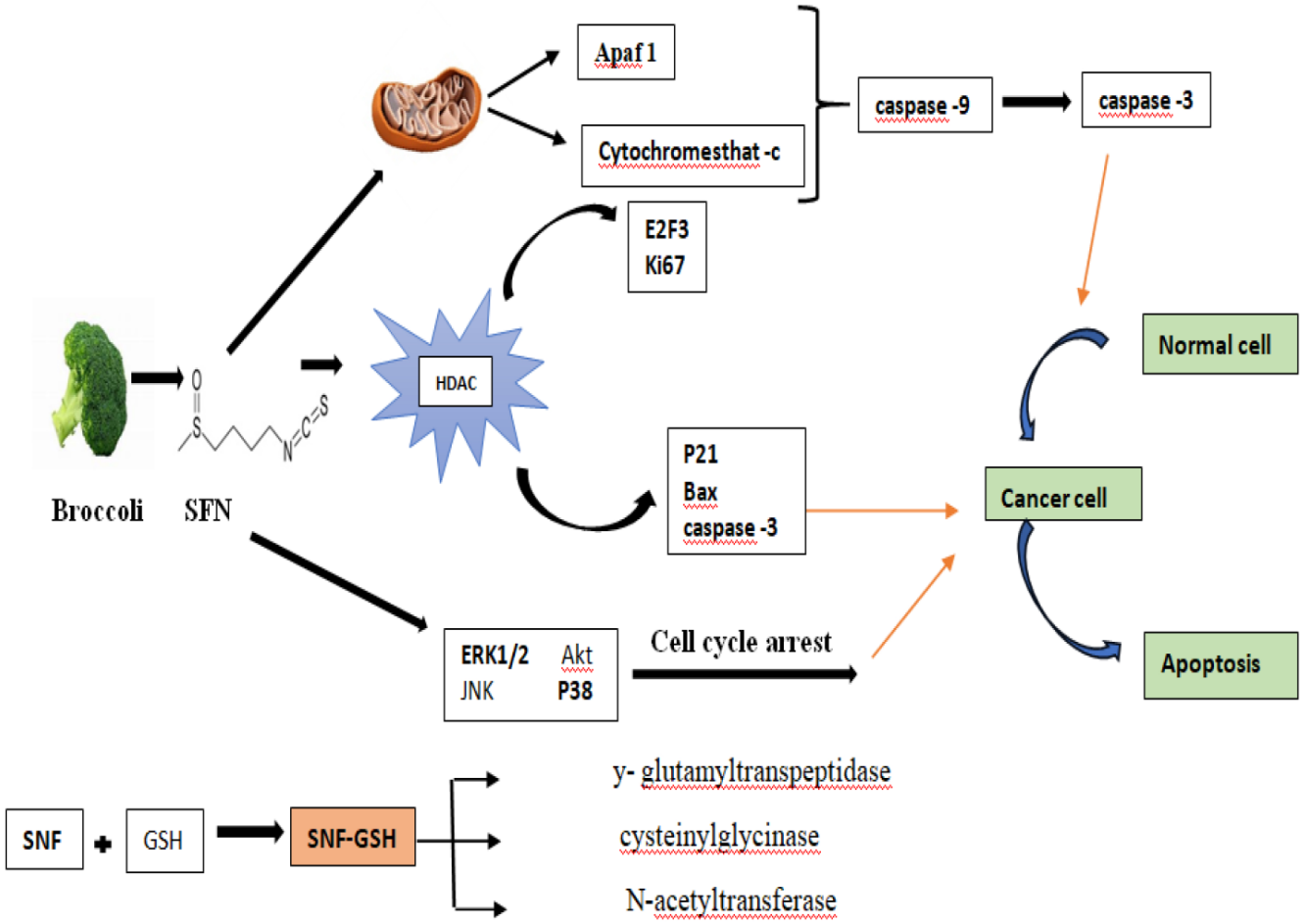

Figure 3: Mechanism of anti-cancer activity of SFN [GSH – Glutathione, HDAC – Inhibitory Effect on Histone Deacetylase].

3.2 Antioxidant activity

ROS production damages biomolecules and leads to chronic diseases such as neurological disorders, CVDs, and age-related malignancies (Uttara et al., 2009). The body creates a lot of ROS due to nicotinamide adenine dinucleotide phosphate oxidases, according to recent research. Further cellular sources of ROS include lipoxygenases, cytochrome P450, neutrophils, monocytes, endothelial cells, and nitric oxide synthases (Bardaweel et al., 2018). ROS affects chronic inflammation, metabolic diseases, oxidative stress/regulation, and normal physiological processes differently. Targeting ROS is linked to antioxidant, anti-inflammatory, antidiabetic, and anti-obesity therapy (Alfadda and Sallam, 2012). Natural or synthetic antioxidants can remove free radicals, inhibit ROS formation, and scavenge ROS (Uttara et al., 2009). Broccoli contains several antioxidants, including carotenoids, phenolic compounds, and vitamins (Jang et al., 2015). Antioxidants neutralize oxidative stress, preventing DNA damage that could lead to cancer. Cells and tissues need antioxidants to prevent oxidative damage. Besides preventing mutations and aberrations, this biological defense can avert cancer. Scavenging free radicals and reducing oxidative stress, antioxidants improve cellular function and integrity and may reduce cancer risk. The body's antioxidant and anti-inflammatory actions are linked. Notably, cancer is

directly linked to chronic inflammation. Antioxidants reduce chronic inflammation caused by oxidative stress and protect body from various diseases. (Rizwan et al., 2014).

3.3 Anti-Inflammatory activity

The immune system's natural reaction to defend the body against damage and infection is inflammation. However, chronic inflammation can cause arthritis, heart disease, and cancers. Antioxidants, phytochemicals, and other bioactive elements reduce inflammation. Broccoli contains SFN, which may alleviate inflammation by blocking inflammatory enzymes (Nandini et al., 2020). Research suggests that it boosts antioxidant enzyme synthesis and protects cells from inflammation-related damage (Santín-Márquez et al., 2019; López-Chillón et al., 2019). Chronic inflammation promotes cancer cell proliferation. Prolonged inflammation may increase growth factors and cytokines, which encourage cell division and help the tumor, establish new blood vessels. Inflammatory cells produce enzymes that damage the extracellular matrix, allowing cancer cells to invade nearby tissues and spread to other organs. Chronic inflammation is connected to many cancers (López-Chillón et al., 2019; Hwang and Lim, 2014). Chronic gastrointestinal inflammation, such as Crohn's disease and ulcerative colitis, raises colorectal cancer risk. In addition, chronic hepatitis B or C infection can induce liver inflammation and malignancy. Also, long-term human papillomavirus infections can inflame the cervix and increase cervical cancer risk (Frazer, 2004).

3.4 Antidiabetic activity

Broccoli supplements type 2 diabetes treatment and prevents its long-term effects (Ares et al., 2013). Several studies evaluated the health benefits of microgreens and broccoli sprouts for diabetics. A novel study examined how broccoli sprouts powder affects insulin resistance in type 2 diabetics. Broccoli sprout powder containing a lot of SFN reduced serum insulin levels and helped with diabetes (Bahadoran et al., 2012b). A recent study found that early broccoli sprout SFN may treat type 2 diabetes. It may activate peroxisome proliferators-activated receptors, which manage glucose balance in high blood sugar and oxidative stress (Bahadoran et al., 2013).

3.5 Anti-Obesity activity

Obesity is connected to metabolic diseases like heart disease and type 2 diabetes, making it a global health issue. Several studies have demonstrated that broccoli sprouts regulate lipid metabolism and reduce obesity. A double-blind clinical trial found that type 2 diabetics supplementing with broccoli sprout powder improved lipid profiles and the ratio of oxidized to low-density lipoprotein, risk factors for obesity and CVD (Bahadoran et al., 2012a). SFN's Nrf2 pathway activation may help broccoli sprouts control lipid metabolism (Bahadoran et al., 2013). Study suggests that broccoli sprout glucose may minimize lipid accumulation and increase Nrf2 activation. It reduces obesity and diabetes by decreasing gluconeogenesis and lipogenesis gene activity (Xu and Ota, 2018).

3.6 Anti-neurodegenerative disorders

Neuroprotective isothiocyanate SFN is produced from glucosinolate glucoraphanin. Parkinson's and Alzheimer's benefit from SFN's Nrf2/ARE pathway activation preventing neurodegeneration. Additional symptoms include oxidative stress, neuronal loss, and inflammation. Thus, broccoli may prevent neurodegenerative illnesses (Tarozzi et al., 2013).

3.6 Against asthma

SFN can reduce nasal irritation. It also decreases asthma and allergy symptoms from particle pollution. A study found that 100-200 g of broccoli with SFN can improve asthma and allergies. Thus, broccoli with glucoraphanin is therapeutic (Heber et al., 2014).

3.7 Other effects

Broccoli has been studied in vitro, in vivo, and clinically for additional health benefits. Broccoli sprouts are rich in bioactive compounds that inhibit Xanthine Oxidase (XO) which may treat gout and other XO-induced illnesses (Gawlik-Dziki et al., 2012b). XO converts xanthine and hypoxanthine to uric acid. Placental insufficiency-related brain damage in newborn rats may be prevented by broccoli sprout supplementation during pregnancy and the first few days of life. The findings suggest a unique way to prevent cerebral palsy and placental insufficiency (Black et al., 2015). Broccoli sprout extracts showed opioid-mediated analgesia and antinociception in two in vivo nociception experiments. This study suggests broccoli sprouts may relieve pain (Baenas et al., 2017b).

4. Conclusion

In recent years, broccoli has become popular and their health-promoting components have been isolated to use them in culinary and pharmaceutical products. Among the different phytochemicals of broccoli the main ingredients are GSLs and their hydrolysis products, followed by phenolic compounds with a wide spectrum. Earlier studies have focused on Broccoli's biological qualities, including their anti-inflammatory, anti-cancer, antibacterial, and antioxidant properties and their potential benefits for cancer, diabetes, neurological disorders and obesity patients. Their toxicity is usually low. Hopefully, more bioactive phytochemicals will be obtained soon from Broccoli and will be separated, and analyzed. However, to confirm Broccoli's health benefits, properly structured clinical trials are needed.

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