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An updated overview on certain plants of family Brassicaceae: Traditional uses, Phytochemistry and Pharmacological activities

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Abstract

Medicinal plants are widely recognized as an important source for a huge number of potentially bioactive chemical constituents which developed as drugs with precise pharmacological activities. Family Brassicaceae (Cruciferae or mustard family) is one of the most important families in plant kingdom and medical fields, which is served as a reservoir of nutraceuticals as vitamins, minerals, dietary fiber, phytochemicals and antioxidants. We are focused on certain plants of family Brassicaceae, which are commonly consumed in Egypt (Brassica rapa subsp rapa, Eruca sativa L. and Raphanus sativus L.). These plants are considered a part of a traditional daily food for Egyptians. There were numerous studies that indicate the potential use of these plants. The present review was performed to give an updated, detailed and critical survey of the literatures, which have been reported on phytochemical constituents, traditional uses and biological activities of these plants in family Brassicaceae. Furthermore, this review aims to emphasize existing knowledge gaps and propose future research guidelines to explore novel bioactive compounds, comprehend their mechanisms of action, and assess their valuable therapeutic applications through innovative pharmacological and clinical studies.

Keywords: Brassicaceace; *Brassica rapa; Eruca sativa; Rapanus sativus*; Phytoconstituents; Biological activities.

1. Introduction

Phytochemicals present in fruits, vegetables, teas, spices and medicinal herbs protect humans from many diseases such as stroke, cardiovascular diseases and cancer [1]. Recent studies focused on the effect of phytochemicals on human health and their abundant role as antioxidants, anticancer and hypoglycemic agents. According to World Health Organization, medicinal plants are still the best and the important source of distinctive drug discovery [2]. The Brassicaceae family, also known as the cabbage or mustard family, includes about 372 genera and 4,060 species, popularly grown in temperate regions. It comprises nutritionally and medicinally important vegetables like cabbage, kale, broccoli, turnip, radish, and watercress [3]. These vegetables are rich in bioactive secondary metabolites, including glucosinolates, flavonoids, and polyphenols, which contribute to preventing cancer, cardiovascular diseases, metabolic disorders, and chronic conditions like asthma and Alzheimer's[4].

Brassica rapa subsp rapa, native to the genus *Brassica* known as turnip. It is a biennial, edible, out-crossing, annual plant and is one of the earliest cultivated vegetables which broadly consumed for human nutrition [5]. It is used in the folk medicine due to its chemical composition as a rich source of glucosinolates, phenolic compounds, organic acid, flavonoids, sulfur compounds and volatiles [6]. Its sharp and potent flavor is closely associated with the high concentration of glucosinolates and sulphur metabolites in the plant. In Egypt, turnip is known as (Left) and usually its roots are used for human food consumption but nowadays leaves are also used in making traditional dishes.

Raphanus sativus L., known as radish; is a small-sized root vegetable. Radish is a species belonging to the genus *Raphanus.* It was extensively cultivated in Egypt during the time of the Pharaohs before the pyramids were built and was popular in ancient Rome as well. The word "radish" is a derivation of the Latin word "radix," or root. Usually, radish is mainly used in salad preparation and eaten raw as a crunchy vegetable. The surface color of radish can vary from white in Asia to red in Europe through purple green and black, while its flesh is white in most European and Asian crops [7]. Parts of radish (roots, leaves and sprouts) have a wide concern due to their high medicinal and nutritional importance. Various reports have recorded the antimicrobial, hepatoprotective, anticancer, antioxidant and antidiabetic activities of radishes [8].

Eruca sativa L. is a leafy vegetable growing crop with dark green color and a strong, pungent and peppery flavor. It is known by other synonym names, including rocket salad, arugula, Jarjeer and Taramira [9]. It was found since Roman times in the Mediterranean area. The leaves of E. sativa are increasingly consumed pure by humans either alone or as part of mixed

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fresh salads. It is known to be diuretic, anti-inflammatory, antibacterial and anticancer agent [10]. It has an aphrodisiac property [11].

In this work, we have compiled and updated traditional knowledge, phytochemical properties, pharmacological insights, and key characterizations of these species. Our aim is not only to represent the existing documented data, but also to identify critical gaps that require further research. By analyzing these findings, we highlight areas where future scientific efforts should be directed, providing a foundation for deeper investigation into these species.

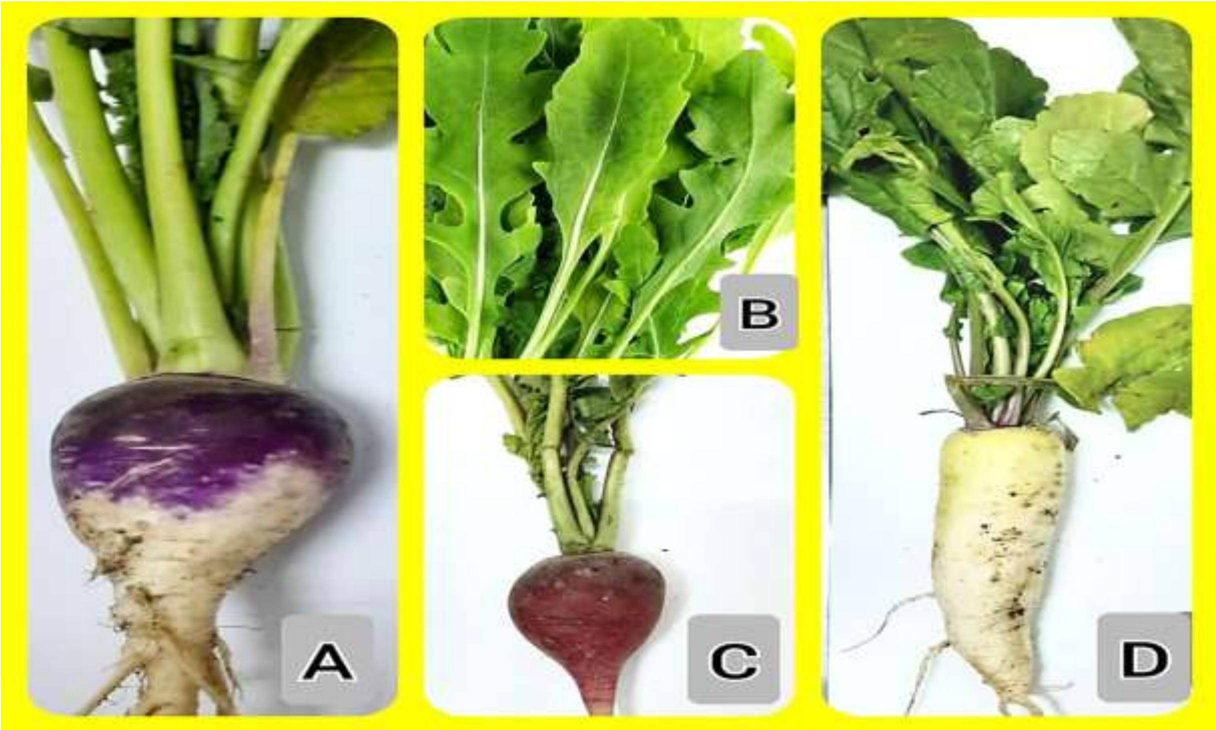


Figure. 1. A, *Brassica rapa* B *Eruca sativa*, C, *Red Raphanus sativus*, D, White *Raphanus sativus*

2. Materials and methods

Data on studies related to specific plants of the Brassicaceae family (*Brassica rapa* subsp. rapa, *Raphanus sativus* L., and *Eruca sativa)* were collected from various online databases, including Google Scholar, Elsevier, PubMed, PubChem, LIPID MAPS, Web of Science, and other accessible libraries. A systematic approach was employed for literature review and study selection, utilizing predefined keywords and Boolean operators. To ensure the inclusion of high-quality and relevant studies, predefined inclusion and exclusion criteria were applied. Only peer-reviewed articles, books, and authoritative sources were considered. The literature review focused on publications from 2000 to the present to ensure comprehensive coverage of relevant research. This study primarily examines the phytochemistry and pharmacological activities of these plants, aiming to identify their active constituents, therapeutic potential and future research prospects.

3. Traditional uses

In folk and traditional medicinal fields, different species of family Brassicaceae were used for treating various diseases and infections in human and administered in many pharmaceutical preparations such as decoctions, aqueous, alcoholic extract and plant juice. In the Unani and Arab traditional medicine *B. rapa* is known for its use in cholecystolithiasis, gastritis, constipation, also it used effectively in the treatment of chest complaints, gonorrhea, oedemas, syphilis, rheumatisms, rabies and liver related problems [12]. The roots of the plant have long been used in traditional medicine for common cold [6]. In folk medicine, the different extracts of *R. sativus* have been reported to be effective in the treatment of cardiac diseases, stomach disorders, urinary infections and hepatic disorders. In Asia, the roots of the plant were preserved in salt to make tasty products that were believed to be beneficial in treatment of liver and respiratory diseases. In China, *R. sativus* was recorded in the first Chinese pharmacopoeia and used as a traditional medicine for over 1400 years [13]. The seeds are a primary ingredient in a well-known Chinese formula for relieving cough and asthma and have also been broadly used in traditional Chinese medicine to treat chronic tracheitis, constipation, and hypertension [14]. *E. sativa* was used conventionally as rubefacient, tonic, astringent, digestive, emollient, stomachic and diuretic [15].

4. Phytoconstituents

Phytoconstituents are plants secondary metabolites that provide protection against various ailments in humans. They prevent from oxidative damage and scavenging free radicals. They guard against numerous conditions such as physiological, neurological and cardiac disorders [16]. Phytochemical studies of different members of family Brassicaceae (B. rapa, R. sativus and E. sativa) revealed the richness of these plants with flavonoids, glucosinolates, isothiocyanates, phenolic acids, volatile oil, sulfur and nitrogenous compounds. The most common published data on the major phytochemical compounds isolated from these plants and their chemical structures are summarized in Tables (1-4) and Figures (2-4).

4.1. Flavonoids and their glycosides

They exist in huge concentrations in the epidermis of fruits and leaves. They are a vital group of natural compounds that have abundant roles as secondary metabolites, UV protection, stimulation of nitrogen-fixing nodules and disease resistance [17]. Flavonols are the most widespread class of flavonoids in Brassicaceae family. kaempferol, quercetin, isorhamnetin are the most predominant flavonols in family species, but the qualitative and quantitative profiles modify between different species. For example, the chief flavonol in cauliflower is quercetin aglycon, but in white cabbage, kaempferol glucosides are the most abundant. The tops of *B. rapa* are considered an appreciable source of flavonoids (ranging from 107 to 191 mg/100 g on fresh weight). All flavonoids were identified by HPLC-DAD/MS techniques. They were glycosylated derivatives of three flavonols (isorhamnetin, kaempferol, and quercetin) and hydroxycinnamic derivatives. Isorhamnetin glycosides were the main flavonoid derivatives identified in this study [18]. Kaempferol 3-O-(feruloyl/caffeoyl)-sophoroside-7-O-glucoside, Kaempferol 3-O-sophoroside-7-O-glucoside, isorhamnetin 3-O-glucoside and isorhamnetin 3,7-O-diglucoside are the major flavonoids in *B. rapa* edible parts (leaves, stems, flower buds and roots) [19]. The majority of the flavonoids identified in the leaves and young greens of *B. rapa* were kaempferol, quercetin and isorhamnetin glycosylated and acylated with different hydroxycinnamic acids by using LC-UV photodiode array detection (PAD)-electrospray ionization (ESI) [20]. Apigenin, kaempferol, isorhamnetin and their glycosides were more abundant in different skin and flesh colors of *R. sativus* [21]. Different edible parts of *E. sativa* (leaves and seeds) were reported to have significant levels of polyglycosylated flavonoids. The most abundant flavonoids identified in *E. sativa* were kaempferol, quercetin, myricetin and isorhamnetin [22]. Kaempferol-3, 4 -di-O-β-glucoside was identified as the main flavonoid in the ethanolic extract of *E. sativa* leaves [23]. The list of the main flavonoids and their chemical structures are illustrated in Table (1) and Figure (2).

4.2. Anthocyanins

Anthocyanins are water-soluble pigments that could be found in sepals, leaves, petals, and fruits. They protect against diabetes, cancer and heart diseases [24]. Additionally, anthocyanins providing color, photoprotection and pathogen defense. Cyanidin, peonidin, malvidin, pelargonidin, delphinidin and petunidin, were the highest concentrated anthocyanins in colored *R. sativus*. Pelargonidins were found to be the major anthocyanin in three cultivars of *R. sativus*, identified by using high-performance liquid chromatography (HPLC) and gas chromatography time-of-flight mass spectrometry (GC-TOFMS)-based metabolite profiling [25]. Purple pigment in *B. rapa* root was identified as anthocyanins [26]. The primary anthocyanins are acylated cyanidin-3-glucosides in *B. rapa* leaves and petioles [27]. Anthocyanins compounds reported in *R. sativus* and *B. rapa* and their chemical structures are documented in Table (2) and Figure (3).

4.3. Phenolic and organic acids

Phenolic acids vary between the species of family Brassicaceae but the most commonly abundant phenolic acids are ferulic acid, caffeic acid, sinapic acid and p-coumaric acid. Sinapic acid is the fundamental hydroxycinnamic acid in *E. sativa* and *R. sativus.* Malic acid, aconitic acid, citric acid, ketoglutaric acid, shikimic acid, and fumaric acid were present in different parts of *B. rapa* (leaf, stem, root and flower). Amid them, malic acid was the predominant one and present in higher concentrations [19]. Ferulic, 4-hydroxybenzoic, gentisic, vanillic, syringic, p-coumaric, sinapic and salicylic acids were identified as free phenolic acids present in the roots of *R. sativus* [28]. The different parts of *E. sativa* (Leaf, seed and flower) were rich with phenolic acids. Ellagic acid, ferulic acid and coumaric acid were detected in the leaf extract of *E. sativa*, while ellagic, tannic, and gallic acid were found in the seed. The Flower of *E. sativa* was reported to have benzoic acid and ellagic acid [15]. Table (3) and Figure (4) describe the main phenolic and organic acids isolated from different species of the family Brassicaceae.

4.4. Glucosinolates (GSLs) and isothiocyanates (ITCs)

GSLs are bioactive compounds and mainly found in family Brassicaceae. They are classified as aliphatic, aromatic and indolic [29]. Recently, the GSLs have attained special concern in the pharmaceutical industry, particularly in the designing of cytotoxic and anti-inflammatory drugs [8]. GSLs are hydrolyzed to various biologically active compounds by the action of enzyme myrosinase (thioglucohydrolase, E.C.3.2.1.147) which found in human gut microflora. Among of these compounds, isothiocyanates (ITCs), indoles, nitriles thiocyanates, ascorbigen, and oxazolidine-2-thiones. This process depending on numerous factors including, existence of myrosinase-interacting proteins, pH, temperature, and presence of ferrous ion [30]. Isothiocyanates are the most abundant product formed upon GSLs degradation. Their health benefits depend on several factors, including the initial GSL concentration, cooking processes, amount of vegetable intake, and human metabolism. The GLSs and ITCs profile of each species in Brassicaceae family varies according to the agriculture, organ of the plant, the method of isolation and recognition techniques [31]. Twenty-four GLSs compounds have been identified in family Brassicaceae, including 16 aliphatic, four aromatic and four indolic [32]. The abundant GSLs in *B. rapa* was Glucobrassicanapin [32]. Glucoraphasatin, glucoerucin, glucoraphanin and glucobrassicin were the dominant in *R. sativus* [33]. While, in *E. sativa* glucosativin is the chief GSLs [32]. The major GLSs hydrolysis compound in *E. sativa* leaves was sativin [34], while in *E. sativa* seeds were erucin and sulforaphane [35]. In *R. sativus* seeds and sprouts, sulforaphene (4-methylsulfinyl-3-butenyl isothiocyanate) was detected as the main ITCs compound [36], while in *R. sativus* roots, the chief ITCs were raphasatin and sulforaphane [37]. *B. rapa* was recognized to be a natural source of ITCs. β-phenylethyl isothiocyanate was reported as the major ITCs product in the root of *B. rapa*, followed by 4-pentenyl isothiocyanate and 3-butenyl isothiocyanate [38]. The main GSLs and ITCs and their chemical structures are documented in Table (4) and Figure (5&6).

4.5. Essential oil

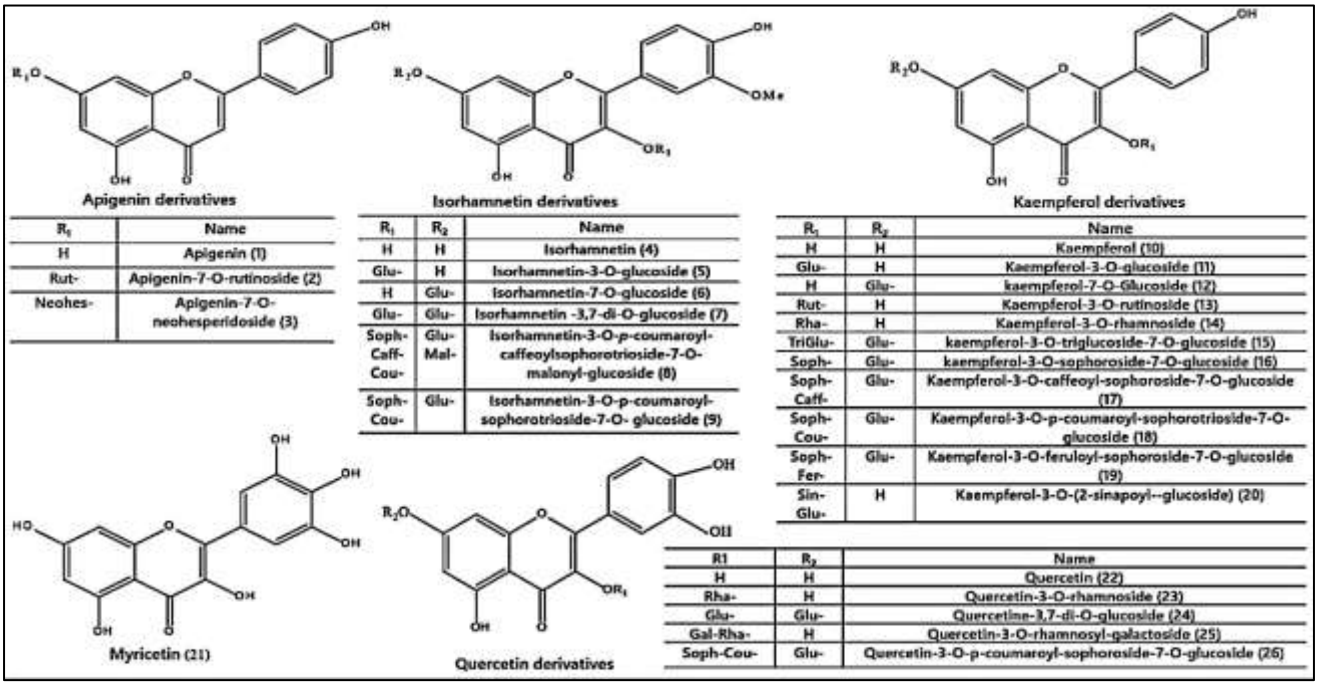
Essential oil is one of the components of *R. sativus* roots that are present in glucoside form. These components the main reason for its special odour and pungent taste. Complex volatile compositions, characterized by the subsequent compounds: sulfur compounds, organic acids, alcoholic compounds, aldehydes, hydrocarbons, esters and terpenes were isolated from the roots of R. sativus [39]. The leaves and roots of *B. rapa* were analyzed by gas chromatography -mass spectrometry (GC-MS) for determination of essential oil composition and sixteen compounds were identified including methyl chavicol, α-pinene and linalool as the main components [40]. The volatile oil of seeds, sprouts and adult plant of *B. rapa* were evaluated via headspace solid-phase micro extraction (HS-SPME) connected with gas chromatography/ion trap-mass spectrometry (GC/IT-MS). A number of constituents were characterized, but isothiocyanates (ITCs) were the main volatile constituents in all parts of *B. rapa* [41]. Volatile constituents like terpineol, myristicin, β- phellandrene, apiole and cis-verbenol, were detected in seeds of *E. sativa* [42], while eugenol, trans-anethole, elemene, (E)-β-damascone were identified in the plant leaves [43]. Sulfur and nitrogen containing compounds (isothiocyanates and nitriles) have an important role in the characteristic aroma of the *E. sativa* oil. Erucin (4-Methylthiobutylisothiocyanate) was the main essential oil component and 5-methylthiopentanonitrile was recognized as the secondary component [44]). The major volatile oil constituents are recorded in Table (5).

4.6. Terpenes and Carotenoids

The most common terpenes in Brassicaceae family are tocotrienols and tocopherols. In *B. rapa* oil, 87.9% of total tocols was recorded as γ-tocopherol followed by α-tocopherol, while β-tocotrienol was not detected [45]. The most common carotenoids in *R. sativus* sprouts were α-carotene, β-carotene, lutein, β-cryptoxanthin, violaxanthin and zeaxanthin [4]. Also, Lutein, followed by β -cryptoxanthin, β -carotene, zeaxanthin and violaxanthin were detected in high concentrations in *E. sativa* leaf [45]. Terpenes as phytol, isophytol and squalene were recognized in *E. sativa* leaves [43]. The chemical structures of the major carotenoids and terpenes are displayed in Figure (7).

Table 1: List of flavonoids present in different parts of a certain species of family Brassicaceae:

Plant	Part used	Compound name	Compound No.	Ref.
R. sativus	Sprouts and seeds	Apigenin	1	**[46]**
R. sativus	Leaves	Apigenin-7-O-rutinoside	2	**[47]**
R. sativus	Leaves	Apigenin-7-O-neohesperidoside	3	**[47]**
E. sativa	Leaves	Isorhamnetin	4	**[48]**
E. sativa	Leaves	Isorhamnetin-3-O-glucoside	5	**[48]**
B. rapa	Leaves	Isorhamnetin-7-O-glucoside	6	**[20]**
B. rapa	Leaves	Isorhamnetin -3,7-di-O-glucoside	7	**[20]**
R. sativus	Roots	Isorhamnetin-3-O-*p*-coumaroyl-caffeoylsophorotrioside-7-O-malonyl-glucoside	8	**[46]**
R. sativus	Leaves	Isorhamnetin-3-O-p-coumaroyl-sophorotrioside-7-O-glucoside	9	**[46]**
R. sativus *E. sativa*	Sprouts and seeds Leaves	Kaempferol	10	**[46]** **[48]**
R. sativus *E. sativa*	Leaves	Kaempferol-3-O-glucoside	11	**[47]** **[48]**
B. Rapa	Leaves	kaempferol-7-O-Glucoside	12	**[20]**
R. sativus	Leaves	Kaempferol-3-O-rutinoside	13	**[46]**
R. sativus	Leaves	Kaempferol-3-O-rhamnoside	14	**[46]**
B. rapa	Leaves	kaempferol-3-O-triglucoside-7-O-glucoside	15	**[20]**
B. rapa	Leaves	kaempferol-3-O-sophoroside-7-*O*-glucoside	16	**[20]**
R. sativus *B. rapa*	Roots Leaves	Kaempferol-3-O-caffeoyl-sophoroside-7-*O*-glucoside	17	**[46]** **[20]**
R. sativus *B. rapa*	Roots Leaves	Kaempferol-3-O-p-coumaroyl-sophorotrioside-7-*O*-glucoside	18	**[46]** **[20]**
R. sativus *B. rapa*	Roots Leaves	Kaempferol-3-O-feruloyl-sophoroside-7-*O*-glucoside	19	**[46]** **[20]**
E. sativa	Leaves	Kaempferol-3-*O*-(2-sinapoyl--glucoside)	20	**[49]**
E. sativa	Leaves	Myricetin	21	**[50]**
R. sativus *E. sativa*	Sprouts and seeds Leaves	Quercetin	22	**[47]** **[48]**
R. sativus	Leaves	Quercetin-3-O-rhamnoside	23	**[46]**
B. rapa	Leaves	Quercetine-3,7-di-O-glucoside	24	**[20]**
R. sativus	Leaves	Quercetin-3-O-rhamnosyl-galactoside	25	**[46]**
R. sativus *B. rapa*	Leaves	Quercetin-3-O-p-coumaroyl-sophoroside-7-Oglucoside	26	**[46]** **[20]**



R1	Name
H	Apigenin (1)
Rut-	Apigenin-7-O-rutinoside (2)
Neohes-	Apigenin-7-O-neohesperidoside (3)

R1	R2	Name
H	H	Isorhamnetin (4)
Glu-	H	Isorhamnetin-3-O-glucoside (5)
H	Glu-	Isorhamnetin-7-O-glucoside (6)
Glu-	Glu-	Isorhamnetin -3,7-di-O-glucoside (7)
Soph-Caff-Cou-	Glu-Mal-	Isorhamnetin-3-O-*p*-coumaroyl-caffeoylsophorotrioside-7-O-malonyl-glucoside (8)
Soph-Cou-	Glu-	Isorhamnetin-3-O-p-coumaroyl-sophorotrioside-7-O- glucoside (9)

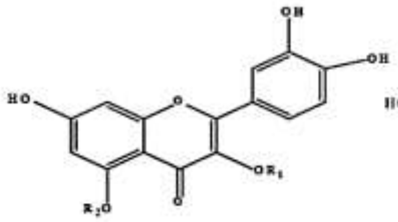
R1	R2	Name
H	H	Kaempferol (10)
Glu-	H	Kaempferol-3-O-glucoside (11)
H	Glu-	kaempferol-7-O-Glucoside (12)
Rut-	H	Kaempferol-3-O-rutinoside (13)
Rha-	H	Kaempferol-3-O-rhamnoside (14)
TriGlu-	Glu-	kaempferol-3-O-triglucoside-7-O-glucoside (15)
Soph-	Glu-	kaempferol-3-O-sophoroside-7-O-glucoside (16)
Soph-Caff-	Glu-	Kaempferol-3-O-caffeoyl-sophoroside-7-O-glucoside (17)
Soph-Cou-	Glu-	Kaempferol-3-O-p-coumaroyl-sophorotrioside-7-O-glucoside (18)
Soph-Fer-	Glu-	Kaempferol-3-O-feruloyl-sophoroside-7-O-glucoside (19)
Sin-Glu-	H	Kaempferol-3-O-(2-sinapoyl--glucoside) (20)

R1	R2	Name
H	H	Quercetin (22)
Rha-	H	Quercetin-3-O-rhamnoside (23)
Glu-	Glu-	Quercetine-3,7-di-O-glucoside (24)
Gal-Rha-	H	Quercetin-3-O-rhamnosyl-galactoside (25)
Soph-Cou-	Glu-	Quercetin-3-O-p-coumaroyl-sophoroside-7-O-glucoside (26)

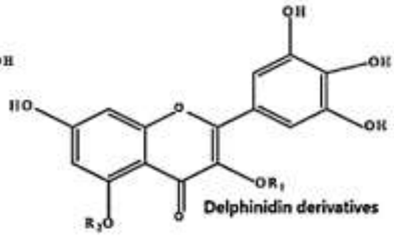
Figure 2. Chemical structures of flavonoids isolated from different parts of a certain species of family Brassicaceae

Table 2: List of anthocyanins present in different parts of a certain species of family Brassicaceae

Plant	Part used	Compound name	Compound No.	Ref.
R. sativus *B. rapa*	Leaves Leaves, roots and petioles	Cyanidin-3-O-glucoside	27	**[46]** **[27]**
R. sativus	Leaves	Cyanidin-3-O-rhamnoside	28	**[46]**
B. rapa	Roots	Cyanidin 3-O-rutinoside	29	**[25]**
R. sativus	Leaves	Cyanidin-3-O-sophoroside-5-O-glucoside	30	**[46]**
R. sativus	Roots and leaves	Cyanidin-3-O-sophoroside-5-O-malonylglucoside	31	**[46]**
R. sativus	Roots	Cyanidin-3-O-caffeoyl-p-coumaroyl-sophoroside-5-O-glucoside	32	**[46]**
R. sativus	Roots	Cyanidin-3-O-di-p-coumaroyl-sophoroside-5-O-malonylglucoside	33	**[46]**
R. sativus	Roots	Cyanidin-3-O-p-coumaroyl-feruloyl-sophoroside-5-O-glucoside	34	**[46]**
B. rapa	Leaves and petioles	Cyanidin 3-diglucoside-5-malonlyglucoside	35	**[27]**
B. rapa	Leaves and petioles	Cyanidin 3-feruloyldiglucoside-5-glucoside	36	**[27]**
B. rapa	Leaves and petioles	Cyanidin 3-coumaroyldiglucoside-5-glucoside	37	**[27]**
B. rapa	Roots	Delphinidin	38	**[26]**
B. rapa	Roots	Delphinidin 3-O-glucoside	39	**[26]**
R. sativus	Roots	Delphinidin-3-O-rutinoside	40	**[46]**
B. rapa	Roots	Delphinidin-3- O-malonyl hexoside	41	**[26]**
B. rapa	Roots	Pelargonidin	42	**[26]**
B. rapa	Roots	Pelargonidin 3-O-beta-D-glucoside	43	**[26]**
R. sativus	Roots	Pelargonidin-3-O-caffeoyl-caffeoyl-diglucoside-5-O-malonyl-glucoside	44	**[46]**
R. sativus	Leaves	Pelargonidin-3-O-feruloyl-diglucoside-5-Oglucoside	45	**[46]**
R. sativus	Leaves	Pelargonidin-3-O-p-coumaroyl-diglucoside-5-O-glucoside	46	**[46]**



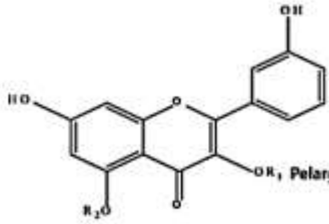
Cyanidin derivatives



Delphinidin derivatives

R1	R2	Name
H	H	Delphinidin (38)
Glu-	H	Delphinidin 3-O-glucoside (39)
Rut-	H	Delphinidin-3-O-rutinoside (40)
Hex- Mal-	H	Delphinidin-3- O-malonyl hexoside (41)

R1	R2	Name
Glu-	H	Cyanidin-3-O-glucoside (27)
Rha-	H	Cyanidin-3-O-rhamnoside (28)
Rut-	H	Cyanidin 3-O-rutinoside (29)
Soph-	Glu-	Cyanidin-3-O-sophoroside-5-O-glucoside (30)
Soph-	Glu- Mal-	Cyanidin-3-O-sophoroside-5-O-malonylglucoside (31)
Soph- Cou- Caff-	Glu-	Cyanidin-3-O-caffeoyl-p-coumaroyl-sophoroside-5-O-glucoside (32)
DiSoph- Cou-	Glu- Mal-	Cyanidin-3-O-di-p-coumaroyl-sophoroside-5-O-malonylglucoside (33)
Soph- Cou- Fer-	Glu-	Cyanidin-3-O-p-coumaroyl-feruloyl-sophoroside-5-O-glucoside (34)
DiGlu-	Glu- Mal-	Cyanidin 3-diglucoside-5-malonlyglucoside (35)
DiGlu-Fer-	Glu-	Cyanidin 3-feruloyldiglucoside-5-glucoside (36)
DiGlu-Cou-	Glu-	Cyanidin 3-coumaroyldiglucoside-5-glucoside (37)



Pelargonidin derivatives

R1	R2	Name
H	H	Pelargonidin (42)
Glu-	H	Pelargonidin 3-O-glucoside (43)
DiGlu-Coff- Coff	Glu- Mal-	Pelargonidin-3-O-caffeoyl-caffeoyl-diglucoside-5-O-malonyl-glucoside (44)
DiGlu-Fer-	Glu-	Pelargonidin-3-O-feruloyl-diglucoside-5-O-glucoside (45)
DiGlu-Cou-	Glu-	Pelargonidin-3-O-p-coumaroyl-diglucoside-5-O-glucoside (46)

Figure 3. Chemical structures of anthocyanins isolated from different parts of a certain species of family Brassicaceae

Table 3: List of phenolic acids and organic acids isolated from different parts of some species of family Brassicaceae

Plant	Part used	Compound name	Compound No.	Ref.
B. rapa	Leaves, stem, roots and flower buds	Aconitic acid	47	**[19]**
E. sativa	Flowers	Benzoic acid	48	**[15]**
R. sativus *B. rapa*	Sprouts and seeds Leaves	Caffeic acid	49	**[47]** **[20]**
B. rapa	Leaves	Chlorogenic acid (3-caffeoylquinic acid)	50	**[20]**
B. rapa	Leaves, stem, roots and flower buds	Citric acid	51	**[19]**
R. sativus *E. sativa*	Leaves Leaves	Coumaric acid	52	**[46]** **[50]**
E. sativa	Leaves, flowers, seeds	Ellagic acid	53	**[15]**
R. sativus *E. sativa* *B. rapa*	Sprouts and seeds Leaves Roots	Ferulic acid	54	**[47]** **[50]** **[19]**
B. rapa	Leaves, stem, roots and flower buds	Fumaric acid	55	**[19]**
R. sativus *E. sativa*	Sprouts and seeds Leaves, seeds	Gallic acid	56	**[47]** **[15]**
R. sativus	Roots	Genistic acid	57	**[28]**
R. sativus	Roots	4- hydroxy benzoic acid	58	**[28]**
B. rapa	Leaves, stem, roots and flower buds	Ketoglutaric acid	59	**[19]**
B. rapa	Leaves, stem, roots and flower buds	Malic acid	60	**[19]**
B. rapa	Leaves	3-*p*-coumaroylquinic acid	61	**[20]**
R. sativus	Sprouts and seeds	Protocatechuic acid	62	**[47]**
R. sativus	Roots	Salicylic acid	63	**[28]**
B. rapa	Leaves, stem, roots and flower buds	Shikimic acid	64	**[19]**
R. sativus *E. sativa* *B. rapa*	Sprouts and seeds Leaves Roots	Sinapic acid	65	**[47]** **[20]** **[19]**
R. sativus	Roots	Syringic acid	66	**[28]**
R. sativus	Roots	Vanillic acid	67	**[28]**

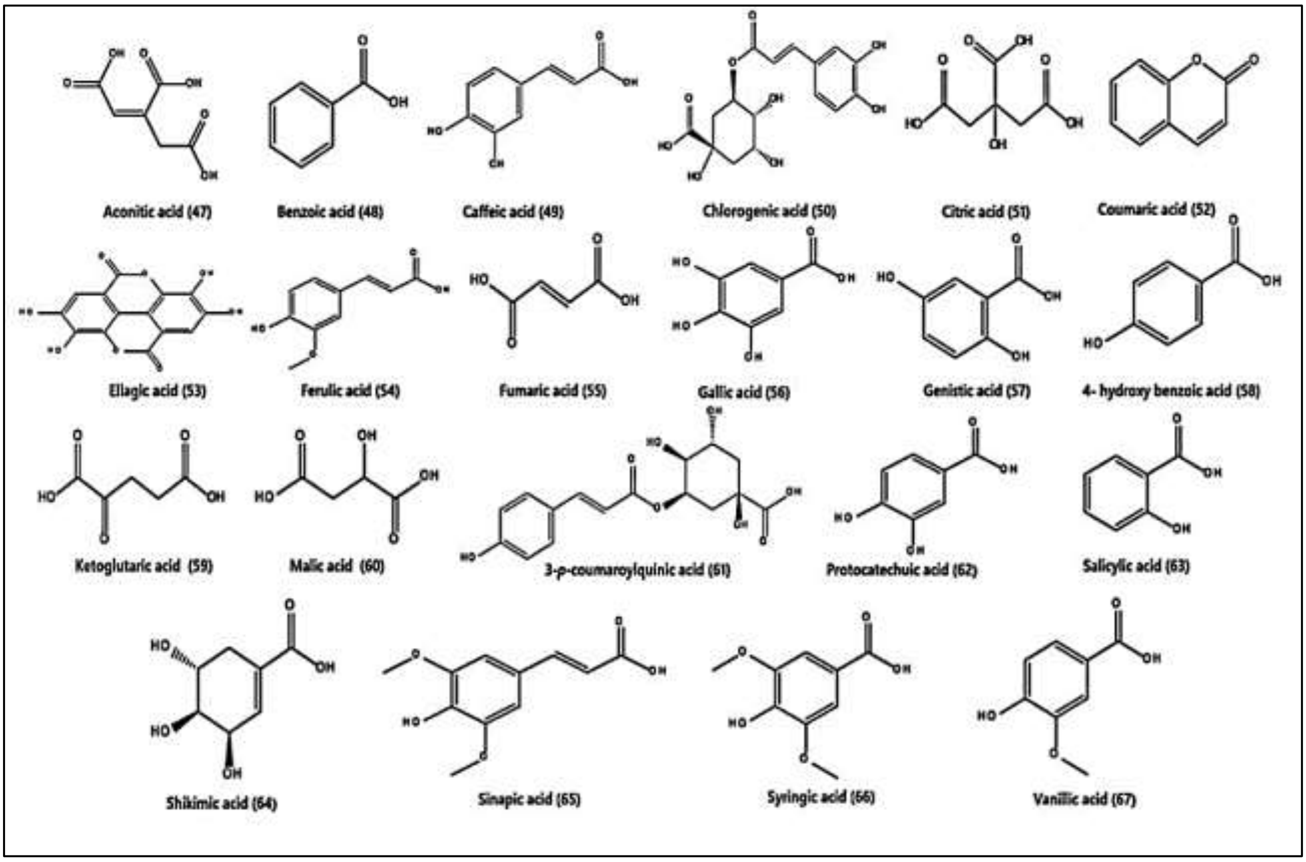


Figure 4. Chemical structures of phenolic and organic acids isolated from different parts of a certain species of family Brassicaceae

Table 4: List of Glucosinolates and isothiocyanates present in different parts of a certain species of family Brassicaceae

Plant	Part used	Compound name	Compound No.	Ref.
B. rapa	seeds, sprouts	Allyl isothiocyanate	68	**[41]**
B. rapa	roots, leaves, seeds	Butyl isothiocyanate	69	**[51]**
R. sativus *B. rapa*	Pods and flowers leaves, seeds	3-Butenyl isothiocyanate	70	**[52]** **[51]**
B. rapa	Leaves	Epiprogoitrin	71	**[20]**
E. sativa	Leaves, seeds	Erucin	72	**[43]**
B. rapa	leaves, roots	Glucoberteroin	73	**[53]**
R. sativus *B. rapa* *E. sativa*	Sprouts Leaves Leaves	Glucobrassicin	74	**[54]** **[20]** **[55]**
R. sativus *B. rapa* *E. sativa*	Sprouts Leaves Leaves	4-OH-glucobrassicin	75	**[56]** **[20]** **[57]**
R. sativus *E. sativa*	Sprouts Leaves	4-methoxyglucobrassicin	76	**[56]** **[58]**
B. rapa	Leaves	Glucobrassicanapin	77	**[20]**
B. rapa *E. sativa*	Roots Leaves	Glucocochlearin	78	**[59]** **[58]**
B. rapa *E. sativa*	Leaves Leaves, roots and seeds	Glucoerucin	79	**[53]** **[60]**
B. rapa *E. sativa*	Leaves Leaves	Glucoalyssin	80	**[61]** **[58]**
B. rapa	Leaves	Glucoiberin	81	**[61]**

B. rapa	Leaves	Glucoiberverin	82	**[61]**
B. rapa	Leaves	Gluconapin	83	**[20]**
E. sativa	Leaves			**[62]**
B. rapa	Leaves	Gluconapoleiferin	84	**[20]**
B. rapa	Leaves	Gluconasturtiin	85	**[20]**
E. sativa	Leaves			**[58]**
R. sativus	Whole plant	Glucoraphenin	86	**[63]**
B. rapa	Leaves			**[20]**
E. sativa	Leaves			**[58]**
E. sativa	Leaves, roots, flowers	Glucosativin	87	**[60]**
B. rapa	Leaves	Glucotropaeolin	88	**[20]**
B. rapa	roots, seeds	2-Phenylethyl isothiocyanate	89	**[51]**
B. rapa	Leaves	Progoitrin	90	**[20]**
E. sativa	Leaves			**[64]**
B. rapa	Leaves	Sinigrin	91	**[51]**
E. sativa	Leaves			**[64]**
R. sativus	Pods and flowers	Sulforaphane	92	**[52]**
R. sativus	Pods and flowers	Sulforaphene	93	**[52]**

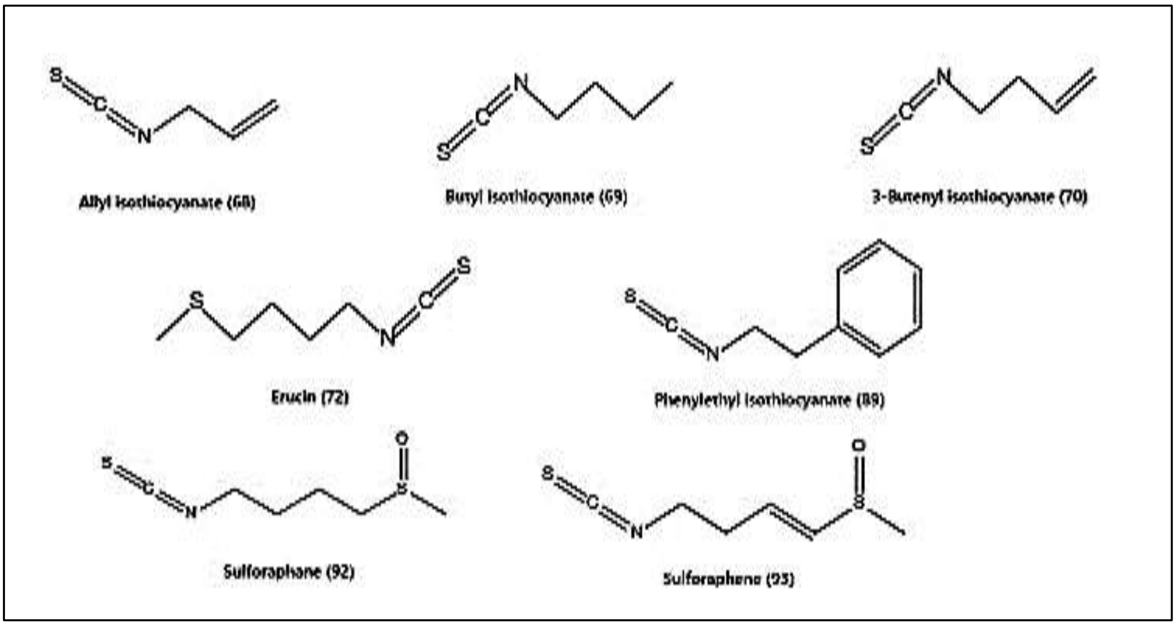


Figure 5. Chemical structures of isothiocyanates isolated from different parts of a certain species of family Brassicaceae

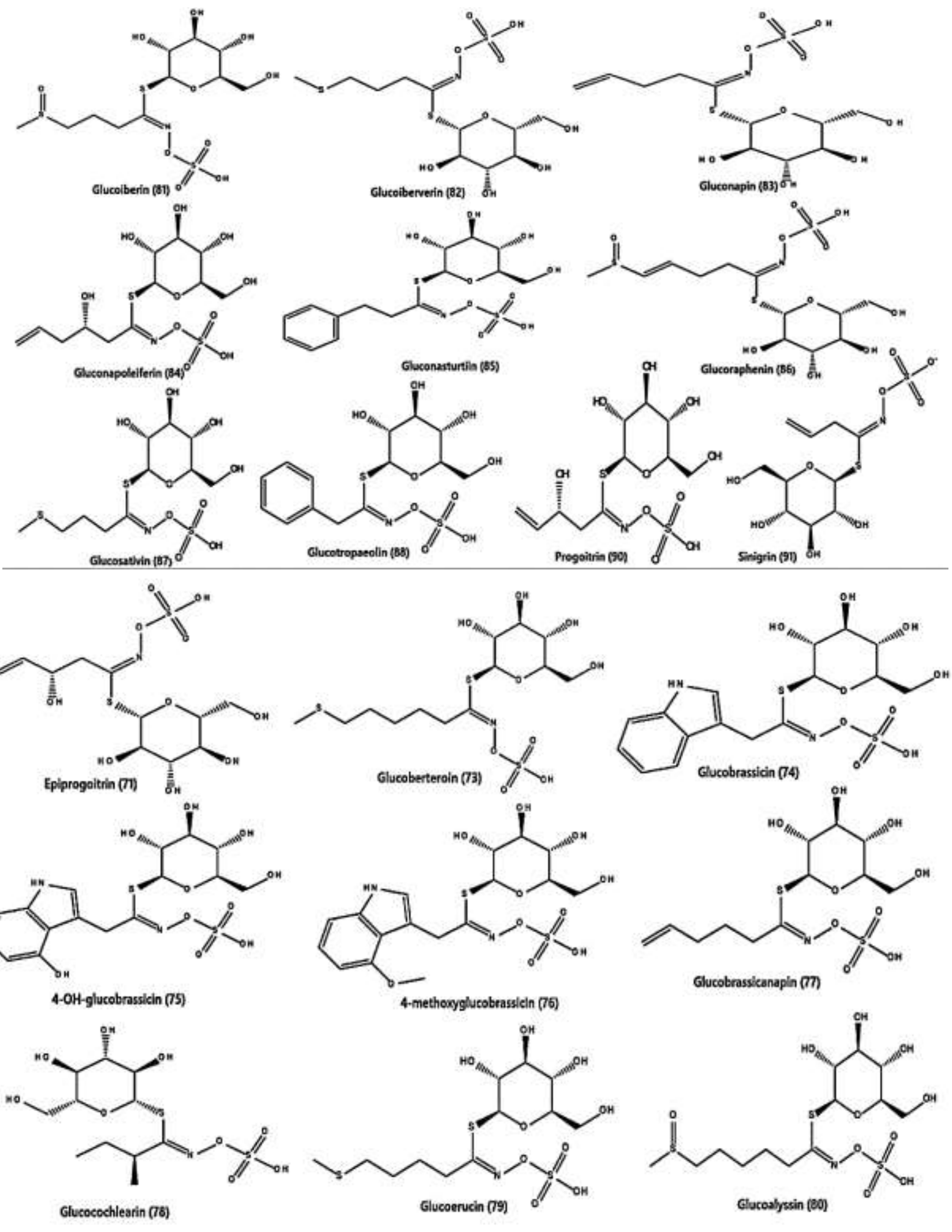
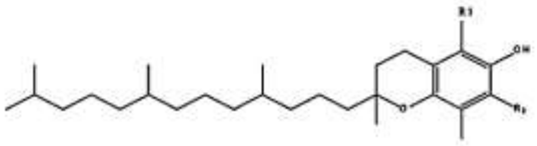


Figure 6. Chemical structures of glucosinolates isolated from different parts of a certain species of family Brassicaceae

Table 5: List of major essential oil isolated from different parts of some species of family Brassicaceae

Plant name	Part used	Compound name	Ref.
B. rapa	Leaves and roots	1-tetradecanol, 1-hexadecanol, 3-hexen-1-ol, 2-octen-1-ol, 1-hexanol, 1-octanol, 1-dodecanol, 1-phenyl ethanol, salicylaldehyde, octadecanal , 6-methyldodecane, 3-methylundecane, 2,6-dimethylundecane, 4-methyltridecane, heptadecene, hexanoic acid, acetic acid , methyl salicylate, ethylacetate, hexylacetate, (Z)-3-hexen-1-ol-acetate, 2-undecanone, 2,4-pentadione, (E)-geranyl acetone, 2-nonanone, acetone, caryophyllene	**[65]**
B. rapa	Adult plants, sprouts, Seeds	1-phenyl ethanol, 2-hexenal, heptanal, 2-heptenal, (E,E)-2,4-heptadienal, 2,4-nonadienal, octanal, phenylacetaldehyde, 2-octenal, nonanal, butyl acetate, ethyl pentanoate, ethyl hexanoate, ethyl benzoate, ethyl octanoate, ethyl decanoate, ethyl dodecanoate, ethyl tetradecanoater, ethyl hexadecanoate, ethyl linoleate, dihydrojasmone, α-pinene, limonene, β-pinene, m-cymene, isomenthone, menthol, phytol, benzenepropanenitrile, 6-methyl-2-heptanone, 2,2,6-trimethylcyclohexanone, safranal, α-Ionone, geranylacetone, β-Ionone	**[41]**
R. sativus	Roots	Nonanal, pentadekanal, dioctylphthalate, diisobutylphthalate, squalene, linoleic acid, linolenic acid, oleic acid, stearic acid, tricosane, tetracosane, pentacosane, hexacosane and heptacosane	**[39]**
R. sativus	Micro greens	1-Octanol, *trans*-2-dodecen-1-ol, 1-nonanol, 2-methyl-4-pentenal, 3-hexenal, nonanal, dodecanal, pentyl isothiocyanate, 4-methylpentyl isothiocyanate, 4-methylthio-3-butenyl isothiocyanate (Raphasatin), phenethyl isothiocyanate, 4-(methylthio)butyl isothiocyanate (erucin), dimethyl disulfide, β-ionone, naphthalene, octadecane, docosane	**[66]**
E. sativa	Seeds	Myristicin, terpineol, apiole, cis-verbenol, and β- phellandrene	**[42]**
E. sativa	Leaves	Eugenol, trans-anethole, elemene, (E)-b-damascone	**[43]**



Tocopherol	R_1	R_2
γ-tocopherol (94)	H	CH_3
α-tocopherol (95)	CH_3	CH_3

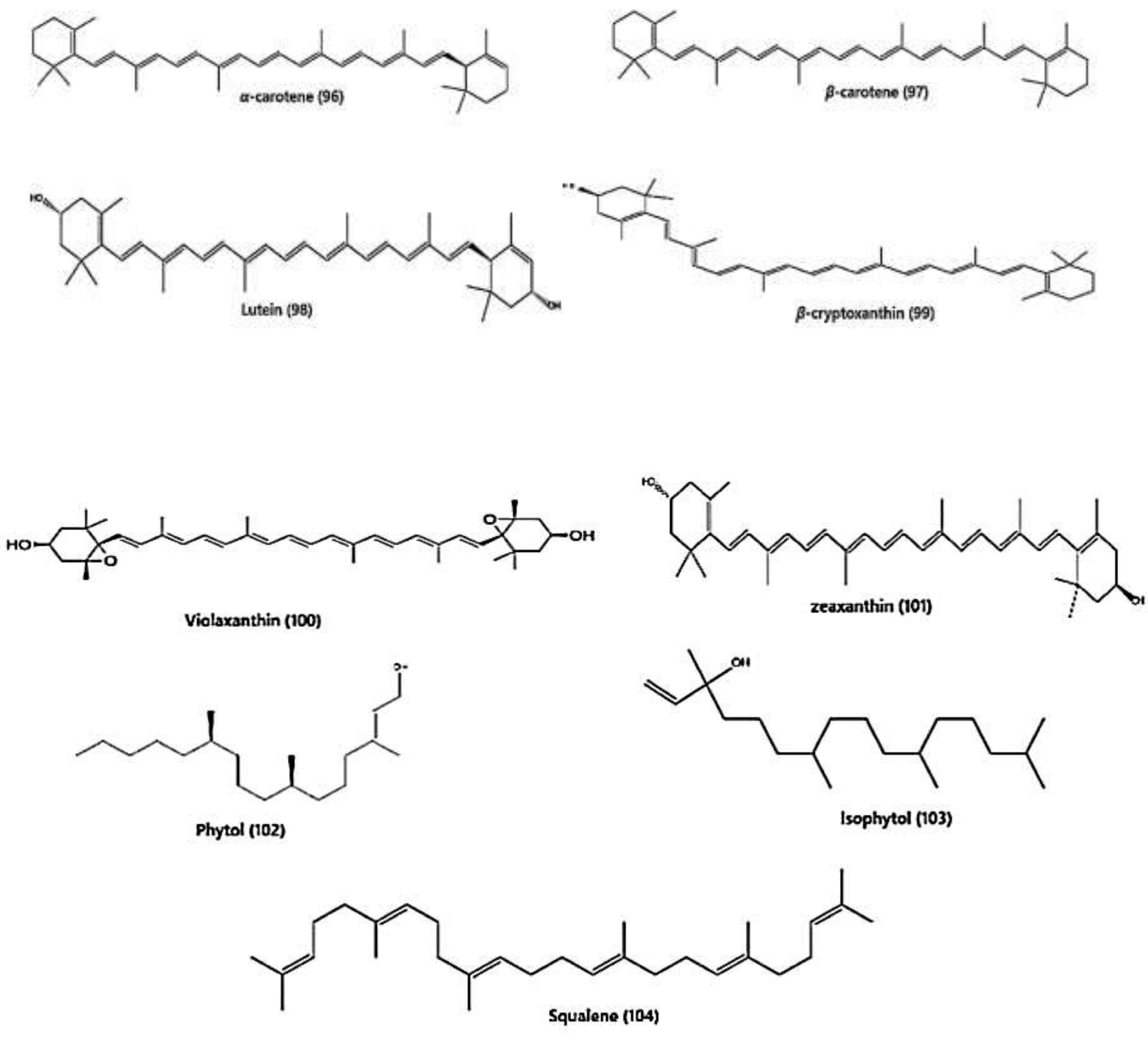


Figure 7. Chemical structures of Carotenoids and terpenes isolated from different parts of a certain species of family Brassicaceae

5. Pharmacological activity

The current review will provide an inclusive overview of the up-to-date research progress on the antioxidant, anti-cancer, hepatoprotective, antibacterial and anti-diabetic activities of important species from family Brassicaceae.

5.1. Antioxidant activity

Aqueous extracts of leaves, stems, flower buds and roots from *B. rapa* were tested for antioxidant activity by 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity. The flower buds the most active part, followed by the leaves and stems, while the roots showed a significantly lower antioxidant capacity **[19].** The leaves of *R. sativus* are considered as an important source of bioactive metabolites with antioxidant potentials [8]**.** Antioxidant activity of white *R. sativus* leaves and roots was measured by 2, 2′-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid (ABTS) and 1,1-diphenyl-2-picrylhydrazyl (DPPH) assays. The results showed that both parts have a vital role in reducing oxidative stress and considered a natural antioxidant, but leaves displayed a higher dose-dependent antioxidative activity than roots in both DPPH (IC_{50} 216.8 vs 359.7 µg/mL) and ABTS (IC_{50} 326.7 vs 549 µg/mL) models **[67].** Another study reported that ascorbic acid content and total phenolic content in leaves of red *R. sativus* was double the value found in roots, while total flavonoid levels in leaves were four times higher than that of the roots that displayed the higher free radical scavenging ability **[68].** The acylated pelargonidin derivatives in *R. sativus* were the main anthocyanin. These derivatives scavenged the 2, 20-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) radicals and utilized free radical scavenging activity in a concentration-dependent manner. The ABTS radical assay is a predominant test to determine the antioxidant capacity using a spectrophotometer **[69].** Antioxidant potential of different parts of *E. sativa* (leaves, seeds, stem and flowers) has been evaluated by using DPPH radical scavenging assay. The seeds reported to have a protective effect against oxidative stress and have a significant potential to be used as a natural anti-oxidant agents **[10].**

5.2. Hepatoprotective activity

B. rapa root has potential hepatoprotective activity against carbon tetra chloride (CCl_4) induced hepatotoxicity damage in hepatocytes in rats. The results showed that the treatment of hepatocytes by juice of the root after exposure to (CCl_4) led to significant decrease in the levels of serum biomarkers of hepatic injury glutamic-oxaloacetic transaminase (GOT), glutamic-pyruvate transaminase (GPT), alkaline phosphatase (ALP) and bilirubin level **[70].** Anthocyanins fraction of red *R. sativus* was selectively extracted and the hepatoprotective activity for the extract was tested against carbon tetrachloride (CCl_4)-induced hepatotoxicity in rats. The percentage of hepatoprotection was increased in a dose-dependent manner and the changes in liver functions were significant in comparison with control group AST (Aspartate transaminase), ALT (Alanine transaminase), ALP (alkaline phosphatase) and bilirubin levels. The results demonstrated the use of the crude extracts of *R. sativus* to treat various liver ailments in Indian folk medicine **[71].** The impact of white *R. sativus* root enzyme extract was evaluated to protect tacrine-induced cytotoxicity in human liver derived cells (HepG2 cells) by using 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) assay and carbon tetrachloride (CCl_4)-induced liver toxicity in rats. The findings suggest that the extract can significantly diminish hepatic damage by toxic agent such as tacrine or CCl_4 **[72].** Ethanolic and aqueous leaf extracts of *E. sativa* demonstrated hepatoprotective response against carbon tetrachloride, paracetamol- caused liver toxicity and phosphoric acid **[15].** The possible hepatoprotective activity of the plant may be due to the presence of the predominant glucosinolate in *E. sativa* (glucoerucin) which has antioxidant effect and H_2O_2 decomposition properties **[73].**

5.3. Anti-diabetic activity

Antidiabetic effect of the ethanolic extract of *B. rapa* was evaluated and it showed improving in insulin resistance and decreasing in blood glycosylated hemoglobin, plasma insulin, hepatic lipids and the hepatic fatty acid synthase activity **[74].** The effect of Egyptian *R. sativus* sprouts was investigated on blood glucose level in normal and streptozotocin-induced diabetic rats. The results exhibited that the plant induced hypoglycemic effect may be related to antioxidant compounds in *R. sativus* such as (flavonoids, phenolic compounds and Vit. C) **[75].** Another study tested the antidiabetic efficacy of *R. sativus* root extract. It was administered orally to normal and streptozotocin (STZ)-induced diabetic rats. The results found that it possesses good hypoglycemic potential coupled with antidiabetic activity **[76]**.

Different parts of *R. sativus* (roots, seeds and leaves) are very beneficial in treatment of diabetes through different mechanisms **[33].** *E. sativa* shows antidiabetic activity via holding effect on carbohydrate metabolism through inhibition of carbohydrate-hydrolyzing enzymes, *α*-amylase, *α*-glucosidase, and *ß*-galactosidase in dose-dependent way **[77].** The hexane fraction of *E. sativa* leaves extract and its fatty acid-rich fraction exhibit anti-diabetic activities in insulin-responsive cell lines in vitro bioassays (C2C12 skeletal muscle cells, H4IIE hepatocytes and 3T3-L1 adipocytes). They have beneficial effect on muscle glucose uptake, hepatic G6Pase activity and showed significant adipogenic activities. *E. sativa* leaves may be useful potential product for the prevention and treatment of type 2 diabetes **[78].**

5.4. Anticancer activity

Brassicaceae vegetables have a protective effect against many types of cancers, due to the excessive concentration of GSLs, ITCs and indoles in these vegetables **[79].** Many studies reported that these compounds have potential anticarcinogenic properties including adjustment of detoxification enzymes, suppression of proliferation and induction of apoptosis in various tumor cells **[80].** *β*-phenylethyl isothiocyanate is the major ITCs in *B. rapa* root and it has anti-cancer properties according to many studies. *β*-Phenylethyl isothiocyanate showed significant inhibition on the growth of human-derived hepatoma cells

(HepG2) in a concentration-dependent manner with an IC_{50} value of 24.6 µM in MTT assays **[38].** Additional study showed that *β*-phenylethyl isothiocyanate significantly reduced the growth of the human prostate cancer cell line DU145 **[81].** Leaves and roots of white *R. sativus* were investigated for their cytotoxic activity against several human cancer cell lines including lung carcinoma (A549), hepatocellular carcinoma (HepG2), breast carcinoma (MDA-MB-231) and (MCF-7) by using MTT assay. The study exposed that the leaves and roots of the plant have cytotoxic activity against all the tested cell lines. The leaf showed a greater anticancer activity than the root. This activity may be due to the presence of glucosinolates and different flavonoid compounds in the plant **[67].**

GC–MS profile revealed that presence of two isothiocyanate compounds: sulforaphane and sulforaphene in the edible parts of *R. sativus* extract giving the extract its anticancer attributes. The plant showed high cytotoxicity and apoptosis induction against the colon cancer cell line (HCT116) **[52].** These compounds are naturally occurring isothiocyanates and extremely inducer of phase 2 cytoprotective enzymes so they have ability to guard versus carcinogens, oxidative stress, and inflammation **[82].** Sulforaphane efficiently decreased the growth of breast cancer cells with fewer harmful to normal cells even at relatively low concentrations (5-10µM). This is associated with disrupted organization of cytoskeleton, declined colonization of cancer cells and induction of cell cycle arrest and apoptosis. Sulforaphane exhibited significant inhibitions of tumor growth against multiple lung cancer cell lines *in vitro* and *in vivo* with a xenograft mouse model. It was identified as a novel natural broad-spectrum small molecule inhibitor for lung cancer **[83].** Sulforaphene in the *R. sativus* can be a promising cytotoxic agent with superior efficacy to cancer cells and lower toxicity to normal cells **[84].** Analysis of hexane extract obtained from *R. sativus* root by GC-MS revealed the presence of several isothiocyanates (ITCs). The extract exerts potential chemo preventive efficacy and induces apoptosis in different cancer cell lines cervical (HeLa), lung (A549) and prostate (PC-3) and breast (MCF-7) cancer cell lines through modulation of genes involved in apoptotic signaling pathway *via* upregulation of pro-apoptotic genes and down regulation of anti-apoptotic genes along with the activation of Caspase-3 **[85].**

The ethanolic extract of *E. sativa* fresh leaves exhibited cytotoxic activity against four different human tumor cell lines including HepG2 (liver carcinoma), MCF7 (breast carcinoma), HCT116 (colon carcinoma), and Hep2 (larynx carcinoma) **[86].** The alcoholic extract of the seed of *E. sativa* showed significant cytotoxic activity for different tumor cell lines including HCT116 (colon carcinoma cell line), Hela (Cervix carcinoma cell line), HEPG2 (liver carcinoma cell line), MCF7 (breast carcinoma cell line) and U251 (brain carcinoma cell line). This activity illustrated may be because of the presence of GSLs compounds including glucoerucin and glucoiberin **[11].**

5.5. Anti-bacterial activity

Phytochemicals from brassicaceae vegetables are well-known alternative medicines as antibacterial substances **[87].** *B. rapa* root is considered as a preventive tool for bacterial infection due to the inhibitory effects of *β*-phenylethyl isothiocyanate against different bacteria (*Vibrio parahaemolyticus*, *Staphylococcus aureus*, as well as *Bacillus cereus*) **[38].** The methanolic extract of *B. rapa* root has been found to be an effective antimicrobial agent *via* inhibition of nine genera of bacteria including three Gram-positive bacteria (*Bacillus cereus, Bacillus subtilis*, and *Sarcina lutea*) and six Gram-negative bacteria (*Escherichia coli, Pseudomonas aeruginosa, Salmonella Paratyphi, Salmonella Typhi, Shigella dysenteriae,* and *Vibrio parahemolyticus*) **[88].** Sulphoraphene and raphanin: sulphur compounds extracted from *R. sativus* seed oil are found to have antibacterial activity against gram-positive and gram-negative bacteria including *streptococcus, Pyococcus, Pneumococcus* and *Escherichia coli.* Erucic acid was present in high concentration in *E. sativa* seed extract and it may responsible for the extract's antibacterial activity **[89].** The seed oil of *E. sativa* showed maximum inhibition of growth against gram-positive and gram-negative bacteria strains. Gram-positive bacteria selected for this study were *Staphylococcus aureus, Staphylococcus epidermidis* while Gram-negative were *Pseudomonas aeruginosa, Salmonella typhi, Klebsiella pneumonia* and *Escherichia coli*. The minimum inhibitory concentration (MIC) values for the seed oil showed that it had almost equal activity to the broad-spectrum antibiotic (Gentamicine). MIC values of seed oil were within the ranges of 52-72 µg/ml as compared to 56-70 µg/ml standard antibiotics (Gentamicine) **[90].** The seed of *E. sativa* is considered as a potential antibacterial agent against resistant Gram-negative and Gram-positive bacteria confirming its usage in conventional medicine for treatment of urinary infections, fever, diarrhea dermatology disorders **[91].**

6. Conclusion

This scientific review highlighted on the phytochemistry and pharmacological activities of a certain plants of family Brassicaceae and facilitated to develop a high-resolution picture about this family. *Brassica rapa* subsp rapa, *Eruca sativa* and *Raphanus sativus* L. are edible plants that usually consumed in Egypt in traditional diet. Recent years have spotted arise on many plants in this family, which led to various studies to give a significant support for many uses for these plants in the treatment of numerous illnesses. Our study focusses on the identification of different chemical compounds in these plants. Sulfur-containing compounds such as glucosinolates, and isothiocyanates together with phenolic acids and flavonoids are the major active metabolites found in these plants. Additionally, the listed bioactive constituents have been displayed a wide spectrum of biological activities, involving antioxidant, anti-cancer, hepatoprotective, antibacterial and anti-diabetic activities. Thus, Brassicaceae plants act for an excellent source of health-promoting phytochemicals. The knowledge gained from the present research is that the consumption of these valuable plants should be enhanced in the future as well as, further studies are needed to continue investigating the nutritional and phytochemical composition of these potential plants. Despite the in-depth research on Brassicaceae plants, there are still gaps and issues that require to be addressed. Future studies should focus and target on the isolation and characterization of novel bioactive compounds, along with their precise mechanisms of action at the molecular level. Further comprehensive pharmacological and clinical investigations are mandatory to validate their therapeutic potential and safety profiles. Additionally, advanced research should analyze the synergistic effects of these

compounds along with other natural or synthetic agents. Understanding their bioavailability, metabolism, and potential applications in functional foods and pharmaceuticals will also be crucial for maximizing their health benefits.
The findings of this review align with several United Nations Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 12 (Responsible Consumption and Production), and SDG 2 (Zero Hunger). The health-promoting properties of Brassicaceae plants, including their antioxidant, anti-cancer, hepatoprotective, antibacterial, and anti-diabetic activities, contribute to SDG 3 by supporting the development of natural therapeutic agents for disease prevention and management. Additionally, the emphasis on these plants as nutraceuticals aligns with SDG 2 by promoting their consumption as part of a healthy and sustainable diet. Furthermore, encouraging the use of these readily available and locally consumed plants supports SDG 12, fostering sustainable agricultural practices and reducing dependency on synthetic pharmaceuticals. Future research should focus on optimizing their cultivation, extraction, and application in functional foods to maximize their contribution to global health and sustainability.

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