Chapter 28
Fruit and Vegetables and Health: An Overview

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Abstract A growing body of evidences suggests that the regular consumption of a diet rich in fruit and vegetables (FAV) reduces the risk of chronic human illnesses and increase lifespan and quality of life. FAV are considered energy poor, are rich sources of minerals, fibers, vitamins and most of all of many phytochemicals belonging to four main classes: polyphenols, terpenoids, sulphur compounds and alkaloids. Polyphenols, and to a certain extent carotenoids and sulphur containing compounds have been shown through epidemiological cohort studies or through mechanistic *in vitro* or animal studies, to prevent coronary heart diseases, chronic inflammatory diseases, obesity, diabetes, neurodegenerative diseases, cancer, macular degeneration, and many others. Owing to their particular chemical structure, theses phytochemicals display strong antioxidant capacity in vitro. Yet due to their poor bioavailability and their short residence time in the organism, it is more and more admitted that these molecules trigger detoxification mechanisms in the body and induce genes associated with energy metabolism, anti-inflammation and endogenous-antioxidant network at the cellular level.

This chapter describes the different phytochemicals found in FAV with emphasis on polyphenols, the most important class of compounds in relation to health benefits and amounts ingested on a daily basis in our diet. The contribution of these chemicals to the prevention of chronic diseases is covered and new insights on their possible mode of action are discussed. The scope of this chapter is broad and intends to brush an overview of this very complex and dynamic field of research, at the interface between plant and human physiology. The reader is guided and often referred to bibliographic reviews on topics as diverse and eclectic as phytochemicals biosynthesis, bioavailability, inflammatory responses, cancer etiology, appetite control, insulin resistance, and cognition.

Keywords Fruits · Vegetables · Health · Polyphenols · Carotenoids · Sulphur compounds · Cancer · Coronary heart disease · Obesity · Diabetes · Neurodegenerative disease · Bioavailability

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Introduction

It is implicitly accepted that fruit and vegetables (FAV) are good for you. Actually, many nutritionists and clinicians now consider fruit and vegetables consumption as a solution to many “diseases of civilization”. These horticultural products bring diversity and stimulate our senses by having organoleptic properties like color, flavor, and texture and contribute to our appetite. FAVs have long been recognized for their nutritive value. They are excellent sources of minerals, essential fatty acids and fibers, but are also unique sources of vitamins (C, E, B, and folic acid). Most of all, they are rich sources of bioactive phytochemicals. They are considered energy poor and contribute, through their high content in non-digestible fibers, to the feeling of satiety. For these reasons, the consumption of FAV and plants in general are at the base of most for food pyramid (Anon 2011). For some, FAV are the most important component of the diet and contribute to a healthy living (Hung et al. 2004). For example, the Mediterranean diet, which is reputed for its quality and is largely composed of fish, alpha-linoleic acid and FAV has been associated with the low incidence of cardiovascular disease of population living in the Mediterranean bassin (de Lorgeril et al. 1994). Other diets, like the Portfolio diet, a reconstitution of the diet of our simian ancestors, is relying on the consumption of high levels of fibers, phytosterols, vegetables and nuts and has been show repetitively to confer significant cholesterol-lowering capacity and reduce the incidence of atherosclerosis (Kendall and Jenkins 2004). Indeed, a growing body of evidence suggests that the regular consumption of a phytochemical-rich diet reduces the risk of many chronic human illnesses and increases life span and quality in humans (Anon 2007; He et al. 2006).

New evidences support the fact that FAV are important in the prevention of cardiovascular (Van’t Veer et al. 2000), vision (Snodderly 1995), bone (Baile et al. 2011), and pulmonary health (Trichopoulou et al. 2003). The World Health Organization has recognized this fact and is actively promoting the consumption of FAV to reduce the incidence of chronic disease (Anon 2007) and public health and growers organization in different countries, regrouped under the umbrella of IFAVA (Anon 2006) are actively promoting the consumption of FAV through the different 5 to 10 a day programs worldwide. There are many epidemiological studies linking the consumption of FAV and/or their constituents to beneficial health effects. For instance, many cohort and case-control epidemiological studies and even intervention studies show the beneficial effects of FAV. In general, an inverse association is found between FAV consumption and cardiovascular disease (SUVIMAX cohort study) (Bazzano 2006; Hercberg et al. 2004), chronic inflammatory diseases (Hermsdorff et al. 2010), diabetes (Bazzano 2005; Hamer and Chida 2007), obesity (Carlton Tohill 2005), neurodegenerative diseases (Cherniack 2012), and many more. However, the evidence for this effect is not as solid for cancer (World Cancer Research Fund 2007) and recently some doubts have been expressed on the link between FAV and coronary hearth disease prevention (Dauchet et al. 2009) since FAV consumption is often confounded with other general healthier life habits like non-smoking, reduced alcohol consumption, just to list a few.

The majority of the studies published over the last 20 years have focused on the identification and demonstration of the activity of bioactive compounds of FAV *in vitro*. They are mostly observational and results are often conflicting. The validity of *in vitro* studies is contested because they provide an incomplete and often biased image of the benefits of FAV to health. Other parameters must thus be considered since the responses of humans to the food they consume are complex and influenced by many confounding factors. Too many studies have not taken into account the poor bioavailability, the interactions between the phytonutrients and have often used supra-optimal non-physiological doses of bioactive compounds to demonstrate their effect and have thus lead to incorrect conclusions on their potential effects. Moreover, these effects have proved to be difficult to reproduce in human clinical trials. Taking into account these caveats, new hypothesis on the mode of action of phytonutrients lean toward a general anti-inflammatory and cell-signaling action.

This chapter is thus intended to briefly review the most pertinent scientific literature on the topic of health effects of FAV and highlights which components are responsible for disease protection and the most probable mechanisms by which they confer these effects. Many excellent reviews on the topic are also available (Crozier et al. 2006, 2009).

FAV are Rich Sources of Nutrients

FAV are rich sources of minerals and vitamins in the diet. They provide large amount of phosphorus, potassium, calcium, magnesium, iron and zinc. They also contain unsaturated lipids and are a very rich source of vitamins and in particular vitamin-C (Table 28.1). Interestingly, they contain a high proportion of water, and have a high content in non-digestible fibers, which have been shown to reduce their energy density (Carlton Tohill 2005). Adding FAV to the diet reduces the overall energy density, increasing the amount of food that can be consumed for a given level of calories. Many comprehensive reviews have evaluated the effect of dietary fibre content on satiety, overall energy intake and body weight (Kim and Park 2011).

Phytochemicals Found in FAV

FAV accumulate several hundred of thousands of so-called "secondary metabolites" to protect themselves from biotic stress like bacteria, fungi and insects (Kliebenstien 2004) and abiotic stress (Dixon and Paiva 1995). These chemicals are essential components of the adaptive arsenal of the plant to the environment and are involved in biotic and abiotic stress protection, cell signaling, plant development, pollinator attraction, plant-microorganism interaction, plant defense, herbivore repulsion and seed dispersion. These phytochemicals are regrouped into four broad classes according to their chemical structure: polyphenols, terpenoids, sulphur compounds, and alkaloids (Fig. 28.1 and Table 28.2).

Table 28.1 Composition of typical fruit and vegetables. Values are per 100 g F.W. (Adapted from the USDA national nutrient database (Anon 2004, 2006)

	Water %	Energy (Kcal)	Pro-tein	Lipid	Fibers	Sugar	Minerals (mg)							Vitamins				
Fruit			(mg)				Ca	Fe	Mg	P	K	Na	Zn	C (mg)	B (mg)	E (mg)	A (µg)	Folate (µg)
Apples	85	52	0.3	0.2	2.4	13.8	6	0.1	5	11	107	1	0.05	4.6	0.2	0.2	3	3
Avocado	73	160	2	14.7	6.7	8.5	12	0.6	29	52	485	7	0.6	10	2.1	2	7	81
Banana	74	89	1	0.3	2.6	12.2	5	0.3	27	22	358	1	0.15	8.7	1	0.1	3	20
Blackberry	88	43	1.4	0.5	5.3	9.1	29	0.6	20	22	162	1	0.5	21	0.7	1.2	11	25
Blueberry	84	57	0.7	0.3	2.4	14.5	6	0.3	6	12	77	1	0.2	9.7	0.5	0.6	3	6
Cranberry	87	46	0.4	0.1	4.6	12.2	8	0.3	6	13	85	2	0.1	13	0.2	1.2	3	1
Figs	79	74	0.8	0.3	2.9	16.3	35	0.4	17	14	232	1	0.2	2	0.6	0.1	7	6
Grapefruit	88	42	0.8	0.1	1.6	10.6	22	0.1	9	18	135		0.1	31	0.3	0.1	58	13
Grapes	81	67	0.6	0.4	0.9	17.2	14	0.3	5	10	191	2	0.04	4	0.5	0.2	5	4
Melon	90	34	0.8	0.2	0.9	8.6	9	0.2	12	15	267	16	0.2	36	0.8	0.1	169	21
Oranges	86	47	0.9	0.1	2.4	11.7	40	0.1	10	14	181		0.1	53	0.5	0.2	11	30
Pears	84	57	0.4	0.1	3.1	9.8	9	0.2	7	12	116	1	0.1	4.3	0.2	0.1	1	7
Raspberry	85	52	1.2	0.7	6.5	11.9	25	0.7	22	29	151	1	0.4	26	0.7	0.9	2	21
Strawberry	91	32	0.7	0.3	2	7.7	15	0.4	13	24	153	1	0.1	59	0.5	0.3	1	24
Vegetables																		
Artichoke	85	47	3.3	0.2	5.4	1	44	1.3	60	90	370	94	0.5	12	1.2	0.2	14	68
Asparagus	93	20	2.9	0.2	2.8	2.5	32	2.9	19	70	271	3	0.7	7.5	1.7	1.5	51	70
Beans green	90	31	1.8	0.2	2.7	3.3	37	1.0	25	38	211	6	0.2	122	0.9	0.4	35	33
Beets	88	34	2.8	0.4	2.8	6.8	16	0.8	23	40	325	78	0.4	4.9	0.5	0.04	2	109
Broccoli	89	34	2.8	0.4	2.6	1.7	47	0.7	21	66	216	33	0.4	89	0.8	0.8	31	57
Brussels sp.	86	43	3.4	0.3	3.8	2.2	42	1.4	23	69	389	25	0.4	85	0.9	0.9	38	61
Cabbage	92	25	1.3	0.1	2.5	3.2	40	0.5	12	26	170	18	0.2	37	0.3	0.2	5	43
Carrot	88	41	0.9	0.2	2.8	4.7	33	0.3	12	35	320	69	0.2	6	1.1	0.7	835	19
Cauliflower	92	25	1.9	0.3	1.9	2.0	22	0.4	15	44	299	30	0.3	48	0.6	0.1	0	57
Celery	95	16	0.7	0.2	1.6	1.8	40	0.2	11	24	260	80	1.3	3.1	0.4	0.3	22	36
Garlic	59	149	6.4	0.5	2.1	1.0	181	1.7	25	153	401	17	1.2	31	1.0	0.1	0	3
Lettuce	95	17	1.2	0.3	2.1	1.2	33	1.0	14	30	247	8	0.2	4	0.4	0.1	436	136
Onion	89	40	1.1	0.1	1.7	4.2	23	0.2	10	29	146	4	0.2	7.4	0.2	0.02	0	19
Pepper	94	20	0.9	0.2	1.7	2.4	10	0.3	10	20	175	3	0.1	80	0.5	0.4	18	10
Spinach	91	23	2.9	0.4	2.2	0.4	99	2.7	79	49	558	79	0.5	28	1.0	2.0	469	194
Tomato	95	18	0.9	0.2	1.2	2.6	10	0.3	11	24	237	5	0.2	14	0.6	0.5	42	15

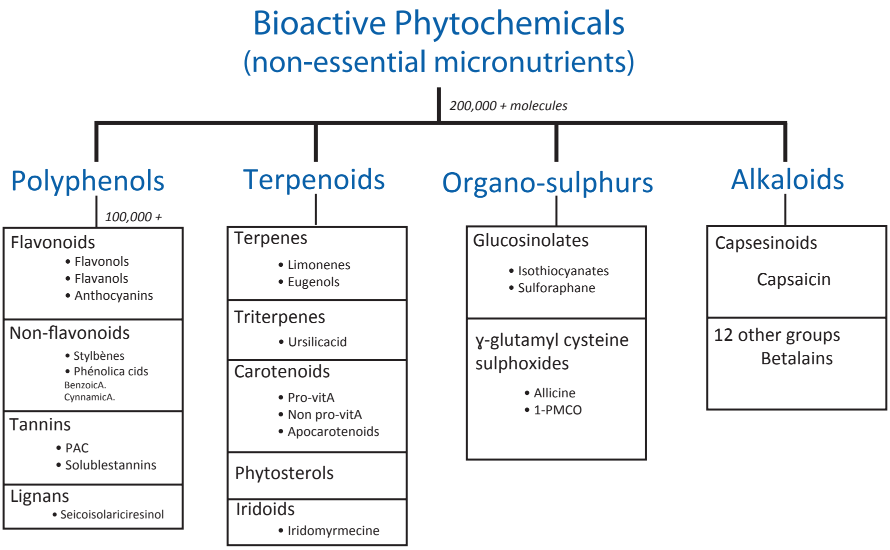


Fig. 28.1 Different classes of bioactive phytochemicals found in FAV

Table 28.2 Photochemicals found in fruit and vegetables

Bioactive compound family	Primary source in fruits and vegetables	Database/source
Terpenoids		
Carotenoids	Leafy vegetables, red and yellow fruits and vegetables	USDA nutrient database (Kimura and Rodriguez-Amaya 2003; Rodriguez-Amaya et al. 2008)
Monoterpenes	Citrus, cherries, mint and herbs	
Saponins	Alliaceae, asparagus	(Güçlü-Üstünda and Mazza 2007)
Apocarotenoids	Fruits	(Bouvier et al. 2005)
Polyphenols		
Phenolic acids	Small fruits, apples, fruit and vegetables	(Rothwell et al. 2012)
Hydrolysable tannins	FAV, pomegrenate, raspberry	(Clifford and Scalbert 2000)
Stylbenes	Grapes, small fruits	(Waffo-Teguo et al. 2008)
Proanthocyanidins	FAV, cacao, small fruits, cranberry, blueberry	(Anon 2003)
Monophenolic alcohols tyrosol	Olive oil, wine	(Romero et al. 2002)
Organo sulphur compounds		
Glucosinolates	Brassicaceae	(McNaughton and Marks 2003)
γ-Glutamyl cysteine sulphoxides	Alliaceae	(Griffiths et al. 2002)
Alkaloids		
Capsaicin	Chili Pepper	(Surh and Sup Lee 1995)
Betalain	Red Beet, Prickly pear, Pittaya	(Stintzing and Carle 2007)

Polyphenols

The evolution of terrestrial plants has coincided and probably been rendered possible through the acquisition of the capacity for phenol biosynthesis from phenylalanine. Central to plant biology is the fact that these phenols polymerized to form lignin which provided mechanical support to plants, and through combined action of cutin and suberin, provided protection against desiccation and consequently the conquest of dry environments (Parr and Bolwell 2000). These molecules designated as polyphenols constitute a very heterogeneous group of molecules with almost 100,000 individual chemical species. This large number of known structures owe to the glycoside complexity of flavonoids, the variable stereochemistry of the molecules and their capacity to form polymers (Harborne 1977).

Polyphenols are characterized by the presence of one or more benzene ring bearing one or many hydroxyl groups. They can be very simple ring molecules of 6C, but can be much more complex structures with many functional groups or polymers (Table 28.3). Within this complex class, flavonoids are the most relevant to biology and food technology. The flavonoids are made of 15 C and are regrouped into ten classes based on the structure of the central heterocycle (Fig. 28.2) and their degree of oxidation. The most oxidized form corresponds to the anthocyanins, which confer color to fruits, while the reduced form correspond to flavan-3-ols, known for their astringency and health properties. The vast majority of polyphenols is water-soluble and is sequestered in vacuoles in glycosylated form, while some are lipophilic (flavone, flavonol methyl esters) and will thus dissolve in waxes and be encountered in the epidermis of plants. The glycosylated flavonoids need to be stripped of their sugar moiety before absorption by the gut epithelium. Polyphenols are generally nucleophilic on the basis of their oxygen atom in the heterocyclic pyrane C ring, also the presence of many double bounds in the aromatic rings and the presence of hydroxyl groups in ortho- and para- position on the A and B ring. They are thus strong antioxidants. They will often complex with metal ions and contribute to the vivid blue color of some flowers. The presence of metal ions also multiplies the antioxidant capacity. Due to the presence of many hydroxyl groups, most flavonoids will interact strongly with proteins (Dangles and Dufour 2006) and with enzymes (McDougall and Stewart 2005). They will contribute to the sensation of astringency by binding proline and tyrosine found in saliva and mouth epithelial proteins (Haslam and Lilley 1988).

Food Sources of Polyphenols

FAV and beverage like wine are especially rich sources of polyphenols and in particular of flavonoids (Table 28.4). Their specific content depends on the species, the degree of maturity of the crop, the cultural management, the processing, the way they are cooked and stored. It is generally considered that the total flavonoid

Table 28.3 Main classes of phenolic compounds found in fruit and vegetables. (Macheix et al. 1990)

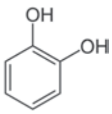
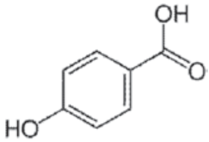
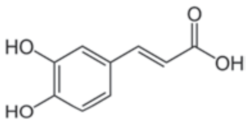
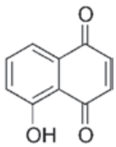
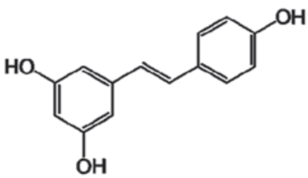
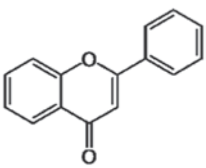
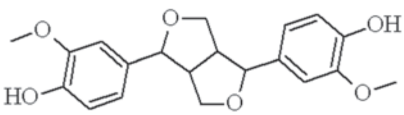
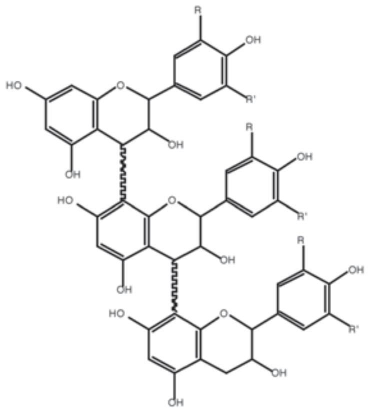
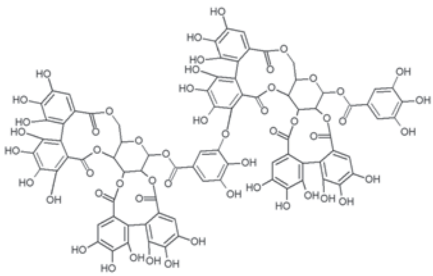
Carbon skeleton	Class	Type	Source
C6 	Simple phenol	Catechol	Many species, degradation products
C6-C1 	Hydroxybenzoic acid	P-benzoic acid, gallic acid, protocatecuic acid	Spices, strawberry, raspberry, blackberry
C6-C3 	Hydroxycinnamic acid, coumaric acid	Caffeic acid	Apples, citrus, potatoes, coffee (green), blueberry, spinach,
C6-C4 	Naphtoquinones	Juglone	Nuts
C6-C2-C6 	Stylbenes	Resveratrol, viniferine	Grapes, wine
C6-C3-C6 	Flavonoids	Quercetine, anthocyanin	Fruits, onion
$(C6\text{-}C3)_2$ 	Lignans	Pinoresinol, seicoisolariciresinol	Pine, kale, broccoli, apricot, strawberry

Table 28.3 (continued)

Carbon skeleton	Class	Type	Source
$(C6\text{-}C3)_n$	Lignin		Stone fruits
$(C6\text{-}C3\text{-}C6)_n$ 	Condensed tannins	Proanthocyanidins	Most fruits, cranberry, persimmon, nuts, chocolate
	Hydrosoluble tannins	Ellagitannins, Sanguiin H10	Strawberry, rubus, pomegranate, nuts

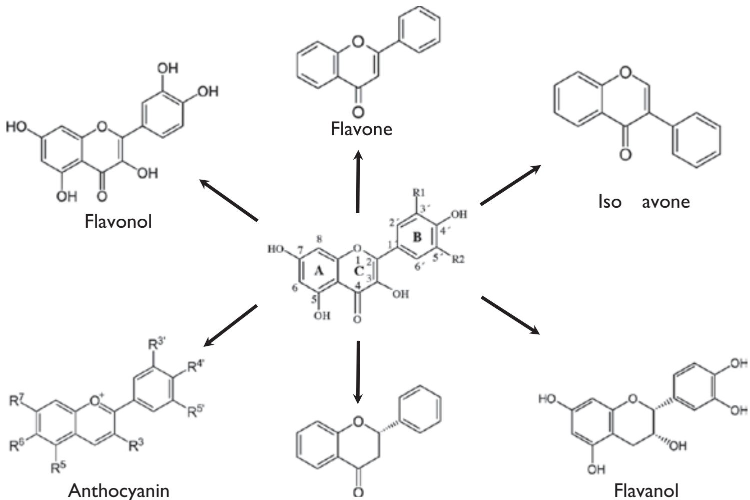


Fig. 28.2 Different classes of flavonoids found in FAV

Table 28.4 Sources of flavonoids in fruit and vegetables

Subclass	Compounds	Primary source
Flavonols	Quercetin, myricetin, kaempferol, rutin, isorhamnetin	Onion, apples, cranberry, broccoli, berries, olives, bananas, lettuce, plums, grapes, wine
Favanones	Hesperin, hesperidin, naringin, naringenin, eriodictol	Citrus
Flavan-3-ols	Catechin, epicatechin, galloylated derivatives	Tea, plums, apple, cranberries, berries, chocolate
Flavones	Luteolin, apigenin	Apples, Apiaceae, celery, sweet red pepper, parsley, oregano, lettuce, beet
Anthocyanins	Cyanidin, delphinidin, pelargonidin, malvidin, peonidin, petunidin (mostly as glycosides)	Berries, red fruits, red cabbage, eggplant

intake of occidentals is about 1 g/d (Kuhnau 1976; Scalbert and Williamson 2000). According to Brat et al. (2006), FAV consumption in France accounts for about 30 % of the overall daily polyphenol intake, which reach about 287 mg GAE/d. Other sources of polyphenols in the diet come from beverages like tea, coffee and wine but also from cereals. Moreover, humans consume a significant proportion of their polyphenols in a polymeric form as proanthocyanidins (PAC), which are often neglected (Saura-Calixto 2012). It is believed that oligomeric and polymeric forms of PAC are not absorbed by the enterocyte (Deprez et al. 2001) and are thus broken down by the gut bacteria where they provide prebiotic benefits (Williamson and Clifford 2010). The PAC are found in large quantities in small fruits like blueberry, cranberry and strawberry and are also abundant in nuts and especially hazelnuts, pecan, pistachio and almonds where their concentration can reach 500, 494, 237 and 184 mg/100 g F.W. respectively (Anon 2003).

Sulphur Compounds

Glucosinolates

Glucosinolates are amino-derived secondary plant metabolites containing a β-thioglucosyl moiety linked to an α-carbon forming a sulphated ketoxime (Fig. 28.3). They are found in the family of *Brassicacea* and are involved in plant/insects-pathogens interactions, and in plant development. The glucosinolate molecule is not involved as such in the biotic interactions but requires an hydrolysis catalyzed by a β-thioglucosidase, also called myrosinase to release the toxic isothiocyanate molecules. More than 120 glucosinolates have been identified in different species (Rosa et al. 1997) (Table 28.5).

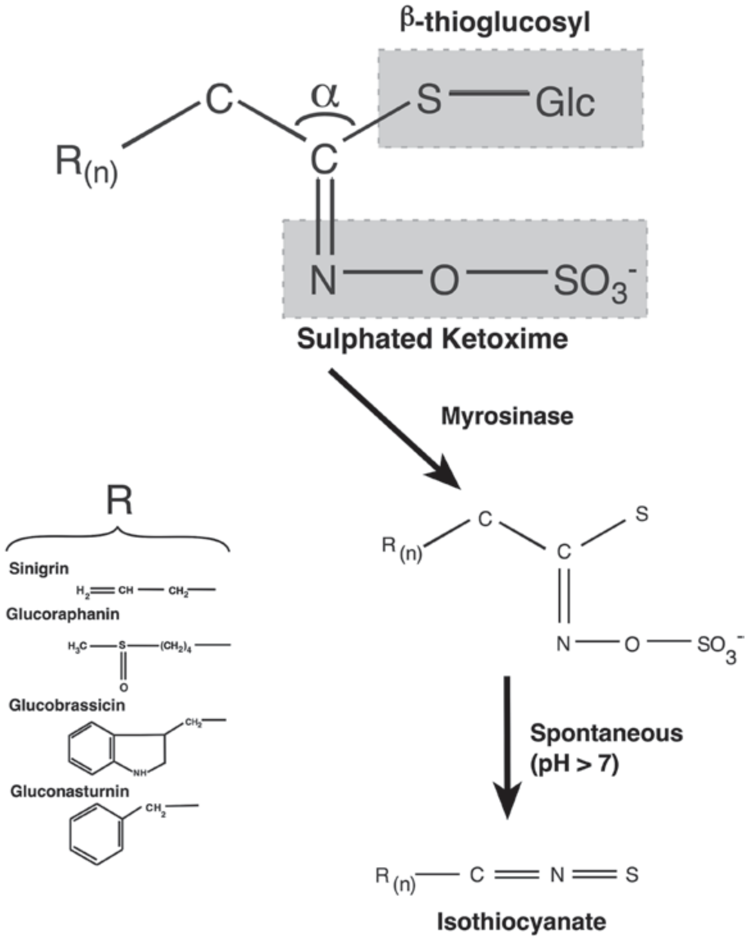


Fig. 28.3 Chemical structure of different common glucosinolates and ensuing thiocyanate

Glucosinolates levels in plants are largely determined by their genetic make up (Rosa et al. 1997) but they are also influenced by abiotic factors like nitrogen, sulphur, or potassium supply (Verkerk et al. 2009). However, genes involved in glucosinolate biosynthesis are also induced by herbivore and pathogen attacks (Agrawal and Kurashige 2003; Brader et al. 2001). Jasmonate and salicylate involved in wounding and herbivory signal transduction increases glucosinolate concentration (Doughty et al. 1995; Kiddle et al. 1994).

Plants have developed efficient defenses against herbivores and pathogens whereby glucosinolate are transformed into isothiocyanate when placed in presence of a thioglucosidase also known as myrosinase (Fig. 28.4). Under normal conditions, the precursor molecule and enzyme are compartmentalized in different tissues; glucosinolates are scattered in vacuoles of most organs while the glucosidase occur only in specific cells called myrosin cells, scattered throughout the plant

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