

A Study of Special Organic Compounds Called Plant Secondary Metabolites

Lalit Pal Singh

Dept. of Chemistry, R.B.S. College, Agra, Uttar Pradesh, India

ABSTRACT: Natural products are substances that are confined from living organisms, they are in the form of primary or secondary metabolites. Secondary metabolites are compounds with varied chemical structures, produced by some plants and strains of microbial species. Unlike primary metabolites (nucleotides, amino acids, carbohydrates, and lipids) that are essential for growth, secondary metabolites are not. Secondary metabolites are produced or synthesized during the stationary stage. Plants synthesize a large diversity of secondary metabolites; plant secondary metabolites are split into four groups namely alkaloids, phenolic compounds, terpenoids, and glucosinolates. Several classes of fungal and bacterial secondary metabolites, their sources, and pharmacological uses associated with the secondary metabolites occur.

KEYWORDS: natural, secondary metabolites, plant, phenolic, terpenoids, glucosinolates, chemical, compounds

I. INTRODUCTION

Secondary metabolites are natural products synthesized mainly by plants, fungi and bacteria. Secondary metabolites are molecules with low molecular weight and various biological activities and chemical structures [1]. Secondary metabolites are also called specialized metabolites; they generally mediate ecological interactions by increasing their ability to survive [2]. Secondary metabolites function as a defense against herbivores and other interspecies in plants; and it was first established by A. Kossel in 1910, and was discovered 20 years later as an end product of nitrogen metabolism by Friedrich Czapek a Botanist [3]. Plants are capable of manufacturing diverse types of organic compounds which are grouped into primary and secondary metabolites [3]. Some secondary metabolites are phenylpropanoids or cinnamic acids, which protect plants from UV damage [4]. Since ancient times, the plant secondary metabolite's biological effects in humans have been known. The herb *Artemisia annua* contains Artemisinin, which is widely used in herbal or traditional medicine. Plant secondary metabolites can be divided into four major classes: alkaloids, phenolic compounds, terpenes, and glucosinolates [5, 6]. Plants are natural products and the oldest source of alkaloids, examples of the most widely recognized alkaloids are morphine, quinine, strychnine, and cocaine [7]. Alkaloids are present as water-soluble salts of organic acids, esters, tannins (*Cinchona* bark) or in plant tissues [7, 8].

Most alkaloids are isolated in the form of crystalline, non-odorous, nonvolatile and amorphous compounds, low molecular weight alkaloids, such as arecoline and pilocarpine, non-oxygen atom alkaloids such as sparteine and nicotine occur in the liquid form, these are all from plant matrices. Majority of alkaloids are colorless with a bitter taste, apart from colchicine and berberine. Alkaloids are derived from plant sources and a diverse group of nitrogen-containing basic compounds, which contain one or more nitrogen atoms. Chemically they are heterogeneous. Based on chemical structures, they are classified into two broad categories [9] Examples of plants with alkaloids include, *Datura stramonium*, *Atropa belladonna*, *Erythroxylum coca*, *Solanaceae* (nightshade) plant family, *Papaver somniferum*, and *Catharanthus roseus*. Alkaloids (about 20,000) are isolated from plants, but it has also been found in microorganisms, marine organisms such as algae, dinoflagellates, and pufferfish, and terrestrial animals such as insects, salamanders, and toads [10].

Classification based on the botanical origin of the alkaloids, their Sources and pharmacological properties are listed below (Table 1). For example., *Papaver* (opium)alkaloids, *Cinchona* alkaloids, *Rauvolfia* alkaloids, *Catharanthus* alkaloids, *Strychnos* alkaloids, Ergot alkaloids, cactus alkaloids, and *Solanum* alkaloids [10], while the structures of some alkaloids are shown in Figure 1.

Alkaloid	Source	Properties
Ajmaline	<i>Rauvolfia serpentina</i>	Antiarrhythmic, antihypertensive
Caffeine	<i>Coffea arabica</i>	Stimulant, insecticide
Camptothecin	<i>Camptotheca acuminata</i>	Antineoplastic
Cocaine	<i>Erythroxylum coca</i>	Analgesic, narcotic, local anesthetic

Alkaloid	Source	Properties
Codeine	<i>Papaver somniferum</i>	Analgesic, antitussive
Emetine	<i>Uragoga ipecacuanha</i>	Antiamoebic, expectorant, emetic
Hyoscyamine	<i>Atropa belladonna</i> and others	Anticholinergic
Morphine	<i>P. somniferum</i>	Analgesic, narcotic
Nicotine	<i>Nicotiana tabacum</i>	Stimulant
Pilocarpine	<i>Pilocarpus jaborandi</i>	Cholinergic
Quinidine	<i>Cinchona</i> spp.	Antiarrhythmic
Quinine	<i>Cinchona</i> spp.	Antimalarial
Reserpine	<i>R. serpentina</i>	Tranquilizer
Scopolamine	<i>Hyoscyamus niger</i> and others	Sedative, anticholinergic
Strychnine	<i>Strychnos nux-vomica</i>	Stimulant, poison
Taxol	<i>Taxus brevifolia</i>	Antineoplastic
Vinblastine and vincristine	<i>Catharanthus roseus</i>	Antineoplastic

Table 1.
Sources and pharmacological uses of selected plant-derived alkaloids.

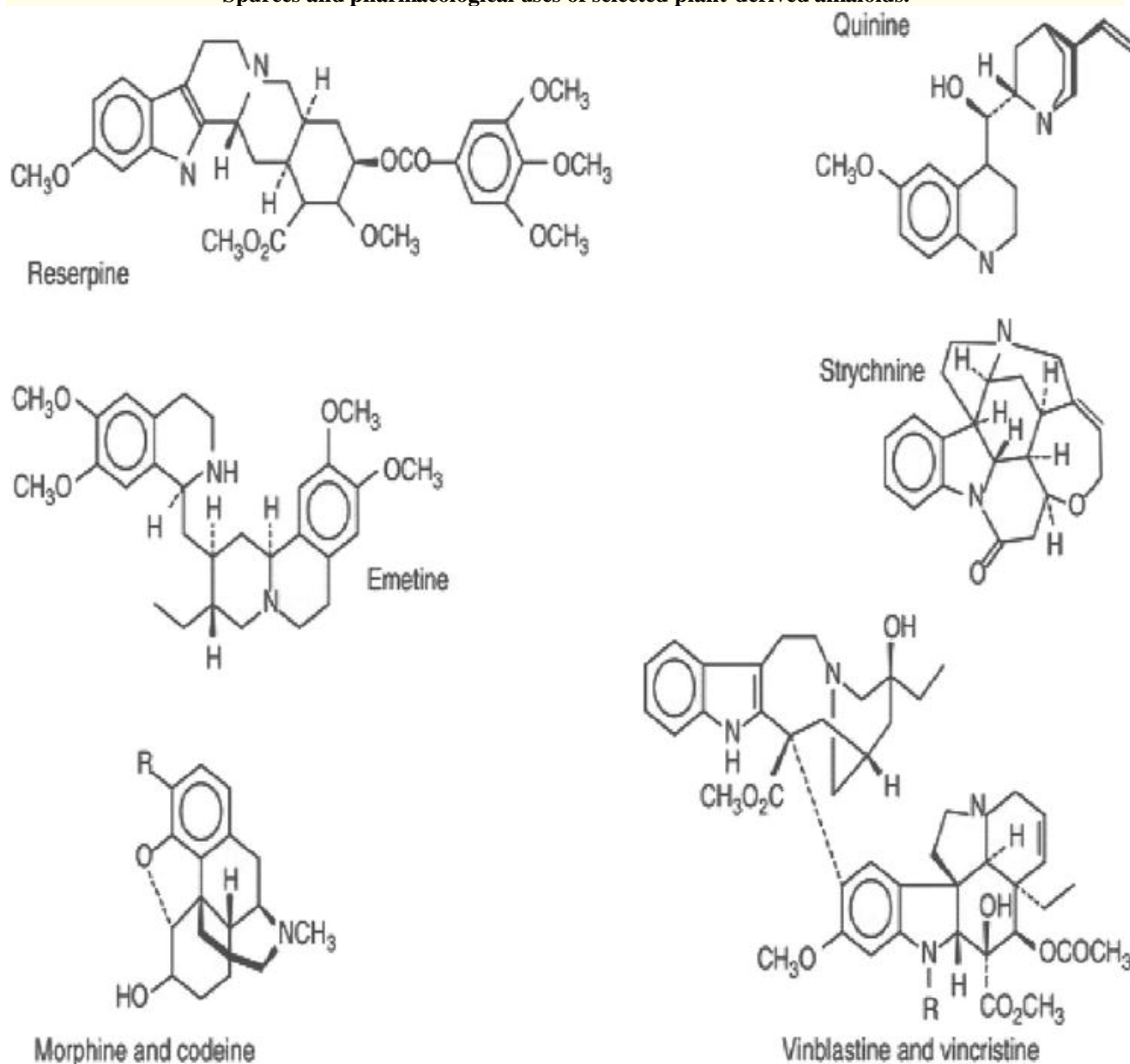


Figure 1.

Structures of some alkaloids. Note that the structures of morphine and codeine are based on the same skeleton, but are decorated with different functional groups in the position represented by 'R'. In morphine, this group is -OH, while in codeine it is CH₂O. Similarly, vinblastine and vincristine are based on the same skeleton, but differ in the nature of the R-group, which for vinblastine is -CH₃ and for vincristine is -CHO.[11]

II. DISCUSSION

Plant secondary metabolism produces phenolic compounds with chemical structures of one hydroxyl aromatic ring. These phenolic compounds are classified based on their carbon chain [11]. Phenolic compounds are found in plant tissues, fruits and vegetables and are also ubiquitously distributed phytochemicals. Phenolic compounds are synthesized through phenylpropanoid and shikimic acid pathways [12]. Phenolic compounds possess numerous bioactive properties and health-protective effects, although they are not nutrients, therefore postharvest treatments have been used to enhance or preserve the phenolic compounds in fruits and vegetables [12]. Phenolic compounds possess an aromatic ring with one or more hydroxyl substituents that can be divided into several classes, which are common chemical structures essential for health benefits [13].

Plant materials like (Tropical Root and Crops) contain two classes of phenolic compounds as hydroxybenzoic acids and hydroxycinnamic acids. Phenolic compounds are present in Nigerian *Centaurea perrottetii* DC. [family COMPOSITAE] and other related genera (*Cheirolophus*, *Rhaponticoides*, and *Volutaria*) [14].

The phenolic compounds found in plants are represented in Table 2, while the categories of phenolic compounds and their representative compounds are shown in Figure 2. Phenolic compounds survive in plant material, in either a soluble or a bound form [15, 16].

Polyphenolic Compounds	Example	Fruit Source
Phenolic acids	<i>Hydroxycinnamic acids</i>	
	Caffeic acid	
	Chlorogenic acid	
	Ferulic acid	Blackberry, raspberry, strawberry, blackcurrant, blueberry, cranberry, pear, sweet cherry, apple, orange, grapefruit, lemon, and peach
	Sinapic acid	
	Caftaric acids	
	Neochlorogenic acid	
	<i>p</i> -Coumaric acid	
	<i>Hydroxybenzoic acids</i>	
	Ellagic acid	Strawberry, raspberry, grapes, longan seed, and pomegranate
Flavonoids	<i>Flavonols</i>	
	Myricetin	
	Quercetin	Apples, apricots, grapes, plums, bilberries, cranberries, olive, elderberries, currants, cherries, blackberries, and blueberries
	Kaempferol	
	Isorhamnetin	
	<i>Flavanones</i>	
	Naringenin	Lemon, orange, grapefruit, and tangerine
	Hesperetin	
	<i>Flavones</i>	
	Apigenin	
	Luteolin	Citrus fruits and pear
	Tangeretin	
	Nobiletin	
<i>Flavan-3-ols</i>		
(+)-Catechin		
(-)-Epicatechin		
(-)-Epicatechin 3-gallate	Apples, apricots, grapes, peaches, nectarines, raspberries, cherries, blackberries, blueberries, cranberries, pears, plums, and raisins	
(-)-Epigallocatechin-3-gallate		
(+)-Gallocatechin		
(-)-Epigallocatechin		

Polyphenolic Compounds	Example	Fruit Source
Polyphenolic Compounds	Procyanidins	Blackberries, blackcurrant, blueberries, black grape, elderberries, strawberries, cherries, plums, cranberry, pomegranate, and raspberry
	Prodelphinidins	
	<i>Anthocyanins</i>	
	Cyanidin 3-galactoside	
	Cyanidin 3-glucoside	
	Cyanidin 3-arabinoside	
	Cyanidin 3-xyloside	
	Malvidin	
	Delphinidin	
	Pelargonidin	
Stilbenes	<i>Dihydrochalcones</i>	Apple
	Phloretin	
	Phloridzin	
	Resveratrol	
Stilbenes	<i>trans</i> -Resveratrol	Grapes
	Catechin polymers	Grape seed/skin, apple juice, strawberries, raspberries, pomegranate, walnuts, peach, blackberry, and plum
Epicatechin polymers		
Ellagitannins		
Proanthocyanidins		
Lignans	Tannic acids	Pear
	Secoisolariciresinol	
Lignans	Matairesinol	

Table 2.
Selected phenolic compounds found in plants.

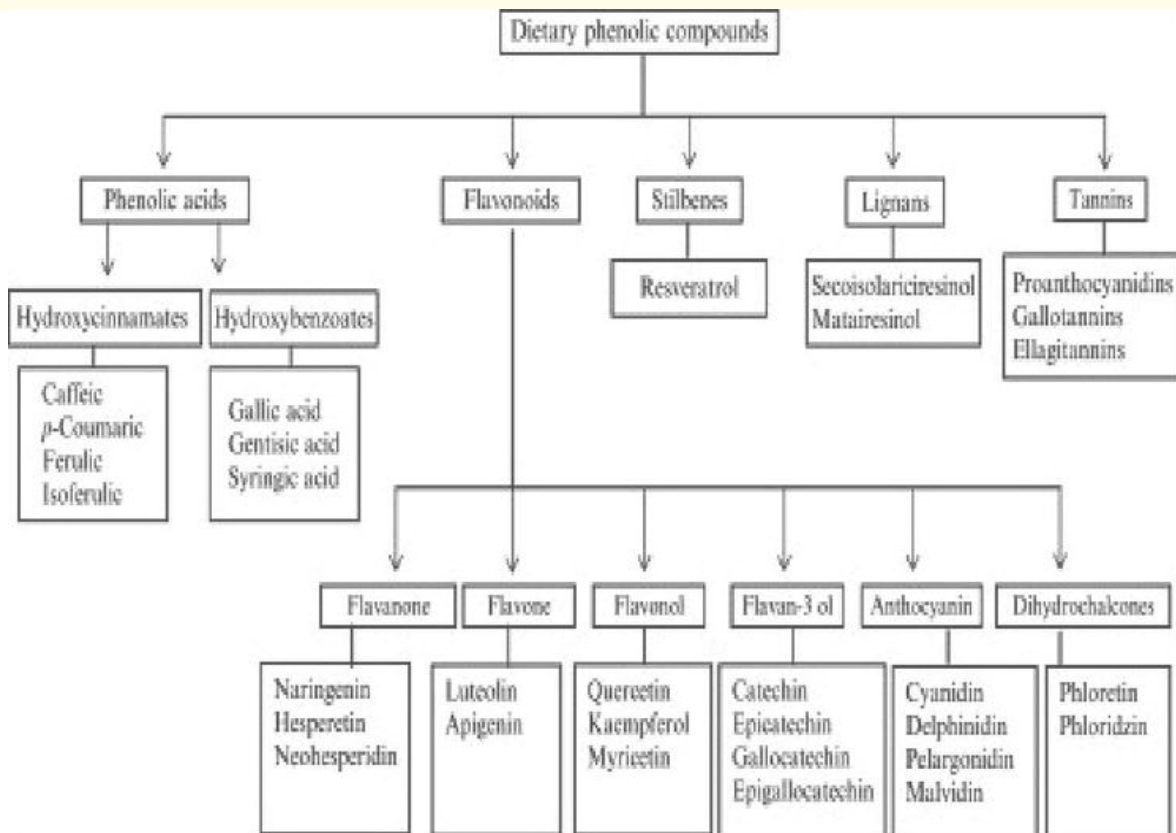


Figure 2.

Categories of phenolic compounds.

III. RESULTS

Terpenes are a unique group of hydrocarbon-based natural products whose structures are derived from isoprene. Terpenoid secondary metabolites occur in plant tissue types often secured in secretory structures [17]. Over 30,000 members of terpenes are in an enormous class of natural products, they have been used for a broad variety of purposes including medicine, flavoring and perfume [18]. Terpenes as a broad group with ecological roles, that exhibit a range of deadly to entirely edible toxicity, which include antimicrobial properties and other properties [19, 20].

Plants and flowering plants (angiosperms) subdivisions have colonized the majority of the terrestrial surface, courtesy of rich levels of specialization and the relationships with other organisms [21].

Terpenes are important plant metabolites that include substances like floral fragrances that serve as plant hormones (gibberellic and abscisic acid), growth inhibitors, insect attractants, pine oil, and insecticides [22].

Terpenoids or isoprenoids are high in plants where many can be considered secondary metabolites and have fundamental roles in the metabolism of all organisms [23]. Terpenoid secondary metabolism in plants began with the recruitment of genes from primary metabolism [24] and accelerated due to the proliferation of cytochrome P450 and terpene synthase gene families in the genomes of plants [25].

Terpenoids play various physiological and ecological functions in plant life and human through direct and indirect plant defenses, because of their enormous applications in the pharmaceutical, food and cosmetics industries [12]. Examples of terpenoids from plant species are 1). Artemisinin, present in *A. annua*, Chinese wormwood. 2). Tetrahydrocannabinol, present in *Cannabis sativa*, cannabis. 3). Azadirachtin, present in *Azadirachta indica*, the (Neem tree). 4). Saponins, glycosylated triterpenes present in *Chenopodium quinoa*, quinoa [15].

IV. CONCLUSIONS

The pungent smell of plants (mustard, cabbage, and horseradish) is due to mustard oils produced from glucosinolates [20]. Glucosinolates are biosynthesized from amino acids, which consists of three glucosinolate subtypes (aliphatic, indole and aromatic glucosinolates) that have their corresponding precursors. Aliphatic glucosinolates are derived from isoleucine, alanine, valine, methionine, and leucine. Indole and aromatic glucosinolates are obtained from phenylalanine or tyrosine and tryptophan. Examples of the three classes of glucosinolates represented by 3-methylsulfinylpropyl glucosinolate; indol-3-ylmethyl glucosinolate; and benzyl glucosinolate in Figure 3.

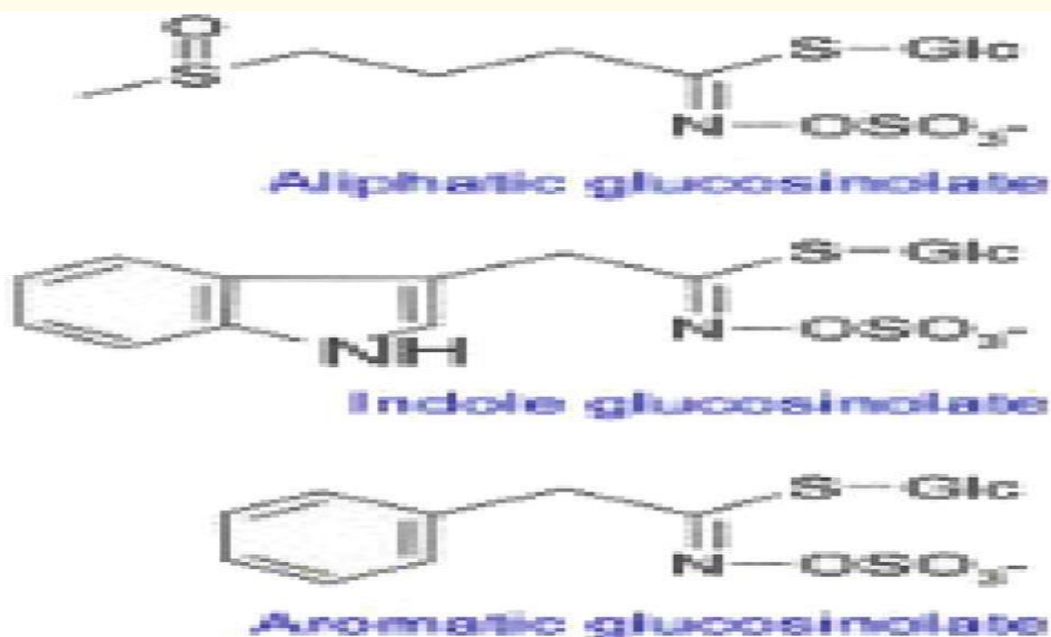


Figure 3.

Glucosinolates.

Glucosinolates are responsible for the pungent properties present in mustard, rucola, horseradish, cruciferous vegetables, and nasturtium and they are sulfur and nitrogen-containing glycosides, which protect against carcinogenesis [21].

The glucosinolates of sulforaphane (Glucoraphanin) present in broccoli, cabbage, and cauliflower (cruciferous vegetables) are responsible for protection against carcinogenesis. The Brown (*Brassica juncea*), white (*Brassica alba*) and black (*Brassica nigra*) mustards are examples of mustard seed with the family Brassicaceae [22].

Secondary metabolites in plants (glucosinolates, isothiocyanates, S-methyl cysteine, allyl sulfurs, phytates, phytoestrogens) likely to protect against cancers, and antioxidant properties (phenolic compounds, flavonoids) [24].

Isothiocyanates are present in cruciferous vegetables, which is the product of the degradation of glucosinolates. S-methyl cysteine is a sulfur-containing phytochemicals found in all brassica vegetables [25].

Glucosinolates contain metabolites found in the plant *Arabidopsis thaliana*. The strong taste of foods (horseradish, wasabi, and mustard) is as a result of glucosinolates [24].

Over 130 glucosinolate compounds have been identified in plants, and one way that they vary is by the amino acid precursor that is incorporated during glucosinolates biosynthesis [25].

REFERENCES

- 1.Návarová H, Bernsdorff F, Döring AC, Zeier J. Pipecolic acid, an endogenous mediator of defense amplification and priming, is a critical regulator of inducible plant immunity. *Plant Cell*. 2012;24(12):5123-5141
- 2.Bourgau F, Gravot A, Milesi S, Gontier E. Production of plant secondary metabolites: A historical perspective. *Plant Science*. 2001;161(5):839-851
- 3.Bruce SO, Onyegbule FA. Biosynthesis of natural products. In: Zepka LQ, do TC, Jacob-Lopes E, editors. *Bioactive Compounds - Biosynthesis, Characterization and Applications*. London: IntechOpen; 2021. DOI: 10.5772/intechopen.97660. Available from: <https://www.intechopen.com/chapters/76931>
- 4.Seigler DS. *Plant Secondary Metabolism*. New York: Springer US; 1998
- 5.Korkina L, Kostyuk V, Potapovich A, Mayer W, Talib N, De Luca C. Secondary plant metabolites for sun protective cosmetics: From pre-selection to product formulation. *Cosmetics*. 2018;5(2):32
- 6.Kumar P, Mina U. *Life Sciences: Fundamentals and Practice*. 3rd ed. New Delhi: Pathfinder Academy; 2013
- 7.O'Connor SE. In: Mander L, Lui H-W, Alkaloids. In book: *Comprehensive Natural Products II Chemistry and Biology*. Vol. 1. Oxford: Elsevier; 2010. pp. 977-1007. DOI: 10.1016/B978-008045382-8.00013-7
- 8.Croteau R, Kutchan TM, Lewis NG. Natural products (secondary metabolites). In: Civjan N, editor. *Natural Products in Chemical Biology*. Hoboken, New Jersey: Wiley; 2012. pp. 1250-1319
- 9.Kukula-Koch WA, Widelski J. Chapter 9 - Alkaloids. In: Delgoda R, editor. *Pharmacognosy. Fundamentals, Applications and Strategies*. Lublin, Poland: Academic Press; 2017. pp. 163-198. DOI: 10.1016/B978-0-12-802104-0.00009-3
- 10.Twyman RM, Stöger E, Christou P. Molecular farming. In: *Encyclopedia of Applied Plant Sciences*. 2nd ed. Vol. 2. Amsterdam: Elsevier Science B.V; 2003. pp. 77-82
- 11.Das PR, Eun J-B. Tea antioxidants in terms of phenolic and nonphenolic metabolites. In: Preedy VR, editor. *Pathology: Oxidative Stress and Dietary Antioxidants*. 1st ed. London: Academic Press; 2020. pp. 357-367
- 12.Bruce SO, Onyegbule FA, Ihekwereme CP. Evaluation of hepato-protective and anti-microbial activities of ethanol extracts and fractions of *Picralima nitida* seed and pod. *Journal of Phytomedicine and Therapeutic*. 2016;1(2):1-21
- 13.Ayad R, Akkal S. Phytochemistry and biological activities of Algerian *Centaurea* and related genera. In: Atta-ur-Rahman, editor. *Bioactive Natural Products, Studies in Natural Products Chemistry*. Vol. 63. Amsterdam, The Netherlands: Elsevier; 2019. pp. 357-414
- 14.Saranraj P, Behera SS, Ray RC. Chapter 7 - Traditional foods from tropical root and tuber crops: Innovations and challenges. In: Galanakis CM, editor. *Innovations in Traditional Foods*. Chania, Greece: Woodhead Publishing; 2019. pp. 159-191. DOI: 10.1016/B978-0-12-814887-7.00007-1
- 15.Gan RY, Chan CL, Yang QQ, Li HB, Zhang D, Ge YY, et al. Bioactive compounds and beneficial functions of sprouted grains. In: Feng H, Nemzer B, DeVries JW, editors. *Sprouted Grains*. United States: Woodhead Publishing and AACC International Press; 2019. pp. 191-246

16. Tiwari R, Rana CS. Plant secondary metabolites : A review. *International Journal of Engineering Research and General Science*. 2015;3(5):661-667. ISSN 2091-2730
17. Bruce SO, Onyegbule FA, Ezugwu CO. Pharmacognostic, physicochemical and phytochemical evaluation of the leaves of *Fadogia cienkowskii* Schweinf (Rubiaceae). *Journal of Pharmacognosy and Phytotherapy*. 2019;11(3):52-60
18. Maimone T. Classic Terpene Syntheses I. In: *An introduction to Terpenes*. Baran Lab; 2002. pp. 1-18
19. Mazid M, Khan TA, Mohammad F. Role of secondary metabolites in defense mechanisms of plants. *Biology and Medicine*. 2011;3(2):232-249
20. Kennedy DO, Wightman EL. Herbal extracts and phytochemicals: Plant secondary metabolites and the enhancement of human brain function. *Advances in Nutrition*. 2011;1:32-50
21. Wang G, Tang W, Bidigare RR. Terpenoids as therapeutic drugs and pharmaceutical agents. In: Zhang L, Demain AL, editors. *Natural Products*. Vol. 12. Totowa, NJ: Humana Press; 2013. pp. 153-175
22. Onyegbule FA, Bruce SO, Onyekwe ON, Onyealisi OL, Okoye PC. Evaluation of the in vivo antiplasmodial activity of ethanol leaf extract and fractions of *Jatropha gossypifolia* in *Plasmodium berghei* infected mice. *Journal of Medicinal Plant Research*. 2019;13(11):269-279
23. Cho KS, Lim Y, Lee K, Lee J, Lee JH, Lee I. Terpenes from forests and human health. *Toxicological Research*. 2017;33(2):97-106
24. Bouvier F, Rahier A, Camara B. Biogenesis, molecular regulation and function of plant isoprenoids. *Progress in Lipid Research*. 2005;44:357-429
25. Weng JK, Philippe RN, Noel JP. The rise of chemodiversity in plants. *Science*. 2012;336:1667-1670