We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter 10

Flavonoids in Agriculture

Mariana Palma-Tenango,

Marcos Soto-Hernández and

Eva Aguirre-Hernández

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.68626

Abstract

Flavonoids are compounds that are secondary metabolites, but which play an important role in the biological activities of plants. They can be responsible for the color of flowers and fruits and for the attraction of pollinators. They also participate in plant-microorganism symbiosis. These relationships can be used to naturally control weeds and insect pests and reduce stress and diseases in order to increase crop yield. To improve the understanding of the different biological systems where flavonoids are involved in their symbiotic relationships and in plant physiology, tools such as metabolomics are used, which give a broader picture and allow to search for strategies to solve problems specific to the agricultural sector.

Keywords: flavonoids, agriculture, plants, metabolomics

1. Introduction

Flavonoids are secondary metabolites of plants; this group of phenolic compounds includes approximately 4500 compounds [1]. They are classified into different subgroups (**Figure 1**). Their nuclear structure includes carbons C6-C3-C6, and the diversity of flavonoids depends on the position of the aromatic ring [2].

Flavonoids and flavones are the most common in plants, whereas flavanones, flavanols, dihydroflavones, and dihydrochalcones have a limited distribution. Flavonoids are present in plant tissues in relatively high concentrations in free forms (aglycones) or conjugated with sugar molecules (glycosides) [5].

INTECH
open science | open minds

© 2017 The Author(s). Licensee InTech. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

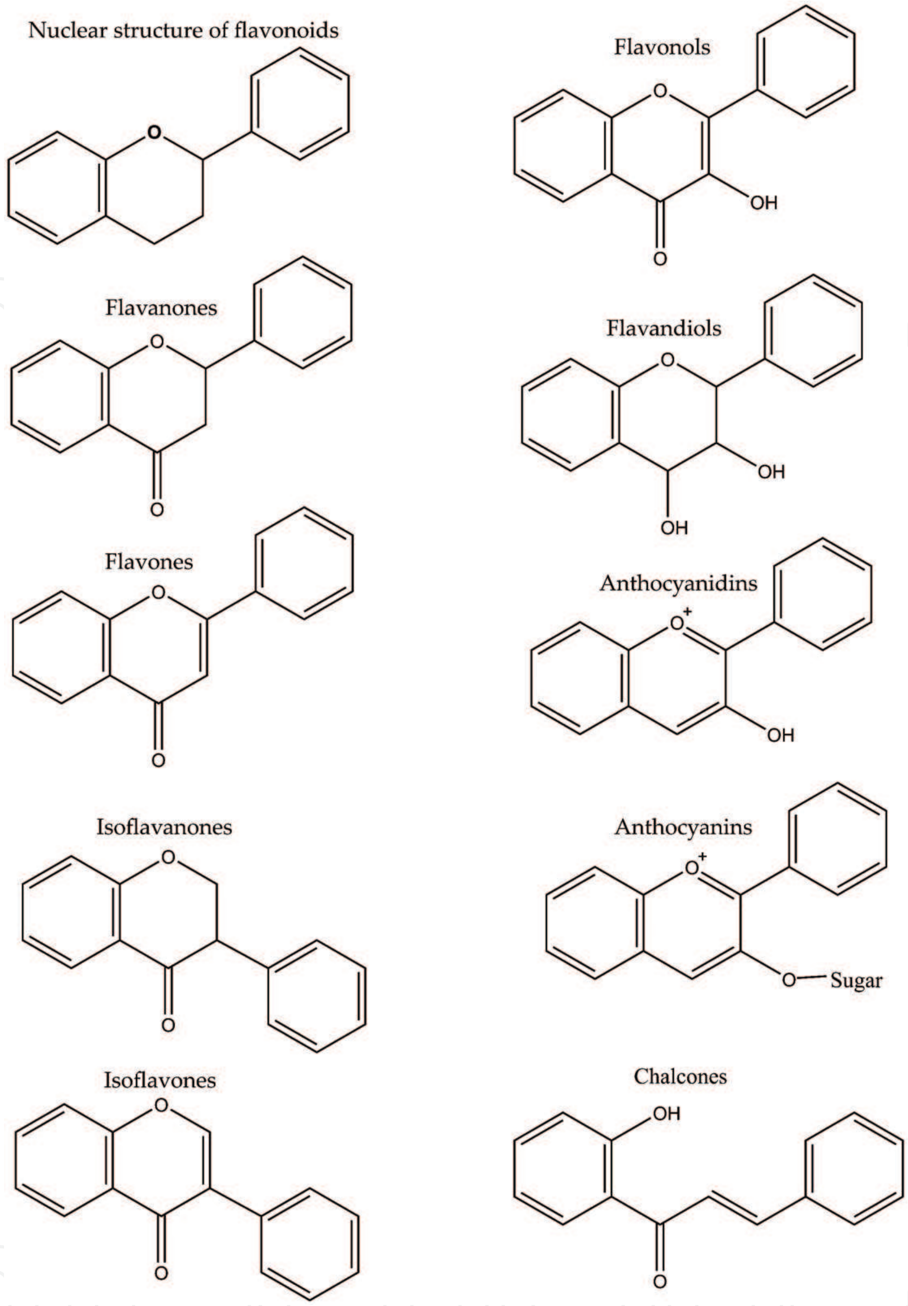

Figure 1. Structure of the different types of flavonoids (modified from Refs. [3, 4]).

Flavonoids are polyphenolic compounds found in all vascular and non-vascular plants [6]. They are important in the diet of humans because they possess a high nutritional value; besides, they are used as effective medicines in the treatments of certain diseases, and therefore, they are called nutraceuticals. Nowadays, a diet rich in fruits and vegetables is recommended to contribute to the prevention and treatment of cardiovascular diseases, diabetes, cancer, chronic inflammatory disorders, and degenerative diseases [7].

Some examples of nutraceutical flavonoids are the following: isoflavones (genistein, daidzein) obtained from celery, soybeans, and other legumes. Isoflavones have antitumor, anticancer,

http://dx.doi.org/10.5772/intechopen.68626

and antioxidant action, and they improve immune response, lower cardiovascular risk, and menopausal symptoms. Quercetin is contained in onion, citrus fruits, broccoli, red grapes, apple, and cherries. Kaempferol is present in broccoli and radishes [8]. Anthocyanins are present in red wine and fruits. These flavonoids are important due to their antioxidant, anticancer, and antithrombotic properties, as well as their ability to lower blood cholesterol [9].

Their concentration can vary among species: in fruits, vegetables, and medicinal plants, ranges from 0 to 6125.6 mg kg^{-1} have been reported. For example, 1720.5 mg kg^{-1} has been observed in spinach, 3575.4 mg kg^{-1} in strawberry, and 459.9 mg kg^{-1} in apple [10].

2. Function of flavonoids in plants

In plants, flavonoids play important roles in many biological processes (**Figure 2**). They participate in seed development and growth [11], fruit growth and ripening [12], pollen tube germination [13], and hormone transport [6]. Flavonoids respond to biotic and abiotic factors by providing antioxidant properties; they prevent damage caused by fungi, viruses, bacteria, and herbivores; function as chemical messengers in association with mycorrhizae and bacteria; act as chemical attractants to pollinating animals; and have allelopathic functions [14, 15].

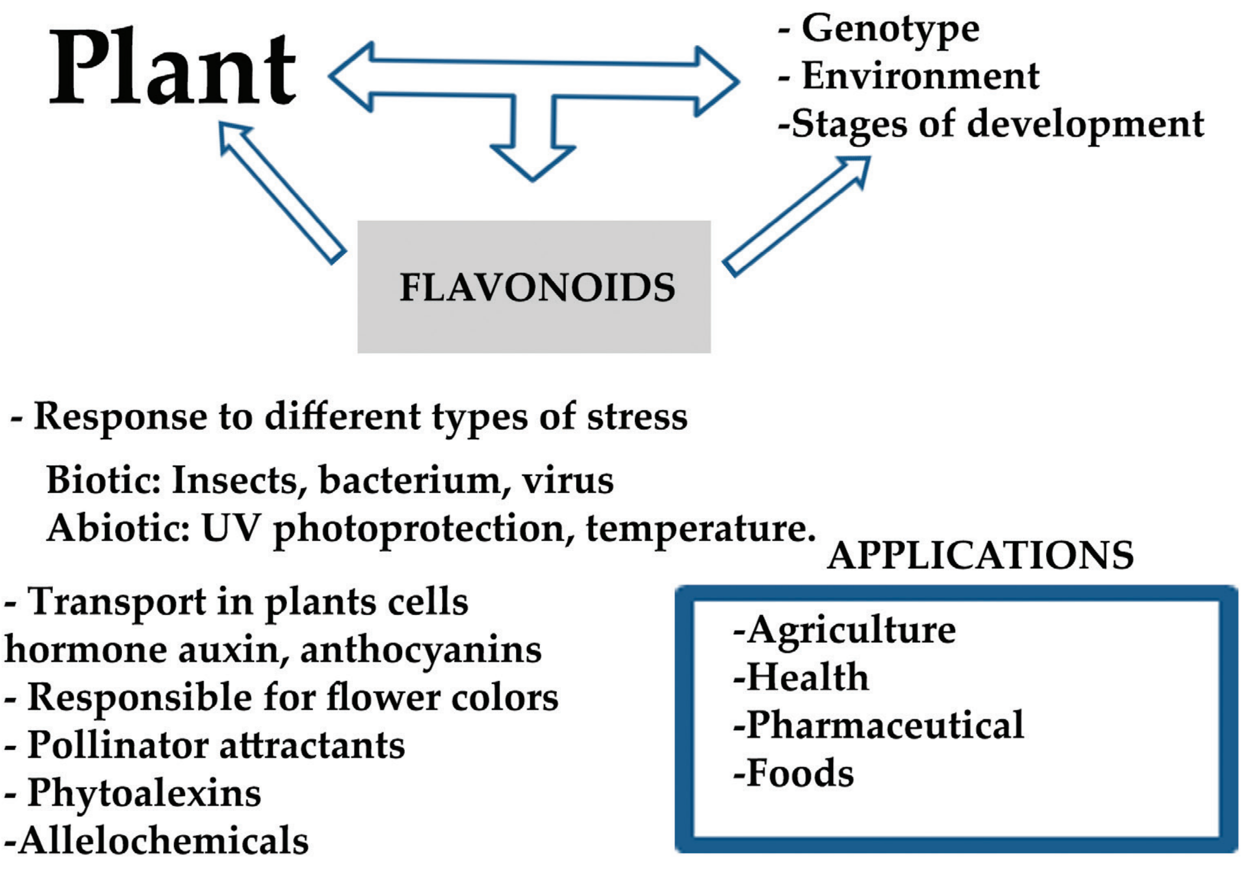

Figure 2. Main functions of flavonoids in plants (modified from Refs. [17–19]).

They also participate in pigment and color differences in flowers, fruits, and seeds [3]. For example, flavonols are related with yellow, flavanols with ochre to brown, and anthocyanins with red to purple [4]. In the case of corn kernels and petunia flowers, anthocyanins and proanthocyanidins are mainly responsible for the pigments. These accumulate in the vacuole or cell wall. In corn, accumulation occurs by vacuolar sequestration of anthocyanins [16].

As part of their defense strategy, plants induce systems of antioxidant activity, reactive oxygen species (ROS), enzymatic and non-enzymatic, soluble in water and in lipids, located in different cell compartments. The enzymatic ROS system consists of several enzymes such as superoxide dismutase (SOD), catalase (CAT), ascorbate peroxidase (APX), monodehydroascorbate reductase (MDAR), dehydroascorbate reductase (DHAR), glutathione peroxidase (GPX), and glutathione reductase (GR). Non-enzymatic antioxidants include pigments (carotenoids, anthocyanidins), vitamins (A, C, E), and flavonoids, among others [19]. The synthesis of the latter compounds by the plants is related to environmental biotic and abiotic stress factors. Plants subjected to conditions of severe stress accumulate dihydroxy B-ring substituted flavonoids, which are effective eliminators of ROS.

Flavonoids activate a network of events, including stress-induced morphogenesis, which protects plants from unexpected lesions of different origins [15]. Therefore, flavonoids play an important role in the protection of biological systems against the harmful effects of oxidative processes on macromolecules, they are important to catalyze electron transport and to eliminate reactive oxygen, especially in the form of superoxide anions, hydroxyl radicals, lipid peroxides, or hydroperoxides. In this way, they block the deleterious activity of these substances on the cells [15, 20].

3. Flavonoids: allelopathy and its applications in agriculture

Allelopathy is defined as the direct or indirect effect of secondary compounds produced by a donor plant on a recipient plant. This type of relationship can be beneficial or harmful [21].

Currently, to solve multiple problems in agriculture, allelopathy is being considered as a natural control of weeds and insect pests and to reduce stress and diseases, in order to increase crop yield [22, 23]. Weeds are the species that compete the most with crops, and for their management, aqueous extracts are used, such as natural herbicides from sorghum, sunflower, eucalyptus, and rice, among others; a greater efficacy is obtained when they are mixed together than alone [24]. On the other hand, it has been demonstrated that exudates of roots of rice plants reduce the attack of fungi of the genus *Fusarium* in melon. In addition, plants of *Brassica napus* L., incorporated into the soil, decrease the population of certain nematodes in orchards [23]. These examples show the potential of some allelochemicals to generate herbicides, fungicides, insecticides, and nematicides.

Knowledge of allelopathy can be valuable to improve crop rotation proposals [22]. Recent publications highlight the role of flavonoids in allelopathy, involved in soil interactions, since they have been identified in significant concentrations in many bioactive root exudates. Simple phenols and flavonoids are released by the decomposition of plant tissues as leachates and by the process of microbial degradation and transformation in the soil [22, 24].

In many legumes, it has been shown that the flavonoids quercetin and kaempferol, free and glycosylated, commonly released by germinating seeds and roots, persist for days in the soil and possess an important phytoinhibitory activity, stimulating seed germination at low concentrations but inhibiting seedling growth at high concentrations. These compounds are also present in leaf extracts of walnut trees [25].

The activity of several flavonoids is highly concentration-dependent; some of these compounds may be inhibitory or stimulatory, depending on the availability of the concentration in the soil/water solution in the rhizosphere [21]. Other allelopathic flavonoids are lutonarin, saponarin, and isovitexin, as well as catechin and cyanidin, luteolin 7-Ob-glucuronide, neochamaejasmin, mesoneochamaejasmin, chamaejasmenin, genkwanol, daphnodorin, and dihydrodaphnodorin, among others [21, 26, 27]. Allelochemicals directly and indirectly affect plants; indirect effects include soil alteration, physicochemical properties, changes in microbial populations, and differential nutrient availability for plants. The direct action is the physiological and biochemical changes generated during plant growth and development [22, 28]. Scientific studies have demonstrated several mechanisms of action of flavonoids when applied exogenously on plants. Such as changes in membrane permeability and inhibition of plant nutrient absorption, inhibition of cell division, elongation and submicroscopic structure, effects on photosynthesis and respiration of the plant, consequences on different enzymatic functions and activities, effects on the synthesis of endogenous hormones and proteins, and the disruption of adenosine triphosphate (ATP) formation [28].

4. Metabolomics: flavonoids as a tool in agriculture

It has been described that over 7000 natural products belong to the flavonoid family and to analyze them, physicochemical methods as nuclear magnetic resonance (NMR) and mass spectrometry have been used [29], but nowadays the most important issue is concerned with the identification of free and conjugated forms of these compounds. Metabolite profiling is an essential tool to analyze the effects of pathway engineering approaches; in this sense, the metabolomics approach used to solve this problem as the liquid-chromatography-mass spectrometry has supported the quantitative and qualitative analysis of flavonoids. In addition, straightforward and efficient methods approach toward rapid flavonoid identification by combining simple high-performance liquid chromatography (HPLC) and NMR methods, facilitating the analysis of flavones and flavanones [30].

The literature describes a lot of information on metabolomics in areas of medicinal plants, chemosystematics, adulteration of plants, and so on, but it is scarce in agriculture [31]. Flavonoids are a diverse group in agricultural crops, and there are studies using metabolomic tools to analyze the content of flavonoids using different analytical techniques (**Table 1**).

Red tomato contains flavonoids mainly in the peel; through omic studies, it may be possible to modify the pattern of flavonoids in the pulp [42]. Metabolic profiling represents a useful tool to characterize varieties with functional markers, such as flavonoids. For example, metabolite profiling allowed the characterization of Italian tomato landraces and different fruit types [43].

Crop	Plant organs	Analytical technique	Compound	Reference
Soybean	Leaves	(RP)-HPLC and ^{1}H NMR	Naringenin, rutin, quercetin, kaempferol and its glucosides, and total flavonoids	[32]
Red tomato	Fruit	HPLC/DAD and LC/NMR, LC/MS, and LC/MS/MS	Naringenin chalcone and rutin	[33]
Red and yellow raspberry cultivars	Fruit	UPLC/QqQ-MS/MS	Flavan-3-ol, quercetin-3,4-diglucoside, quercetin, kaempferol-3-glucuronide, rutin, and the conjugates of isorhamnetin	[34]
Avocado	Fruit	MS/MS LC-DAD-ESI-TOF MS	Catechin and epicatechin Rutin, Naringin, kaempferol, apigenin, luteolin, isorhamnetin	[35]
Maize	Kernels	LC-MS/MS	Apigenin, luteolin, methyl chrysoeriol, malvidin, pentose, rhamnose, selgin, tricin, chalcone synthase, chalcone isomerase	[36]
Rice	Leaf and bran	LC-QTOF-MS	Tricin, tricin 7-O-rutinoside, and tricin 7-O-β-ᴅ-glucopyranoside	[37]
Wheat	Flag leaf	UPLC-QTOF MS/MS	Isovitexin, isoorientin, Isoschaftoside, quercetin 3-rutinoside-7-glucoside and methylisoorientin-2″-O-rhamnoside	[38]
Grape	Berries	LC-MS	Quercetin and derivatives, kaempferol and isorhamnetin	[39]
Broad bean	Pods	UHPLC-ESI-qTOF-MS^2	Glycosylated flavonoids	[40]
Tea	Leaves	UPLC-Q-TOF MS	Flavan-3-ols, flavonols and their glucosides	[41]

Table 1. Metabolomic studies of flavonoids in agricultural crops.

Another study related with metabolomic profiling is the analysis of flavonoid distribution in three *Momordica* species, where 13 flavonoids were found in a special pattern [44].

The novel approach of genetic metabolomics referred to as metabolite profiling combined with quantitative trait locus (QTL) analysis was applied to detect flux control points in flavonoids biosynthesis of *Populus*. It was found that flavonoid profile can be used for QTL analysis to reveal loci that control the flux of their biosynthesis [45].

Plant metabolism is disrupted by several types of stress. Flavonoids are involved in the response toward abiotic stress [46]; a good model to understand how flavonoids contribute to the mitigation of oxidative and drought stress is *Arabidopsis thaliana*. Another example is the metabolomic analysis of tea, where the effects of light intensity and temperature on the metabolites in tea grown in the shade were evaluated; they found that most flavonoids (flavan-3-ols, flavonols, and their glucosides) decreased significantly in the shading treatments. Their study also showed a greater effect of temperature on galloylation of catechins than light intensity [41].

The growing stage of plants has been studied in connection with flavonoid synthesis, an interesting metabolomic study is the analysis of soybean leaves [47], it showed significant changes in the content of flavonoids and isoflavonoids, and kaempferol derivatives were used

http://dx.doi.org/10.5772/intechopen.68626

as markers. The results demonstrated that metabolite production changed depending on the growing stage, and they mention that the information can be useful to understand physiological characterization and suggest an optimal harvesting time of this crop.

Metabolic analysis has the potential to generate a complete vision of metabolic networks and has revealed multiple detection, quantification, and analysis strategies to evaluate numerous metabolites such as flavonoids. This tool attempts to integrate compound and metabolite analyses along with other biological data overview of plants, for example, phenotypic, morphological, and genetic data [48].

5. Symbiosis flavonoids-microorganisms

Flavonoids are considered signaling compounds in plant-microorganisms symbiosis; their function is signaling in response to pathogens, bacteria, fungi. Their participation is important in the nodulation of roots, where they are secreted to the rhizosphere [21], in the case of legumes under low nitrogen conditions, and where their interaction is specific with gram-negative bacteria called rhizobia that are nitrogen fixers [49]. They are also involved in the transcription of genes for the biosynthesis of rhizobial signaling molecules called Nod factors, which are perceived by the plant to allow symbiotic root infection [49]. Therefore, they can stimulate or inhibit rhizobial Nod gene expression. Root exudates can be flavonoids that participate as signaling compounds in the arbuscular mycorrhizal symbiosis [50]. Root exudation of flavonoids increases or decreases depending on the response to the symbiotic and pathogenic interaction of the plant and microbes.

It has been shown that certain flavonoids are stimulants for the germination of ectomycorrhizal fungi spores [50]. Depending on the arbuscular mycorrhizal fungi colonizers of the roots and the stage of symbiosis development [51].

The flavonoid role in the rhizosphere (**Table 2**) is important in agriculture because flavonoid interaction in the symbiosis with microorganisms can be a tool for nitrogen fixation in soils

Participation	Flavonoid	Species	Symbiosis type	Cite
Stimulant for germination of spores	Coumestrol, medicarpin, ononin, formononetin, daidzein, genistein, biochanin A and 4′,7-dihydroxyflavanone, 4,4′-dihydroxy-2′-methoxychalcone	*Medicago sativa* L. cv. Sitel	Fungus	[51]
	hesperidin, morin, rutin, quercetin, naringenin, genistein, and chrysin	*Suillus bovinus*	Fungus	[52]
Chemo attractant response from the rhizobia	Luteolin and apigenin	–	Bacterium	[53]
Auxin transport inhibitors	Kaempferol	*Medicago truncatula*	–	[54]

Table 2. Role of flavonoids in the rhizosphere.

poor in macronutrients. It can be a strategy to stimulate beneficial bacteria or inhibit harmful bacteria and fungi. It can also be considered in the genetic improvement of plant species.

6. Importance of flavonoids in pest control

Every day, the demand for natural products obtained from plants increases to be used as pest control agents. New pesticides are being developed using flavonoids, as they are an alternative to synthetic pesticides. They can inhibit enzymatic activity and prevent the growth of larvae of different insect species [55]. Some flavonoids interfere in the process of moulting and reproduction of several insects, that is, they inhibit the formation of juvenile hormone (ecdysone). Flavonoids inhibit transcription of ecdysone receptor-dependent genes (EcR) [56].

It has been reported that some types of flavonoids have had an effect on agricultural pests with ovicidal effect, oviposition, fecundity, mortality, weight reduction, and emergence of adults [57, 58]. Quercetin, rutin, and naringin showed positive effects for the control of nymphs and adults of the aphid *Eriosoma lanigerum* Hausmann. These can be used as an insecticide in the integrated management programs of this aphid [59]. Some flavonoids can influence agricultural pests depending on the concentration applied; if they are low, they do not affect them [60]; therefore, it is necessary to test the minimum concentrations for the flavonoid to have an insecticidal effect.

7. Concluding remarks

Throughout this chapter, the importance and interest in the knowledge of flavonoids as a big group of natural products, present in different organisms, have been emphasized. They have been widely investigated, from their biosynthesis, analytical techniques for their analysis, to their biological activity. They are compounds with different responses to biotic and abiotic factors, which can influence the agricultural sector as attractants for pollinators, as pigment to flowers and fruits, allelochemical functions, symbiosis with beneficial organisms, and as pest control.

The importance of flavonoids lies not only in the functions in plants but also in different therapeutic and nutraceutical applications. It is a group that is present in a wide variety of plant species, in different concentrations. In addition, its beneficial effects on health have been demonstrated and one of the most notable examples is its antioxidant activity.

However, the information linked to agriculture is scattered. Therefore, the purpose of this chapter is to provide an overview of their applications and show that metabolomics is an effective tool for research linked to metabolic processes of flavonoids with various agricultural crops.

Author details

Mariana Palma-Tenango[1], Marcos Soto-Hernández[2]* and Eva Aguirre-Hernández[1]

*Address all correspondence to: msoto@colpos.mx

1 Department of Ecology and Natural Resources, Laboratory of Phytochemistry, Faculty of Science, Universidad Nacional Autónoma de México, Ciudad Universitaria, Coyoacán, México

2 Department of Botany, Laboratory of Phytochemistry, Colegio de Postgraduados, Campus Montecillo, Texcoco, México

References

[1] Croteau R, Kutchan T, Lewis N. Secondary metabolites. In: Buchanan B, Gruissem W, Jone R, editors. Biochemistry Molecular Biology of Plants. Sommerset New Jersey, American Society of Plant Physiologists ed. 2000. pp. 1250-1318. DOI: 10.1016/j.phytochem.2011.10.011

[2] Heim KE, Tagliaferro AR, Bobilya DJ. Flavonoid antioxidants: Chemistry, metabolism and structure-activity relationships. Journal of Nutritional Biochemistry. 2002;**13**:572-584. DOI: http://doi.org/10.1016/S0955-2863(02)00208-5

[3] Falcone FM, Rius SP, Casati P. Flavonoids: Biosynthesis, biological functions, and biotechnological applications. Frontiers in Plant Science. 2012;**3**:1-16. DOI: http://doi.org/10.3389/fpls.2012.00222

[4] Petrussa E, Braidot E, Zancani M, Peresson C, Bertolini A, Patui S, et al. Plant flavonoids-biosynthesis, transport and involvement in stress responses. International Journal of Molecular Sciences. 2013;**14**(7):14950-14973. DOI: http://doi.org/10.3390/ijms140714950

[5] Di Carlo G, Mascolo N, Izzo A, Cappasso F. Flavonoids old and new aspect of a class of natural therapeutic drugs. Life Sciences. 1999;**65**(4):337-353

[6] Peer WA, Murphy AS. Flavonoids and auxin transport: Modulators or regulators? Trends in Plant Science. 2007;**12**:556-563. DOI: http://doi.org/10.1016/j.tplants.2007.10.003

[7] Ghasemzadeh A, Ghasemzadeh N. Review flavonoids and phenolic acids: Role and biochemical activity in plants and human. Journal of Medicinal Plants Research. 2011;**5**: 6697-6703

[8] Zeng S, Wu M, Zou C, Liu X, Shen X, Hayward A, et al. Comparative analysis of anthocyanin biosynthesis during fruit development in two Lycium species. Physiologia Plantarum. 2014;**150**:505-516

[9] Rivera G, Bocanegra G, Mongec A. Traditional plants as source of functional foods a review. Journal of Food. 2010;**8**:159-167

[10] Sultana B, Anwar F. Flavonols (kaempferol, quercetin, myricetin) contents of selected fruits, vegetables and medicinal plants. Food Chemistry. 2008;**108**:879-884. DOI: http://doi.org/10.1016/j.foodchem.2007.11.053

[11] Song C, Xiang DB, Yan L, Song Y, Zhao G, Wang YH, et al. Changes in seed growth, levels and distribution of flavonoids during tartary buckwheat seed development. Plant Production Science. 2016;**1008**:1-10. DOI: http://doi.org/10.1080/1343943X.2016.1207485

[12] Andreotti C, Ravaglia D, Ragaini A, Costa G. Phenolic compounds in peach (*Prunus persica*) cultivars at harvest and during fruit maturation. Annals of Applied Biology. 2008;**153**:11-23. DOI: http://doi.org/10.1111/j.1744-7348.2008.00234.x

[13] Ylstra B, Touraev A, Moreno RM, Stöger E, Van T, Vicente O, et al. Flavonols stimulate development, germination, and tube growth of tobacco pollen. Plant Physiology. 1992;**100**:902-907. DOI: http://doi.org/10.1104/pp.100.2.902

[14] Wink M. Introduction: Biochemistry, physiology and ecological functions of secondary metabolites. Annual Plant Reviews. 2010;**40**:1-19

[15] Agati G, Azzarello E, Pollastri S, Tattin M. Flavonoids as antioxidants in plants: Location and functional significance. Plant Science. 2012;**196**:67-76

[16] Koes R, Verweij W, Quattrocchio F. Flavonoids: A colorful model for the regulation and evolution of biochemical pathways. Trends in Plant Science. 2005;**10**(5):236-242. DOI: http://doi.org/10.1016/j.tplants.2005.03.002

[17] Winkel-Shirley B. Biosynthesis of flavonoids and effects of stress biosynthesis of flavonoids and effects of stress. Current Opinion in Plant Biology. 2002;**5**:218-223. DOI: http://doi.org/10.1016/S1369-5266(02)00256-X

[18] Cesco S, Mimmo T, Tonon G, Tomasi N, Pinton R, Terzano R, et al. Plant-borne flavonoids released into the rhizosphere: Impact on soil bio-activities related to plant nutrition. A review. Biology and Fertility of Soils. 2012;**48**(2):123-149. DOI: http://doi.org/10.1007/s00374-011-0653-2

[19] Dinakar C, Djilianov D, Bartels D. Photosynthesis in desiccation tolerant plants: Energy metabolism and antioxidative stress defense. Plant Science. 2012;**182**:29-41

[20] Xu C, Sullivan JH, Garrett WM, Caperna TJ, Natarajan S. Impact of solar ultraviolet-B on the proteome in soybean lines differing in flavonoid contents. Phytochemistry. 2008;**69**(1):38-48

[21] Weston LA, Mathesius U. Flavonoids: Their structure, biosynthesis and role in the rhizosphere, including allelopathy. Journal of Chemical Ecology. 2013;**39**(2):283-297. DOI: http://doi.org/10.1007/s10886-013-0248-5

[22] Farooq M, Bajwa AA, Cheema SA, Cheema ZA. Application of allelopathy in crop production. International Journal of Agriculture and Biology. 2013;**15**:1367-1378

[23] Muzell TM, Vidal RA, Balbinot JA, Von HB, Da Silva SF. Allelopathy: Driving mechanisms governing its activity in agriculture. Journal of Plant Interactions. 2016;**11**(1):53-60

[24] Cho MH, Lee SW. Phenolic phytoalexins in rice: Biological functions and biosynthesis. International Journal of Molecular Sciences. 2015;**16**(12):29120-29133

[25] Hai Z, Jin-Ming G, Wei-Tao L, Jing-Cheng T, Xing-Chang Z, Zhen-Guo J, et al. Allelopathic substances from walnut (*Juglans regia* L.). Allelopathy Journal. 2008;**21**:425-432

[26] Beninger CW, Hall JC. Allelopathic activity of luteolin 7-O-β-glucuronide isolated from *Chrysanthemum morifolium* L. Biochemical Systematics and Ecology. 2005;**33**(2):103-111

[27] Yan Z, Guo H, Yang J, Liu Q, Jin H, Xu R, et al. Phytotoxic flavonoids from roots of *Stellera chamaejasme* L. (Thymelaeaceae). Phytochemistry. 2014;**106**:61-68

[28] Li ZH, Wang Q, Ruan X, Pan CD, Jiang DA. Phenolics and plant allelopathy. Molecules. 2010;**15**(12):8933-8952. DOI: doi:10.3390/molecules15128933

[29] Maciej S, Piotrr K. Liquid chromatographic-mass spectrometric analysis of flavonoids. In: Weckwerth W, Kahl G, editors. The Handbook of Plant Metabolomics. Germany: John Wiley Sons; 2013. pp. 197-212

[30] Blunder M, Orthaber A, Bauer R, Bucar F, Kunert O. Efficient identification of flavones, flavanones and their glycosides in routine analysis via off-line combination of sensitive NMR and HPLC experiments. Food Chemistry. 2017;**218**:600-609. DOI: http://doi.org/10.1016/j.foodchem.2016.09.077

[31] Ibarra-Estrada E, Soto-Hernández RM, Palma-Tenango M. Metabolomics as a Tool in Agriculture. In: Prasain J, editor. Croatia, Metabolomics-Fundamentals and Applications. INTECH; 2016. DOI: 10.5772/66485

[32] Yun DY, Kang YG, Yun B, Kim EH, Kim M, Park JS, et al. Distinctive metabolism of flavonoids between cultivated and semiwild soybean unveiled through metabolomics approach. Journal of Agricultural and Food Chemistry. 2016;**64**:5773-5783

[33] Le Gall G, Dupont MS, Mellon FA, Davis AL, Collins GJ, Verhoeyen ME, et al. Characterization and content of flavonoid glycosides in genetically modified tomato (*Lycopersicon esculetum*) fruits. Food and Chemistry. 2003;**51**:2438-2446

[34] Carvalho E, Franceschi P, Feller A, Palmieri L, Wehrens R, Martens S. A targeted metabolomics approach to understand differences in flavonoid biosynthesis in red and yellow raspberries. Plant Physiology and Biochemistry. 2013;**72**:79-86

[35] Hurtado-Fernandez E. Avocado (*Persea americana*): complementary of different omics technologies for its metabolic characterization [thesis]. Granada Spain: Universidad de granada; 2014. p. 544. Available from: http://hdl.handle.net/10481/34097

[36] Wen W, Li D, Li X, Gao Y, Li W, Li H, et al. Metabolome-based genome-wide association study of maize kernel leads to novel biochemical insights. Nature Communications. 2014;**5**:3438. DOI: http://doi.org/10.1038/ncomms4438

[37] Yang Z, Nakabahashi R, Mori T, Takamatsu S, Kitanaka S, Saito K. Metabolome analysis of *Oryza sativa* (rice) using liquid chromatography-mass spectrometry for characterization

organ specific of flavonoids with anti-inflammatory and anti-oxidant activity. Chemical and Pharmaceutical Bulletin. 2016;**64**:952-956

[38] Zhang Y, Ming X, Wang X, Liu J, Huang B, Guo X, et al. UPLC-QTOF analysis reveals metabolic changes in the flag leaf of wheat (*Triticum aestivum* L.) under low-nitrogen stress. Plant Physiology and Biochemistry. 2017;**111**:30-38. DOI: http://doi.org/10.1016/j.plaphy.2016.11.009

[39] Ruocco S, Stefanini M, Stanstrup J, Perenzoni D, Mattivi F, Vrhovsek U. The metabolomic profile of red non-V. vinifera genotypes. Food Research International. 2017:1-10. DOI: http://doi.org/10.1016/j.foodres.2017.01.024

[40] Abu-Reidah IM, Ar´ráes-Román D, Waras I, Fernández-Gutiérrez A, Segura-Carretero A. UHPLC/MS2-based approach for the comprehensive metabolite profiling of bean (*Vicia faba* L.) by-products: A promising source of bioactive constituents. Food Research International. 2017;**93**:87-96. DOI: http://doi.org/10.1016/j.foodres.2017.01.014

[41] Zhang Q, Shi Y, Ma L, Yi X, Ruan J. Metabolomic analysis using ultra-performance liquid chromatography-quadrupole-time of flight mass spectrometry (UPLC-Q-TOF MS) uncovers the effects of light intensity and temperature under shading treatments on the metabolites in tea. Plos ONE. 2014;**9**:11. DOI: http://doi.org/10.1371/journal.pone.0112572

[42] Bovy A, Schijlen E, Hall RD. Metabolic engineering of flavonoids in tomato (*Solanum lycopersicum*): The potential for metabolomics. Metabolomics. 2007;**3**:399-412

[43] Baldina S, Picarella M, Troise AD, Pucci A, Ruggieri V, Ferracane R, et al. Metabolite profiling of Italian tomato landraces with different fruit type. Frontiers in Plant Science. 2016;**7**:2-13

[44] Madala NE, Piater L, Dubery I, Steenkamp P. Distribution patterns of flavonoids from three Momordica species by ultra-high performance liquid chromatography quadrupole time of flight mass spectrometry: A metabolomics profiling approach. Revista Brasileira de Farmacognosia. 2016;**26**:507-513

[45] Morrel K, Goeminne G, Storme V, Sterck L, Ralph J, Coppieters W, et al. Genetic metabolomics of flavonoids biosynthesis in Populus: A case study. The Plant Journal. 2006;**47**:224-237

[46] Nakabayashi R, Mori T, Saito K. Alteration of flavonoids accumulation under drought stress in *Arabidopsis thaliana*. Plant Signaling and Behavior. 2014;**9**(8):e29518

[47] Song H, Ryu HW, Lee KJ, Jeong Y, Kim DS, Oh SR. Metabolomics investigation of flavonoid synthesis in soybean leaves depending of the growth stage. Metabolomics. 2014;**10**:833-841

[48] Dixon RA, Gang DR, Charlton AJ, Fiehn O, Kuiper HA, Reynolds TL, et al. Applications of metabolomics in agriculture. Journal of Agricultural and Food Chemistry. 2006;**54**:8984-8994. DOI: http://doi.org/10.1021/jf061218t

[49] Liu CW, Murray J. The role of flavonoids in nodulation host-range specificity: An update. Plants. 2016;**5**:1-13. DOI: http://doi.org/10.3390/plants5030033

[50] Steinkellner S, Lendzemo V, Langer I, Schweiger P, Khaosaad T, Toussaint JP, et al. Flavonoids and strigolactones in root exudates as signals in symbiotic and pathogenic plant-fungus interactions. Molecules. 2007;**12**(7):1290-1306. DOI: http://doi.org/10.3390/12071290

[51] Larose G, Chênevert R, Moutoglis P, Gagné S, Piché Y, Vierheilig H. Flavonoid levels in roots of *Medicago sativa* are modulated by the developmental stage of the symbiosis and the root colonizing arbuscular mycorrhizal fungus. Journal of Plant Physiology. 2002;**159**(12):1329-1339. DOI: http://doi.org/10.1078/0176-1617-00896

[52] Kikuchi K, Matsushita N, Suzuki K, Hogetsu T. Flavonoids induce germination of basidiospores of the ectomycorrhizal fungus *Suillus bovinus*. Mycorrhiza. 2007;**17**(7):563-570. DOI: http://doi.org/10.1007/s00572-007-0131-8

[53] Phillips DA. Flavonoids: Plant signals to soil microbes. In: Ibrahim RK, Stafford HA, editors. Phenolic Metabolism in Plants. 1st ed. Colorado, North America: Springer US; 1992. pp. 201-216

[54] Zhang J, Subramanian S, Stacey G, Yu O. Flavones and flavonols play distinct critical roles during nodulation of *Medicago truncatula* by *Sinorhizobium meliloti*. The Plant Journal. 2009;**57**:171-183

[55] Kim JS, Kwon CS, Son KH. Inhibition of *ά*-glucosidase and *ά*-amylase by luteolin, a flavonoid. Bioscience, Biotechnology, and Biochemistry. 2000;**64**:2458-2461

[56] Oberdorster E, Clay MA, Cottam DM, Wilmot FA, McLachlan JA, Milner MJ. Common phytochemicals are ecdysteroid agonists and antagonists: A possible evolutionary link between vertebrate and invertebrate steroid hormones. Journal of Steroid Biochemistry and Molecular Biology. 2001;**77**:229-238

[57] Salunke BK, Kotkar HM, Mendki PS, Upasani SM, Maheshwari VL. Efficacy of flavonoids in controlling *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae) a post-harvest pest of grain legumes. Crop Protection. 2005;**24**:888-893

[58] Goławska S, Sprawka I, Łukasik I, Goławski A. Are naringenin and quercetin useful chemicals in pest-management strategies? Journal of Pest Science. 2014;**87**(1):173-180

[59] Ateyyat M. Impact of flavonoids against woolly apple aphid, eriosoma lanigerum (Hausmann) and its sole parasitoid *Aphelinus mali* (Hald.). Journal of Agricultural Science. 2012;**4**:227-236

[60] Monique S, Simmonds J. Importance of flavonoids in insect-plant interactions: Feeding and oviposition. Phytochemistry. 2001;**56**:245-252