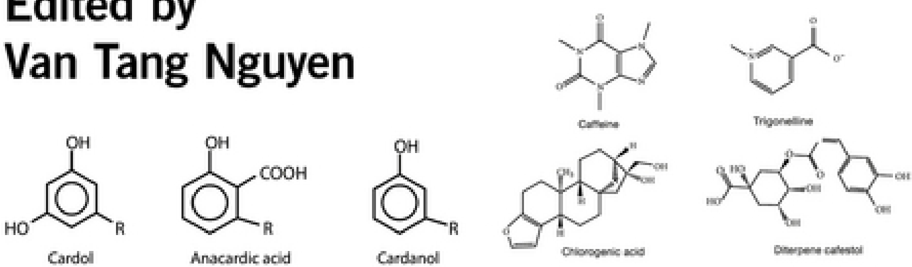
Recovering Bioactive Compounds from Agricultural Wastes

Edited by
Van Tang Nguyen



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University of Newcastle, Australia
Nha Trang University, Vietnam

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This book is dedicated to my dad Van Tac Nguyen, my mom Thi Thuy Duong, my wife Thi Le Nguyen, my son Trong Nhan Nguyen and my daughter Dan Thanh Nguyen.

Contents

List of Contributors

Md. Ariful Alam
Department of Pharmaceutical Technology, Faculty of Pharmacy, International Islamic University Malaysia (IIUM), Pahang, Malaysia

Fiorella P. Cárdenas-Toro
Department of Engineering, Section of Industrial Engineering, Pontifical Catholic University of Peru, San Miguel, Lima, Peru

Sahena Ferdosh
Department of Plant Science, Faculty of Science, International Islamic University Malaysia (IIUM), Kuantan Campus, Pahang, Malaysia

Kashif Ghafoor
Department of Food Science and Nutrition, King Saud University, Riyadh, Saudi Arabia

Rukshana Akter Happy
Department of Biochemistry and Biotechnology, Faculty of Basic Medical and Pharmaceutical Sciences, University of Science and Technology Chittagong (USTC), Foy's Lake, Chittagong, Bangladesh

Thang Trung Khong
Nha Trang University, Nha Trang, Khanh Hoa, Vietnam

Van Tang Nguyen
School of Environmental and Life Sciences, Faculty of Science and Information Technology, University of Newcastle, Ourimbah, NSW, Australia

and

Department of Food Technology, Faculty of Food Technology, Nha Trang University, Nha Trang, Khanh Hoa, Vietnam

Hong Ngoc Thuy Pham
School of Environmental and Life Sciences, Faculty of Science and Information Technology, University of Newcastle, Ourimbah, NSW, Australia

and

Department of Postharvest Technology, Faculty of Food Technology, Nha Trang University, Nha Trang, Khanh Hoa, Vietnam

Md. Zaidul Islam Sarker
Department of Pharmaceutical Technology, Faculty of Pharmacy, International Islamic University Malaysia (IIUM), Pahang, Malaysia

Nguyen Thi Thao
Department of Quality Management, School of Biotechnology and Food Technology, Hanoi University of Science and Technology, Hanoi, Vietnam

Hoang Quoc Tuan
Department of Quality Management, School of Biotechnology and Food Technology, Hanoi University of Science and Technology, Hanoi, Vietnam

Giovani L. Zabot
Federal University of Santa Maria (UFSM), Cachoeira do Sul, RS, Brazil

About the Editor

Van Tang Nguyen was born in Hai Duong province, Vietnam. He obtained an Engineer degree in Food Technology from the Hanoi University of Science and Technology, Vietnam. He then received a Master's degree in Food Science from the National Taiwan Ocean University, Taiwan and a PhD in Food Science from the University of Newcastle, Australia. He has worked as a Demonstrator in Food Science and Human Nutrition at the School of Environmental and Life Sciences, Faculty of Science and Information Technology, University of Newcastle, Australia. He also works as a Lecturer in Food Technology at the Department of Food Technology, Faculty of Food Technology, Nha Trang University, Vietnam. His research has focused on natural bioactive compounds, pharmacological activity, value-added products and functional foods. His current expertise is in the extraction, isolation and quantification of bioactive compounds from natural materials and the determination of biological activity *in vitro* and *in vivo*.

Van Tang Nguyen has been interested in the use of agricultural residues/byproducts from the processing and production of food products for the production of value-added products for over a decade. He has published more than 25 research papers in peer-reviewed journals (*Food Science*, *Chemical Papers*, *Drying Technology*, *Chemistry and Biodiversity*, *Industrial Crops and Products*, *Food Processing and Preservation*, etc.) and has authored/edited five book chapters and five books in the field of Food Science and Technology. He has presented over 15 scientific reports at international conferences and served as the reviewer for many reputed journals (*Food Science*, *Food Biochemistry*, *Pharmaceutical Biology*, *Industrial Crops and Products*, *Current*

Pharmaceutical Research, and so on). He is currently Editor-in-Chief and Founder of Bioactive Research and a member of the Institute of Food Technologist (USA) and Pancreatic Cancer Research Group (Australia).

Van Tang Nguyen is married to Thi Le Nguyen. They have two children, Trong Nhan Nguyen and Dan Thanh Nguyen.

Preface

Agriculture is regarded as one of the most important fields of human industry, due to its role in ensuring global food security for over 7 billion people around the world and supporting other industries. Agricultural production creates a great amount of residues/byproducts, which are considered 'wastes'. Interestingly, agricultural wastes contain many valuable bioactive compounds, possessing a wide range of potential pharmacological properties, which have great contributions to make in related industries, such as nutraceuticals/functional foods, medicines, pharmaceuticals and cosmetics. However, they are still underutilised as abundant, inexpensive, renewable and sustainable sources of natural bioactive compounds.

In order to increase the value of agricultural production, reduce pollution risks and promote the development of related industries, we have prepared *Recovering Bioactive Compounds from Agricultural Wastes* to introduce the potential of agricultural wastes obtaining from the different sectors of agricultural production, such as tea, coffee, cacao, cashew, fruit and vegetable, wine, edible oil, starch and sugar, and to present, discuss and recommend various techniques for the extraction, isolation, purification and application of these bioactive compounds in different fields. We also discuss the economic and market analysis of agricultural wastes and bioactive compounds derived from these sources, based on a number of actual recovery processes to be established at pilot and industrial scales. Hopefully, this book will be a helpful reference for researchers, producers and traders in agricultural production and related industries.

Van Tang Nguyen, Editor
University of Newcastle, Australia
Nha Trang University, Vietnam

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1

Potential, Uses and Future Perspectives of Agricultural Wastes

Van Tang Nguyen

School of Environmental and Life Sciences, Faculty of Science and Information Technology, University of Newcastle, Ourimbah, NSW, Australia
Department of Food Technology, Faculty of Food Technology, Nha Trang University, Nha Trang, Khanh Hoa, Vietnam

1.1 Introduction

Agriculture has a developmental history going back thousands of years and is considered one of the most important fields of human knowledge because of its special role in ensuring global food security for over 7 billion people around the world. It also has an important role in supporting and promoting the development of other industries, such as nutraceuticals, medicines, pharmaceuticals and cosmetics. In particular, agriculture produces a large amount of wastes, containing a significant quantity of valuable bioactive compounds, such as polyphenols, phenolic acids, flavonols, flavanols, flavonoids, procyanidins, proanthocyanidins, anthocyanins, glycosides, carotenoids, saponins, tannins, alkaloids, sterols, steroids, triterpenes, quinones, peptides and carbohydrates, which have been proved to possess a variety of biological activities, including antioxidant, antibacterial, antifungal, antiviral, antimicrobial, antidiabetic, anticancer, antidiarrhoeal, antihypertensive, antimutagenic, anti-inflammatory, anticholesterol and anticardiovascular properties (Figure 1.1) (Balasundram et al., 2006; Santana-Méridas et al., 2012). However, the utilisation of agricultural wastes as an abundant, biorenewable and low-cost source for the production of high value-added products is still under investigation, with limited outcomes. Therefore, research is needed into the application of environmentally friendly traditional and advanced techniques with low production costs in the extraction, isolation and purification of phytochemical compounds from agricultural wastes in high yields and at maximal quality. This strategy will increase the value of agricultural wastes and reduce pollution risks for the environment in both the short and the long term, and will enable sustainable development, one of the most important goals of modern global agricultural production.

1.2 Potential of Agricultural Wastes

According to the Food and Agriculture Organization of the United Nations (FAOSTAT, 2015), the total harvested crop area worldwide in 2013 was about 4.36 billion ha, producing approximately 21.70 billion tonnes, with a total gross production value of US$24

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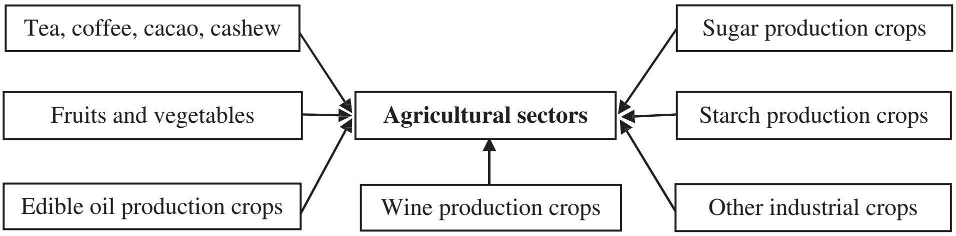

Figure 1.1 Major agricultural sectors in the recovery of bioactive compounds.

Table 1.1 Total harvested crop area, total production and total gross agricultural production value in 2013. *Source:* FAOSTAT (2015).

Location	Total harvested area (billion ha)	Total production (billion tonnes)	Total gross production value (billion US$)
Africa	0.71	1.90	1295.47
Americas	0.89	5.22	3503.55
Asia	1.82	9.94	15543.06
Europe	0.86	4.43	4350.89
Oceania	0.08	0.21	239.35
Total	4.36	21.70	24932.32

932.32 billion (Table 1.1). In Asia, the total harvested crops area was 1.82 billion ha (41.81% of total), producing 9.94 billion tonnes (45.80%), with a total gross production value of US$15 543.06 billion (62.34%).

Sugar cane had the highest production globally (1910 million tonnes), followed by maize, rice, wheat, potatoes, fresh vegetable, cassava, soybeans, palm fruit and sugar beet (1020, 741, 716, 376, 280, 277, 276, 266 and 247 million tonnes, respectively) (Table 1.2). All of these crops produced a large amount of relevant wastes, including leaves, tops and bagasse from sugar cane; straw, stalks, husk, bran and cobs from maize, rice and wheat; foliage, tops, peels and pulps from potatoes; leaves, stems, peels, skins and seeds from fresh vegetables; and peels, stalks and bagasse from cassava (FAOSTAT, 2015).

The wastes from crop-based residues, in terms of aerial biomass, roots, leaves, straw and stems, are rich sources of bioactive compounds, including polyphenols, flavonoids, sterols, anthocyanins and carbohydrates, which have direct links with potent pharmacological properties, such as antioxidant, antibacterial, antifungal, antimicrobial, anti-inflammatory and anticholesterol capacity (Table 1.3). Many valuable bioactive compounds, such as glycosides, procyanidins, proanthocyanidins, flavonols, flavanols, flavonoids, phenolic acids, carotenoids, saponins, tannins, alkaloids, steroids, triterpenes, quinones and peptides, can also be isolated from processing-based residues, such as from the fresh fruit, dry fruit, brewing, wine, cereal, oil, essential oil, sugarcane and tobacco industries (Table 1.4). The bioactive compounds isolated from these sources have been proved to possess a wide range of biological activities, including antioxidant, anticancer, antidiarrhoeal, antibacterial, antifungal, antiviral,

Table 1.2 Total harvested area, total production and total gross production value of major crops in 2013, as well as their main residues/wastes. *Source:* FAOSTAT (2015).

Crop	Total harvested area (million ha)	Total production (million tonnes)	Total gross production value (billion US$)	Main residues/wastes
Tea, coffee, cacao and cashew				
Tea	3.52	5.35	22.22	Fruit, flower, old leaves, dust, stalk and fibre
Coffee	10.14	8.92	16.37	Outer skin, pulp/mucilage, parchment/hull/husk, silver skin and spent coffee grounds
Cacao	10.01	4.59	6.95	Leaves, shell, husk, pulp/mucilage and hull
Cashew	5.46	4.44	2.82	cashew apple, outer shell, inner skin and nut shell
Fruits and vegetables				
Fruit fresh nes	5.01	33.52	13.39	Peels, pulps, seeds, stalks and skins
Vegetable fresh nes	19.79	280	135.42	Leaves, stems, peels, skins and seeds
Wine production crops				
Grapes	7.16	77.18	78.50	Pomace (seeds, skins), leaves, stalks, rachis and lees
Edible oil production crops				
Palm fruit	18.05	266	31.34	Shells, husks and fronts
Olives	10.31	20.40	19.47	Leaves and stalks
Coconuts	12.07	62.45	10.47	Shells, husks and fronts
Soybeans	112	276	131.26	Straw and pods
Sunflower seed	25.45	44.55	26.08	Foliage and stems
Rapeseed	36.50	72.70	53.13	Straw
Cotton seed	n/r	47.07	9.75	Stalks
Sugar production crops				
Beet	4.37	247	14.04	Roots, pulps and scums
Cane	26.94	1910	108.55	Leaves, tops and bagasse
Others	0.12	0.93	nr	Pulps and bagasse
Starch production crops				
Rice	165	741	429.27	Straw, husk and bran
Wheat	219	716	242.25	Straw
Maize	185	1020	382.34	Straw, stalks and cobs
Potatoes	19.34	376	149.51	Foliage, tops, peels and pulps
Cassava	20.39	277	47.31	Peels, stalks and bagasse
Barley	49.15	144	36.30	Straw

(Continued)

Table 1.2 (Continued)

Crop	Total harvested area (million ha)	Total production (million tonnes)	Total gross production value (billion US$)	Main residues/wastes
Other crops				
Beans, dry	29.05	22.81	16.06	Straw and pods
Beans, green	1.54	21.37	40.53	Straw and pods
Pepper	0.48	0.47	2.88	Leaves and stems
Seed cotton	32.17	73.05	82.62	Stalk

n/r, not reported

Table 1.3 High added-value products from crop-based residues. *Source:* Santana-Méridas et al. (2012). Reproduced with permission of Springer.

Activity	Species	Waste type	Bioactive compounds	Applications
Horticultural production				
Melon	*Cucumis melo*	Aerial biomass	Xanthan	Rheology modifier, food additive
Broccoli	*Brassica oleracea*	Aerial biomass	Glucosinolates, phenolic acids, flavonoids, vitamin C	Antioxidant
Carrot	*Daucus carota*	Roots	Hydroxycinnamic acid, anthocyanins	Antioxidant
Spinach	*Spinacea oleracea*	Leaves	Flavonoids	Antioxidant
Pepper	*Capsicum annuum*	Leaves, stems	Capsaicin, dihydrocapsaicin	Antioxidant, anti-inflammatory
Cucumber	*Cucumis sativus*	Leaves	Isovitexin, saponarin, vicenin-2, apigenin	Antioxidant
Tomato	*Lycopersicum sculentum*	Leaves	Solanesol	Antibacterial, anti-inflammatory
Cereal production				
Wheat	*Triticum* sp.	Straw	Xylose, polyphenols	Food ingredient
Others	sp.	Straw	Lignin	Value-added products
Tuber production				
Potato	*Solanum tuberosum*	Leaves	Solanesol	Antibacterial, anti-inflammatory

Table 1.3 (Continued)

Activity	Species	Waste type	Bioactive compounds	Applications
Fruit production				
Ginja cherry	*Prunus cerasus*	Stems, leaves	Polyphenols (catechin > 70%)	Antioxidant, antimicrobial
Pineapple	*Ananus comosus*	Straw (leaves)	Fibre	Polymer reinforcement
Grass production				
Ryegrass	*Lolium perenne*	Grass chaff	β-adenosine	Mushroom production
Miscanthus	*Miscanthus* × giganteus	Biomass	Lignin, phenols, sterols	Fuel, antioxidant, anticholesterol
Oil production				
Olive	*Olea europaea*	Leaves	Polyphenols	Antimicrobial, antioxidant
Medicinal and condimentary herbs				
Creosote bush	*Larrea tridentate*	Leaves	Poly and monomeric phenols	Antifungal
Saffron	*Crocus sativus*	Leaves	Kaempferol, orientin, vitexin	Antioxidant

Table 1.4 High added-value products from processing-based residues. *Source:* Santana-Méridas et al. (2012). Reproduced with permission of Springer.

Activity/crops	Species	Waste type	Bioactive compounds	Activity/applications
Fresh fruit industry				
Mango	*Mangifera indica*	Peels, pits/seeds	Tannins, vanillin, mangiferin	Antioxidant
Apple	*Malus domestica*	Pomace (peels, core, seeds, calyces, stems)	Pectin, catechins, hydroxycinnamates, phloretin glycosides, quercetin glycosides, procyanidins	Antioxidant
Watermelon	*Citrullus lanatus*	Rinds, flesh	Lycopene, citrulline, phenolic compounds	Antioxidant, food additives
Rambutan	*Nephelium lappaceum*	Peels	Ellagitannins	Antioxidant
Mangosteen	*Garcinia mangostana*	Pericarps	Proanthocyanidins	Antioxidant

(Continued)

Table 1.4 (Continued)

Activity/crops	Species	Waste type	Bioactive compounds	Activity/applications
Guajava	*Psidium guajava*	Bagasse	Epicatechin, quercetin, syringic acid, mirycetin	Antimicrobial
Banana	*Musa sapientum*	Dried leaves, pseudostems	Sugars	Fermentation
		Peels	α-amilasa, laccasa, citric acid	Enzyme production
Lemon	*Citrus limon*	Peels	Flavanoids, saponins, tannins, alkaloids, steroids, triterpenes	Antimicrobial
			Essential oil	Nematostatic activity
			Limonene	Insecticidal (larvicidal)
Orange	*Citrus sinensis*	Peels	Citric acid	Additive, detergent, cosmetic
			Essential oil	Nematostatic activity
Pineapple	*Ananus comosus*	Peels, core, crowns, stems	Bromelain	Food and textile industries, anti-inflammatory, anti-diarrhea, digestive
Pomegranate	*Punica granatum*	Husks	Poly- and monomeric phenols	Antifungal
Grapefruit	*Citrus paradisi*	Peels	Essential oil	Nematostatic activity
Mandarin	*Citrus reticulata*	Peels	Phenolic compounds	Antioxidant, antimicrobial
Papaya	*Carica papaya*	Peels, seeds	Phenolic compounds	Antioxidant, antimicrobial
Bergamot	*Citrus bergamia*	White tissues	Brutieridin, melitidin	Anticholesterolaemic
		Seeds	Limonoids	Antiviral
Satsuma mandarin	*Citrus unshiu*	Peels	Hesperidin, narirutin, quercetagetin	Antioxidant
Citrus fruits	*Citrus* sp.	Seeds, molasses	Limonoids	Anticancer
		Peels	Flavonoids (hesperidin, diosmin, narirutin, didymin, sinesetin), carotenoids (violaxanthin, β-crytoxanthin, β-carotene), vitamin C, essential oils (limonene), minerals	Antioxidant
Horticultural industry				
Artichoke	*Cynara scolymus*	Bracts, receptacles, stems, juice, heads	Neochlorogenic acid, chlorogenic acid, caffeoylquinic acids	Antioxidant

Table 1.4 (Continued)

Activity/crops	Species	Waste type	Bioactive compounds	Activity/applications
Beet	*Beta vulgaris*	Stalks	Azelaic acid	Antimicrobial
Onion	*Allium cepa*	Fresh peeling	Condensed tannins, flavonoids, quercetin aglycone	Antioxidant, textile dyes
		Skins, top–bottom wastes, scales, discarded onions	Flavonoids, fructans and alk(en)yl cystein sulphoxides, quercetin aglycone, minerals	Antioxidant, dietary fibre
Tomato	*Solanum lycopersicum*	Seeds, pulps, skins	Lycopene, β-carotene, sterols, tocopherols, terpenes, glycoalkaloids	Antioxidant, anticholesterol
Coffee industry				
Coffee	*Coffea Arabica*	Spent coffee grounds	Caffeine, chlorogenic acid	Allelopathy
Dry fruit industry				
Peanut	*Arachis hypogaea*	Skins, seed coats	Polyphenols oligomeric proanthocyanidins, indole alkaloids, phenolic acids	Antioxidant anticancer, Blood vessels protector, Antimicrobial
Almond	*Prunus dulcis*	Hulls	Triterpenes (olcanoic, ursolic, betulinic acids), daucosterol	Anticancer
Hazelnut	*Corylus avellana*	Skins, hard shells, leafy covers	Phenolic acids (gallic, caffeic, *p*-coumaric, ferulic, sinapic)	Antioxidant
Chestnut	*Castanea sativa*	Shells (outer, inner)	Tannins, polyphenols, tocopherols	Antioxidant
Walnut	*Juglans regia*	Shells	Holocellulose, α-cellulose, lignin	Panel manufacture
Pecan nut	*Carya illinoensis*	Shells (endocarp)	Poly and monomeric phenols	Antifungal
Pistachio	*Pistachia vera*	Hulls	Phenolic compounds	Antioxidant
Legume industry				
Pea	*Pisum sativum*	Husks	Growth factors (nitrogen and carbon)	Carrier for rhizobial inoculants
		Pods	Fibre, polyphenols	Antioxidant, texturing additive
Faba bean	*Vicia faba*	Pods	Fibre, polyphenols	Antioxidant, texturing additive
		Off-quality grains	Protein	Food ingredient

(Continued)

Table 1.4 (Continued)

Activity/crops	Species	Waste type	Bioactive compounds	Activity/applications
Chickpea	*Cicer arietinum*	Off-quality grains	Peptides	Metal chelating, antihypertensive, food ingredient
Common bean	*Phaseolus vulgaris*	Off-quality grains	Peptides	Antioxidant, metal chelating
Cereal industry				
Rice	*Oryza sativa*	Rice brand	Tocotrienols-tocopherols, γ-oryzanol, β-sitosterol	Anticholesterol
Wheat	*Triticum durum*	Wheat brand	Vitamin E, carotenoids, quinines	Nutrients, antioxidant
Wine industry				
Grape	*Vitis vinifera*	Stems	Betulinic acid, stilbenoid *trans*-resveratrol, *trans*-3-viniferin, sitosterol 6′-*O*-acylglucosides	Anticancer
		Pomace	Flavonols, flavonols glucosides, flavanols, gallate esters, anthocyanins, proanthocyanins	Antioxidant, antimicrobial
		Seeds	Epicatechin, caffeic and gallic acids	Antimicrobial
Brewing industry				
Barley	*Hordeum vulgare*	Spent grains	Xylitol, cellulose, hemicelluloses, lignin, xylose, glucose, arabinose, protein, ferulic and *p*-coumaric acids	Growth medium, lactic acid production, diabetes treatment (xylitol)
Oil industry				
Olive	*Olea europaea*	Olive mill wastewaters 'alpechin'	Hydroxytyrosol, gallic acid, oleuropein, ligstroside isomers and derivatives, squalene, tocopherols, triterpenes, soluble sugars, polyphenols	Antimicrobial, antioxidant, anti-inflammatory, textile dyes
		Pomace (solid wastes)	Hydroxytyrosol, tyrosol, caffeic protocatechuic, vanillic, p-coumaric and syringic acids, vanillin, oleuropein, apigenin	Antioxidant