Food Byproducts Management and Their Utilization

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CRC Press
Taylor & Francis Group
APPLE ACADEMIC PRESS

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APPLE ACADEMIC PRESS

First edition published 2024

Apple Academic Press Inc.
1265 Goldenrod Circle, NE,
Palm Bay, FL 32905 USA

760 Laurentian Drive, Unit 19,
Burlington, ON L7N 0A4, CANADA

CRC Press
2385 NW Executive Center Drive,
Suite 320, Boca Raton FL 33431

4 Park Square, Milton Park,
Abingdon, Oxon, OX14 4RN UK

Apple Academic Press exclusively co-publishes with CRC Press, an imprint of Taylor & Francis Group, LLC

Library and Archives Canada Cataloguing in Publication

Title: Food byproducts management and their utilization / edited by Ricardo Gómez-García, PhD, Ana A. Vilas-Boas, Débora A. Campos, PhD, Maria Manuela Pintado, PhD, Cristóbal Noé Aguilar, PhD.
Names: Gómez-García, Ricardo, editor. | Vilas-Boas, Ana A., editor. | Campos, Débora A. editor. | Pintado, Maria Manuela, editor. | Aguilar, Cristóbal Noé editor.
Description: First edition. | Includes bibliographical references and index.
Identifiers: Canadiana (print) 20230452019 | Canadiana (ebook) 20230452043 | ISBN 9781774912959 (hardcover) | ISBN 9781774912966 (softcover) | ISBN 9781003377801 (ebook)
Subjects: LCSH: Food industry and trade—By-products. | LCSH: Food industry and trade—Waste minimization. | LCSH: Bioactive compounds. | LCSH: Food—Biotechnology.
Classification: LCC TP373.8 .F66 2024 | DDC 664/.08—dc23

Library of Congress Cataloging-in-Publication Data

Names: Gómez-García, Ricardo, editor.

Title: Food byproducts management and their utilization / edited by Ricardo Gómez-García, PhD, Ana A. Vilas-Boas, Débora A. Campos, PhD, Maria Manuela Pintado, PhD, Cristóbal Noé Aguilar, PhD.

Description: First edition. | Palm Bay, FL : Apple Academic Press, 2024. | Includes bibliographical references and index. | Summary: "Food byproducts derived from industrial processing is a serious worldwide problem because it generates environmental pollution and results in significant food and economic losses from food waste. This new volume shows how food byproducts can be value-added renewable sources with the application of novel biotechnologies that avoid hazardous chemicals. The volume discusses the importance of valorizing food wastes and illustrates their value-added properties for industry. It explains the significant progress in bioresources processing for compound extraction and production as well as the increasing interest of food ingredients development, in which health care, environment, and economics play an essential part in biotechnological research. It considers the waste byproducts of various crops, such as tomato, melon, maize, berries, soybean, coffee, and their uses in the generation of health-benefiting bioactive compounds. The volume goes on to explore the various biotechnological strategies to extract, produce, and recover bioactive compounds along with the cost-effectiveness of these methods. This volume, Food Byproducts Management and Their Utilization, presents strategies that are of interest in food engineering, green chemistry, biotechnology, and some other areas, while paying special attention to biorefinery approaches and new challenges that industries are dealing with in the era of sustainable development. It aims to encourage not only researchers but also governmental and enterprise sectors to recognize the value and applications of food byproducts and waste"-- Provided by publisher.

Identifiers: LCCN 2023023230 (print) | LCCN 2023023231 (ebook) | ISBN 9781774912959 (hardback) | ISBN 9781774912966 (paperback) | ISBN 9781003377801 (ebook)

Subjects: LCSH: Food industry and trade--By-products. | Agricultural wastes. | Food processing by-products industry.

Classification: LCC TP373.8 .F626 2024 (print) | LCC TP373.8 (ebook) | DDC 664/.08--dc23/eng/20230712

LC record available at https://lccn.loc.gov/2023023230

LC ebook record available at https://lccn.loc.gov/2023023231

ISBN: 978-1-77491-295-9 (hbk)
ISBN: 978-1-77491-296-6 (pbk)
ISBN: 978-1-00337-780-1 (ebk)

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Ricardo Gómez-García, PhD, completed his doctorate program in Biotechnology at the Catholic University of Portugal (2017–2022). He graduated as a chemical engineer (2016) from the School of Chemistry, Autonomous University of Coahuila (UA de C), Mexico. He started his scientific career at the UA de C Food Research Department, where he gained great expertise in food engineering and technology, food chemistry, and biotechnology. For his PhD, he worked to develop innovative and sustainable technologies within the context of a zero-waste and circular economy approach for the extraction and identification of functional bioactive compounds with industrial interest from fruit byproducts for their valorization and reincorporation into the industrial value chains. Dr. Gómez-García is the author and co-author of 16 articles in indexed journals, seven chapters in books of international circulation with prestigious publishers, and one European provisional and one national patent applications. He has participated in more than 15 international congress communications in areas related to biotechnology, food science and technology, and bioengineering. He has also been participating in several national and international entrepreneurship programs in Portugal and across Europe through the European Institute of Innovation and Technology (EIT Food).

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Abbreviations

ABTS	2, 2'-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (biochemical reagent)
ACE	angiotensin-converting enzyme
ADF	antioxidant dietary fiber
APCR	anaerobic-packed column reactor
AX	arabinoxylans
BBI	Bowman–Birk inhibitor
BOD	biological oxygen demand
BSG	brewery spent grains
Ca	calcium
CAT	catalase
CBD	cannabidiol
CH	coffee pulp
CNS	central nervous system
CO2	carbon dioxide
COD	chemical oxygen demand
COX	cyclooxygenase
CS	coffee husk
CSE	conventional solvent extraction
CVD	cardiovascular diseases
DF	dietary fiber
DPPH	2,2-diphenyl-1-picrylhydrazyl (biochemical reagent)
DW	dry weight
EU	European Union
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
Fe	iron
FEL	liquid-state fermentation
FES	solid-state fermentation
FLW	food losses and waste
FRAP	ferric reducing antioxidant power
FVE	flash vacuum expansion
GAE	gallic acid equivalent
GRAS	generally recognized as safe

GSH-Px	glutathione peroxidase
HAT	hydrogen atom transfer
HDL	high-density lipoprotein
HP	high pressure
HPH	high-pressure homogenization
IDF	insoluble dietary fiber
IL-10	interleukin 10
IL-1β	interleukin-1 beta
IL-8	interleukin-8
K	potassium
KTI	Kunitz soybean trypsin inhibitor
LC-MS	liquid chromatography with tandem mass spectrometry
LDL	low-density lipoprotein
MAE	microwave-assisted extraction
MALDI-TOF MS	matrix-assisted laser desorption ionization-time-of-flight mass spectrometry
MBC	minimum bactericidal concentration
MDA	malondialdehyde
MHA	Mueller–Hinton agar
MIC	minimum inhibitory concentration
Mn	manganese
MW	molecular weight
NF-Kb	nuclear factor kappa light chain enhancer of activated B cells
OHAE	ohmic heating-assisted extraction
OHC	oil holding capacity
ORAC	oxygen radical antioxidant capacity
P	phosphorus
PLE	pressurized liquid extraction
PR	pathogenesis related
PS	particle size
PUFA	polyunsaturated fatty acids
ROS	reactive oxygen species
SBH	soybean hull
SCFAs	short-chain fatty acids
SCG	spend coffee grounds
SDF	soluble dietary fiber
SDS-PAGE	sodium dodecyl sulfate-polyacrylamide gel electrophoresis
SOD	superoxide dismutase

SFE	supercritical fluid extraction
TEAC	trolox equivalent antioxidant capacity
TNF-α	tumor necrosis factor alpha
TOC	total organic carbon
UAE	ultrasonic-assisted extraction
UASB	up-flow anaerobic sludge blanket
USA	United States of America
VLDL	very low-density lipoprotein
W	watts
WHC	water-holding capacity
WRC	water-retention capacity
WSC	water swelling capacity
ZN	zinc

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Preface

Over the last decade, some pressing issues have been affecting the balance between human society and the environment worldwide. Food byproducts and waste that are overproduced by the food processing industries because of their poor sustainable management have turned into a big global concern causing environmental pollution and economic losses. In this context, biotechnological researchers have been redirecting their objectives to focus on the valorization of these renewable resources attributed to the richness of bioactive compounds, which have shown attractive potential applications in different industries. Furthermore, several methodologies are being developed to extract and recover these value-added products, mainly employing green chemistry approach due to its considerably lower implications of harming the environment. Moreover, biotechnology coupled with green chemistry have shown some interesting results in the development of novel techniques that lead to the creation of commercial products, namely functional ingredients, food additives, and supplements.

Value-added compounds obtained from these renewable resources through green extractive methodologies such as protein precipitation, flash vacuum, microwave and supercritical methods, enzymatic hydrolysis, or fermentation process are considered as attractive technological tools that could be implemented in the industries, particularly in pharmaceutics, nutraceuticals, and food areas and consequently improve the traditional industrial processes allowing a circular economy implementation. Furthermore, due to the green chemistry through the zero-waste context approach, it will be possible to decrease or eliminate the constant overproduction of food waste thus avoiding soil, air, and water pollution. As a result, the application of all these involved concepts (biotechnology, green chemistry, zero-waste, and circular economy) together may need to grow as a multidisciplinary option with regards to biomass utilization and transformation into useful value-added products in an attempt to generate new food supplies with beneficial properties and their application for industrial economic revenue. Therefore, this book provides an insight and understanding of consolidated process systems for waste management by using tools of biotechnology, microbiology, food, and chemical engineering, among other branches of science.

Functional foods are described as food stuff or food ingredients that could improve health by helping in the prevention or risk reduction of certain diseases such as cancers, cardiovascular and inflammatory disorders and diabetes. These benefits are well-attributed to the content of bioactive compounds, which comprise a wide array of natural molecules with bioactivities such as antioxidant, antimicrobial, anticancer, antihypertensive, prebiotic, among many others. Enzymes are biomolecules with natural biological properties and are essential to many industrial processes such as high added-value compounds release, enzymatic synthesis of useful compound, degradation of residual materials, along with many other processes. Production and extraction of these biomolecules are significant factors to improving the industrial processes by increasing the production of high-quality products, boosting human life stability and world sustainability.

All the topics that are described in this book aim to create a fundamental professional awareness due to the significant evidences and facts on food waste management and valorization which could increase scientific, social, and industrial interests to recover value-added compounds with health beneficial bioactivities through developing sustainable technologies. This in turn can contribute to decreasing the negative effects on the environment, reducing cost, energy and time consumption, improving profitability and efficiency for industries. Thus, this book provides significantly accepted and interesting knowledge for readers interested in the fields of nutrition, chemistry, food processing and engineering, and biotechnology.

EDITORS' CRITICAL OPINION

The history of the human behavior related with food consumption and all the involved steps for its production has been changing from the middle of 20th century to the beginning of the 21st century. Such changes have arisen by the conscious issues that society is facing and nowadays are having an evident and significant negative impact on the three main pillars of sustainability: society, economy, and environment. Since human beings learned how to treat soil and some cultivation techniques (agriculture) for production of their own food, they has been repeating the same linear behavior, which involves the traditional linear economy "take-make-dispose", in other words, "production-manufacturing-discard" of food. Through the application of this linear behavior in the food industry, some issues related with food loss and wastage were detected, which consequently are linked to huge economic expenses and environmental pollution. Based on these issues, the linear economy approach is no longer acceptable within the modern food industry. Therefore, a couple of years ago a new approach was introduced—"circular economy" with the aim to reduce these issues and create a more sustainable food supply chain, avoiding food byproducts and waste production. Moreover, the circular economy approach has gained interest not only between researchers of biotechnology, environment and food science, and technology areas, but also for industrial and governmental sectors, looking/working for the same objective, decreasing the current issues by promoting a suitable and correct management of food byproducts. In this regard, such byproducts must be recycled and valorized due to their richness in biofunctional compounds (polyphenols, carotenoids, oils, protein, fibers, among others) with the purpose to (1) minimize the exhaustion of natural resources and (2) satisfy the current demand of nutritional functional food ingredients with health benefits, while the environmental pollution is mitigated, and a bioeconomy is created within industries.

Even though all the chapters presented in this book possess different and unique information that can be used as references to develop new innovative research on the topics of food waste and byproducts production along the food value chain as well as on research on their bioactive constituents extracted/recovered by novel and consolidated technologies, there is still one thing in common among the chapters: their usefulness in large-scale commercial and industrial applications in real food waste management instances in order to exploit the great hidden value that these renewable sources can offer as raw materials of biofunctional ingredients. This will, hopefully, lead to important work that must be carried out during the next years, beyond only research, to highly encourage the generation of new business, revenue streams, and jobs for human well-being and to contribute to sustainable development.

PART I

Food By-Products Generation and Their Valuable Bioactive Compounds

CHAPTER 1

Tomato Agro-Industrial Wastes as a Rich Source of Bioactive Compounds

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ABSTRACT

Tomato (*Lycopersicon esculentum*) is a widely cultivated vegetable crop and it is mainly processed to tomato paste, juice, ketchup, purée, and canned tomatoes. However, tomato processing at the industrial scale leads to large quantities of wastes, such as pulp, seeds, peels, and fibrous part residues. The tomato waste management is therefore a worldwide problem in terms of environmental and economic aspects. It is generally agreed that reuse or recycle of these byproducts could decrease processing costs and the corresponding wastes could be considered rich sources of nutrients and bioactive compounds.

This chapter will therefore focus on the various bioactive compounds extracted from tomato wastes, such as carotenoids, proteins, peptides, oil, and dietary fibers. The extraction methods for the release and extraction of these bioactive compounds are also highlighted in this book chapter.

1.1 INTRODUCTION

Tomato (*Lycopersicon esculentum*) is likely originated in Peru and then introduced into Italy as an ornamental plant at the beginning of the 16th

Food Byproducts Management and their Utilization. Ricardo Gómez-García, Ana A. Vilas-Boas, Débora A. Campos, Maria Manuela Pintado, & Cristóbal Noé Aguilar (Eds.)

century; however, until the middle of that century, it did not begin to be grown for food applications. The cultivation of tomato has become widespread over the next centuries and is now considered one of the world's most commonly commercially produced vegetables.[1] United States, Spain, Italy, and Turkey are the leading tomato-growing countries and the world production of tomato reached 124,111,781 metric ton.[2]

Tomato contains remarkable levels of various traditional nutrients. Its folate content is similar to the levels found in carrots and potatoes, and about 10% of the concentrations observed in spinach. It is also rich in vitamin C and potassium.[3] Tomato is consumed at high levels and is therefore a significant source of vitamin C, vitamin A, carotenoids (e.g., β-carotene and lycopene), and flavonoids (e.g., quercetin and kaempferol) in the Western diet. The β-carotene content in fresh tomato is reported to be 0.39 mg 100 g^{-1} and its content in canned tomato sauce is found to be 0.41 mg 100 g^{-1}, while its lycopene content is higher than β-carotene (15.91 mg and 3.02 mg 100 g^{-1} in canned tomato sauce and fresh tomato, respectively).[4] Tomato is mainly consumed as a fresh fruit and after processing into different products including tomato sauce, paste, juice, ketchup, and puree (Figure 1.1).[5] In addition, its dried products are commonly applied in pizza and various vegetable and spicy dishes.[2]

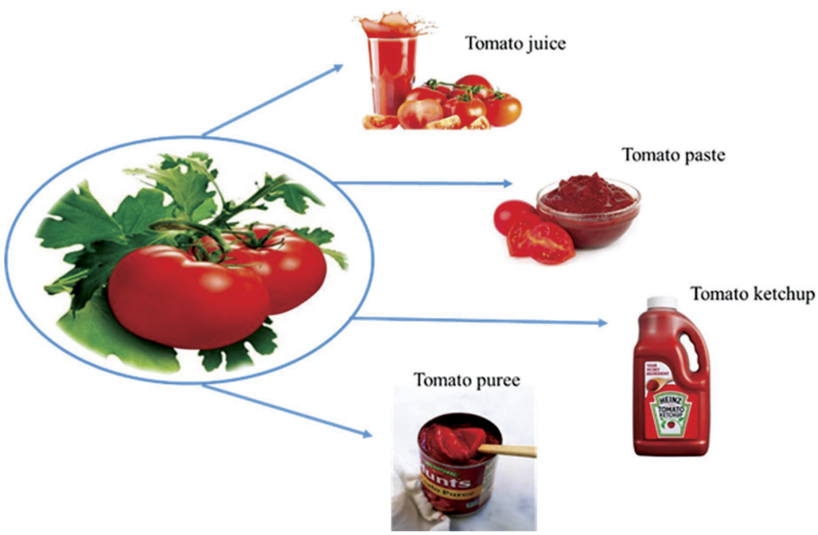

FIGURE 1.1 Tomato products.

Tomato pomace is a byproduct generated during tomato processing, representing approximately 4% of the fruit weight.[6,7] Tomato pomace consists mainly of tomato peels and seeds, and is one of the most promising candidate materials.[8] It contains mainly fiber (25.4–50.0%), protein (15.4–23.7%), fat (5.4–20.5%), and mineral (4.4–6.8%).[6] Therefore, tomato wastes consist of good quality nutrients with the potential to be widely used as food, feed, or fertilizer. Indeed, economic and technological limitations lead to nonutilization of the tomato waste, thereby contributing to environmental pollution.[9] In this context, the use of byproducts of tomato processing industry could provide extra income and decrease the waste disposal problem.[6] This chapter, therefore, focuses on the value-added compounds isolated from the tomato pomace. The extraction procedures of these bioactive molecules are also highlighted in this book chapter.

1.2 TOMATO WASTE RECOVERY

Tomato waste usually represents an environmental problem for the industry. It is potential reutilization for the recovery of various bioactive compounds, such as lycopene, protein, pectin, oil, and dietary fiber could be of benefit (Figure 1.2).[10]

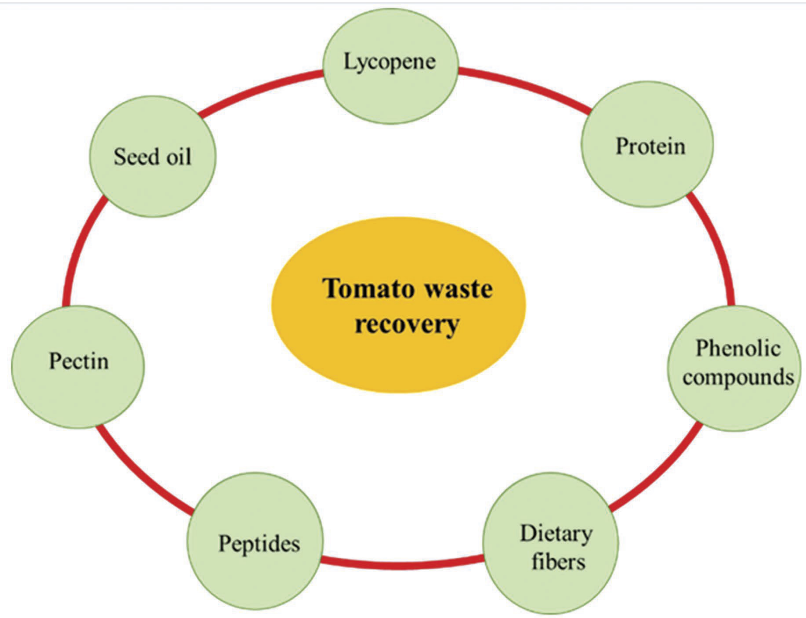

FIGURE 1.2 Bioactive compounds of tomato waste.

1.2.1 LYCOPENE

Tomato contains versatile antioxidative molecules like vitamin E, vitamin C, phenolics, flavonoids, and carotenoids. Among them, lycopene has recently attracted remarkable attention for its possible health-promoting effects. It is the main pigment, with a deep red color, of ripe tomatoes,[8] and the processing, heating, and homogenization treatments lead to lycopene release from cell wall carotenoid–protein complexes. Therefore, processed products have a better lycopene bioavailability compared with fresh tomatoes.[11] Lycopene is classified chemically as a hydrocarbon. It is an oligomer of isoprenoid type consisting of 8 isoprene units joined together into a symmetrical chain containing 13 double bonds (11 conjugated and 2 nonconjugated double bonds).[12] A high degree of conjugated double bonds confers strong antioxidative activities to lycopene molecule, making it one of the most powerful antioxidant compounds.[7]

Lycopene, due to its antioxidant activity, has a high potential to provide protection against cancer and other degenerative diseases and to reduce the incidence of ischemic heart diseases.[13] It has been reported that lycopene is mainly accumulated in the tomato peel and the water-insoluble fractions (72–90%) than in the flesh. The valorization of tomato-processing byproducts is therefore of high interest of researchers and manufacturers.[14,15]

It is also worthwhile of noting that lycopene is mainly found in the plant chromoplast (and further in chromoplasts, during ripening-induced chloroplast-chromoplast transformation). Lycopene is also a highly hydrophobic compound and, therefore, arranged exclusively within the inner part of the lipid bilayer of the vesicles. Moreover, lycopene is present in a complexed form with proteins within the vegetable cells. Thus, more intensive thermal or mechanical treatments and organic solvents are required for lycopene recovery from tomato peels, leading to environmental problems and lycopene thermal degradation.[14]

1.2.2 SEED OIL

Seed is the major component of the tomato pomace (~60%, 1.3 million tons), which is usually used as a low-value material for livestock feed or is otherwise dumped in landfills, causing environmental problems.[16] Therefore, tomato processors are pressingly searching for alternate uses of tomato seeds to protect the environment and increase the economic value of tomato seeds.[17] Tomato seeds contain approximately 20% oil and fatty acid composition of the oil is similar to the low-linolenic soybean oil; accordingly, tomato seeds would be considered a good source of salad oil.[18] Palmitic acid (C16:0; 7–24%) is the main saturated fatty acid of the tomato seed oil. The oil also contains stearic acid (C18:0; 4–13%), oleic acid (C18:1; 18–30%), myristic acid (C14:0; 0.1–2.3%), linolenic acid (C18:3; 1–6%), margaric acid (C17:0; 0.1–0.3%), palmitoleic acid (C16:1; 0.3–7%), arachidic acid (C20:0; 0.2–3%), and behenic, lignoceric, and gondoic acids in very small amounts.[19] Tomato seed oil could be therefore extracted and used as an edible oil with high nutritional quality.[20]

1.2.3 PECTIN

Pectin is abundant in most vegetables and fruits and considered the major part of the primary cell wall of nonwoody plants. From a functional viewpoint, it is a hydrocolloid with the ability to trap water molecules and form gels at low concentrations. Thanks to its excellent safety/health profile and water solubility, pectin is extensively used to add desirable textures to various food products.[21] Tomato waste is a good source of pectin and it has been therefore subjected to different extraction methods for the extraction of high-quality pectin.[22,23] It has been suggested that pectin extracted from tomato wastes has a remarkable quality and could be used as a valuable additive in food industry[22]

1.2.4 PHENOLIC COMPOUNDS

The phenolic compounds are dietary phytochemicals present in plant tissues and an essential part of the human diet, which are of considerable interest because of their antioxidative features. It is well known that tomato byproducts have higher concentrations of phenolic compounds compared with pulp and the removal of peel/seed during tomato processing could lead to a loss of the antioxidant property of these bioactive compounds.[10] The main phenolic compounds of tomato are quercetin, naringenin, rutin, and chlorogenic acid.[24] These phenolic compounds (e.g., flavonoids and hydroxycinnamic acid) show multiple biological properties including metal chelation, free radical-scavenging, modulation of signal transduction pathways and enzymatic activity, and inhibition of cellular proliferation.[25] Phytochemicals with remarkable antioxidant property extracted from byproducts of tomato processing industry could be successfully used as functional ingredient for the development of novel functional foods with health-enhancing effects.[26]

1.2.5 PROTEINS AND PEPTIDES

Tomato seed protein contains globulin, prolamine, gluteline, and albumin, with a high nutritional quality comparable with soybean proteins.[27] It is a rich source of lysine (8–10 g/16 g N) which makes tomato seed protein an ideal candidate for supplementing proteins in cereal products. Moreover, tomato seed proteins could be used as a bioactive ingredient in functional food systems and used for human consumption.[28] Additionally, the lack of antinutritional factor or harmful constituent in the tomato seed makes it a better protein source over other nonconventional sources.[27] It could be also noteworthy that tomato seeds contain almost all essential amino acids, especially leucine and lysine,[29] and protein hydrolysates and peptides of the tomato seeds show antioxidant and ACE inhibitory activities.[30]

1.2.6 DIETARY FIBERS

Dietary fibers have various technological (e.g., gel formation, water/lipid binding, texture modification, and increasing sensory attributes) and biological (e.g., anticancer, antidiabetic, antiobesity, hypocholesterolemia effect, and blood glucose attenuation) functions.[31] Dietary fibers are generally classified as water-insoluble dietary fiber (IDF) and water-soluble dietary fiber (SDF). Compared with IDF, SDF (such as oligosaccharides, pectin, and β-glucans) indicate higher viscosity and have the potential to reduce blood cholesterol and glucose, and improve the commercial values of related functional foods.[32] Tomato peels could be employed as a cheap source of SDF,[33] and it has been reported that they contain 48.5% IDF and 8.9% SDF.[32]

1.3 EXTRACTION METHODS

Extraction, especially conventional solvent extraction (CSE), is generally applied to provide the bioactive molecules from fruit and vegetables. Nonetheless, CSE needs long processing time and high solvent volumes, thereby causing environmental pollution. Thus, new, modern, faster, and more effective extraction methods have been recently developed to increase the extraction efficiency and lower the volume of organic solvents (Table 1.1).[34]

TABLE 1.1 Novel Extraction Methods used for Bioactive Extraction from Tomato and Its By-Products.

Extraction method	Bioactive components	Part of tomato	Conditions	Reference
Microwave-assisted extraction	Lycopene	Peel	Solvent ratio solid liquid ratios, microwave power, delivered energy equivalents	35
	Polyphenols	Peel	Solvents, temperatures (25, 55, and 90°C), times (5 and 10 min)	36
	Phenolic compounds	Tomato	Ethanol concentration (20–80%), temperatures (60–100°C), times (0–4 min)	37
Supercritical fluid	*Trans*-lycopene	Tomato	Carbon dioxide at 40°C without modifier	38
	lycopene	Dried tomato skin	Temperature (40 and 70°C), pressure (25 and 45 MPa), modifier concentration (5 and 15%)	39
	lipids, lycopene, and, *β*-carotene	Tomato-processing waste (skins and seeds)	Pressures (250 and 300 bar), temperatures (60 and 80°C), particle sizes (80 and 345 µm, solvent flow rates (0.792 and 1.35 kg/h)	12
Ultrasonic extraction	Lycopene	Tomato-processing waste	Ternary solvent system composed of 31% acetone, 38% ethyl acetate, and 31% hexane	40
	Carotenoids	Dry tomato pomace	Hexane proportion in the solvent (25, 50, 75%), 25–45°C, 6 min	41
Ohmic extraction	Oil	Tomato seed	Electric field strength (10–14 V/cm), end point temperature (40–60°C), holding time (5–15 min)	42
	Phenolic compounds	Tomato wastes	70°C, 15 min, 70% ethanol	43
High-pressure/High-pressure homogenization	Flavonoids Lycopene	Tomato pulp	450 MPa, 60% hexane concentration	44
	Proteins Polyphenols	Peel	20,000 RPM, 5 min, 10 passes	14

1.3.1 MICROWAVE-ASSISTED EXTRACTION (MAE)

The MAE is considered an advanced extraction procedure that uses microwave energy to heat solvents effectively. The analytes could be subsequently partitioned from the sample matrix into the extraction medium (i.e., solvent). The MAE is able to significantly reduce both solvent consumption and extraction time.[37] Ho et al.[35] determined the optimal MAE conditions for lycopene extraction from tomato peels. Optimal conditions were: 400 W at 0:10 solvent ratio with an all-trans-lycopene yield of 13.592 mg/100 g. Moreover, ethyl acetate was found to be a better MAE solvent for the recovery of lycopene than hexane. In addition, significant structural disruption was observed in MAE-treated samples, likely leading to the improved lycopene extraction. In another study, the MAE process was optimized to maximize flavonoids/phenolic acids recovery from tomato. The tomato extract obtained in optimum processing conditions showed a high potential to be used as nutraceuticals or active ingredients in the development of functional foods.[45] The application of MAE as an innovative technique has been also studied for the isolation of polyphenols from tomato peel waste. The results showed that the extraction time (5 and 10 min) had no significant effect on total phenols, total flavonoids, and phenolic compounds recovery. On the other hand, the temperature and the solvent had significant effects on the polyphenols yield, and the tomato peel waste was therefore suggested as a sustainable resource of polyphenols for MAE extraction purposes.[36]

1.3.2 SUPERCRITICAL FLUID EXTRACTION (SFE)

The SFE uses supercritical fluids to separate the extractant from the matrix. CO_2 is considered the main extraction solvents for botanicals. CO_2 supercritical extraction is performed above the critical pressure of 74 bar and the critical temperature of 31°C. Supercritical fluids are highly compressible gases with attractively combined gas and liquid properties. These fluids have a potential to initiate reactions, which are not usually achievable in conventional solvents. The SFE is a fast process (10–60 min) and the supercritical fluid is separated from the analyte by simply releasing pressure; a pure residue with almost no trace is therefore yielded.[46] Rozzi et al.[47] used SFE for lycopene extraction from tomato, ant the extraction yield of 61% was obtained under optimum conditions of 34.47 MPa, 86°C, and 500 mL of CO_2 (2.5 mL/min flow rate). In another study, the highest carotenoid concentration (with 90.1% lycopene) from industrial tomato waste was achieved by SFE at 80°C and 460 bar, while tocopherols- and phytosterols-rich products were obtained above 300 bar and 40°C.[48]

1.3.3 ULTRASONIC-ASSISTED EXTRACTION (UAE)

Ultrasound received the most attention among agitation techniques mainly due to its ability to either disrupt cell wall of biological cells or provide a better solvent diffusion into cellular materials and enhance the mass transport. This is due to the cavitation phenomenon, which formed tiny bubbles in the liquid bulk collapse (nonsymmetric) and exploded during a compression cycle. Therefore, the ultrasound-assisted extraction (UAE) is considered a proficient extraction technique capable of reducing working times and increasing extraction yields.[49] Tomato waste was treated with ammonium oxalate/oxalic acid by CSE and UAE at 37 kHz and temperatures of 60°C and 80°C for the pectin extraction purposes. The CSE at 60°C resulted in the highest yield, but UAE during a sonication time of 15 min produced the pectin of better quality. The pectin yields obtained after the extraction at 80°C were similar at times of 24 h for CSE and 15 min for UAE. Thus, it could be deduced that the main advantages of UAE are the lower extraction time and environmentally friendly status.[22] Moreover, the extraction yield of lycopene from tomato paste-processing wastes by UAE and CSE showed that UAE requires lower solvent, lower temperature, and less time than CSE.[50] The UAE has been also used for the efficient extraction of carotenoids from dry tomato pomace.[41]

1.3.4 OHMIC EXTRACTION

Ohmic heating, also called Joule heating, is an alternative fast heating method, which occurs when an alternating electrical current is passed through food and the electrical resistance of food leads to food heating. It is a rapid, uniform, and more environmentally friendly heating method with a high potential to yield a high-quality product with minimal changes in nutritional, structural, or organoleptic properties.[51,52] Coelho et al.[53] optimized the extraction of phenolic compounds from tomato byproducts using ohmic heating technology. The best extraction conditions of polyphenols were 70°C for 15 min, using 70% ethanol as a solvent, and the recovery of rutin was 77%

higher than control samples. Ohmic heating led to recover up to 4.93 μg/g lycopene from tomato byproducts without resorting to organic solvents. Thus, ohmic heating could be a fast, economical, and environmental-friendly process to recover polyphenols from industrial tomato byproducts. Similar observations were outlined in the literature.[43]

1.3.5 HIGH-PRESSURE AND HIGH-PRESSURE HOMOGENIZATION

High-pressure (HP) processing can effectively reduce the extraction time and increase process efficiency. The HP is able to cause some structural changes, such as cell membrane damage or cell deformation that increase the permeability of cell and the diffusion of secondary metabolite and in turn mass transfer rates. Interestingly, it has minimal effects on low-molecular-weight components such as flavors, vitamins, and pigments. Therefore, HP has been recently applied to extract biologically active compounds from natural sources.[55]

The high-pressure homogenization (HPH) technology pressurizes a fluid to flow through a narrow gap valve. This leads to a marked increase in its velocity and in turn a pressure drop with high shear stress and cavitation. The suspended particles and macromolecules in the fluid undergo twisting and deformation under high mechanical stresses applied.[57] HPH is an effective and fast method for the micronization of plant tissue in suspension and to release active biomolecules from cells, resulting in high extraction yields. Thanks to its ease of operation, reproducibility, scalability, and high throughput, HPH is considered a method particularly suitable for industrial applications.[14] HP and HPH technologies have been successfully applied to extract bioactive compounds from tomato wastes. Briones-Labarca et al.[44] studied the effect of operating HP and solvent polarity (solvent mixture) on extraction yield, flavonoid, and lycopene content from tomato pulp. The HP and solvent mixture had significant effects on the responses. The optimum HPH extraction condition was acquired at 60% hexane and 450 MPa, provided the maximum extraction yield of 8.71%, flavonoid content of 21.52 ± 0.09 mg QE/g fresh weight and lycopene content of 2.01 ± 0.09 mg QE/100 g fresh weight. In another study, it has been reported that the tomato peels treatment by the HPH method could increase the release of intracellular compound, such as proteins (+70.5%) and polyphenols (+32.2%), and improve the antioxidant activity (+23.3%) and reduce the oil–water interfacial tension (−15.0%).[14] Thus, HPH extraction could be a powerful tool to increase the extraction and release of bioactive compounds from tomato wastes.

1.4 TOMATO PRODUCTS

1.4.1 TOMATO PASTE

The tomato paste-manufacturing industry is known as one of the most important sections in the food industry.[58] The production pipeline of the tomato paste involves multiple uses of heat (Figure 1.3). In brief, the intact fruit is sorted, washed, and then crushed. The crushed tomato goes through a heat exchanger and is subjected to steam heating (88–99°C) to inactivate pectinase enzymes. This process is known as the hot break. Then, the juice of crushed tomatoes is separated from skins and seeds by an extractor. The juice goes through a multieffect evaporation step to lower its moisture content and form the paste. The paste is subjected to sterilization process *via* steam heating and is then packaged aseptically.[59]

1.4.2 KETCHUP

Ketchup, as one of the most popular products of tomato in the global market, needs lower equipment and simple processing.[5] Tomato paste (23–35° Brix) is generally used for ketchup production.[60] Ketchup is a heterogeneous spiced product and its consistency is an important feature from the consumer and engineering views.[61] Thickening agents are also added to the formulation to increase the consistency and inhibit serum separation from ketchup.[5] The microbial stability of tomato ketchup is based on final pH ($pH < 4.0$), on pasteurization or the addition of preservatives. Ketchup subjects to several relatively important heat treatments and the product can be therefore stored at room temperature for one or more years.[62]

1.4.3 TOMATO JUICE

Tomato juice consists of suspended particles (>150 μm) which include intact or broken cells, water-insoluble pectic, long-chain polymers of cellulose, hemicellulose, and lignin material.[63] Tomato juice is a well-known healthy beverage containing 93.1% moisture, 4.89% carbohydrate, minerals, and vitamins, and is low in fat and protein.[64] The color of fruit juice is a primary factor in evaluating juice quality and sensory acceptance by consumers. It could be also noteworthy that the nutritional quality of tomato juice is mainly attributed to the presence of vitamin C and other biologically active compounds, such as lycopene, which is responsible for the color of tomato juice. And epidemiological studies show that tomatoes and the related products, such as tomato juice, could decrease the probability of cardiovascular diseases and developing prostate cancers.[65]

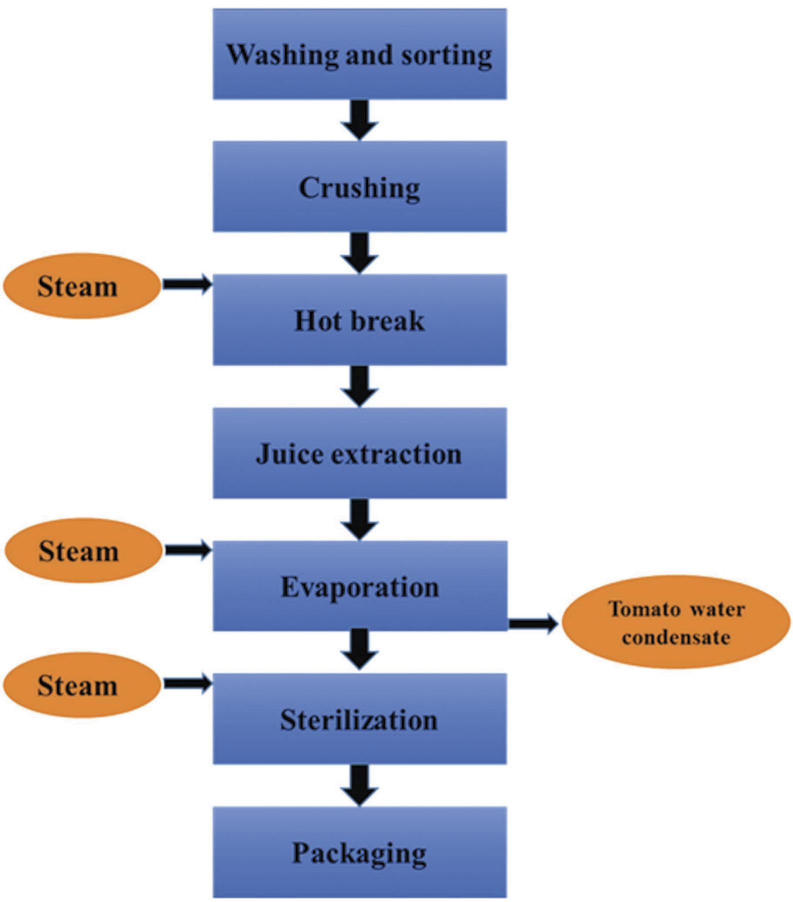

FIGURE 1.3 Flow diagram of processes in tomato paste production under conventional processing.[59]

Source: Adapted from Ref. [59].

1.4.4 TOMATO SAUCE

Tomatoes are generally consumed in the form of industrially processed products, especially tomato sauces. Dietary antioxidants (such as hydroxytyrosol, virgin olive oil), phenolic compounds from vegetables (such as garlic, peppers, carrots, and onions), spices, and herbs could be added to tomato sauces to improve its health benefits and sensory properties.[66] It is worthwhile noting that tomato sauce represents 40.8% of all sauce consumption in Spain.[67]

1.4.5 TOMATO PUREE

Cold-break and hot-break processes are conventionally applied for tomato puree processing. In this context, cold-break process (<66°C) leads to partial inactivation of polygalacturonase, and the corresponding paste has a good color and taste quality; however, the viscosity instability during storage and the relative low consistency of the product are the main problems related to this technique. Indeed, a tomato product with low consistency could not retain its solid fraction in suspension, and the product undergoes syneresis during the storage period. The hot-break process is generally applied to overcome syneresis problems, and tomatoes are processed at about 75–100°C for 30 min. The enzymes polygalacturonase and pectin-methyl esterase are therefore completely inactivated and a paste with firm consistency is achieved after concentration.[68]

1.5 CONCLUSIONS

The ever-growing level of agricultural waste has motivated the manufacturers and researchers to utilize these waste materials to develop green-processing technologies and extract bioactive compounds with health-promoting effects from this waste. This book chapter summarized the main bioactive components of tomato wastes and the advanced technologies to extract them. It was shown that different valuable compounds could be extracted by various technologies from tomato wastes and used as functional ingredients to develop novel functional foods. However, further research and optimization studies on the extraction techniques of tomato bioactive compounds might be necessary to increase their relevance for industrial applications.

KEYWORDS

- **bioactive compounds**
- **extraction**
- **lycopene**
- **polyphenols**
- **tomato waste**

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