Scientia Agropecuaria
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REVIEW

Recent highlights on passion fruit waste valorization: A review

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Received: 31 December 2022. Accepted: 23 July 2023. Published: 11 August 2023.

Abstract
In the present review, with the help of the descriptive method, some main highlights regarding the possibilities for the valorization of passion fruit waste are systematically presented. To the best of the author's knowledge, there is still no published review in the English-language scientific literature that examines opportunities, prospects and challenges for the valorization of passion fruit waste. For the preparation of the current review, scientific publications referenced in some of the most authoritative world-renowned scientific databases were used (Scopus, Web of Science, PubMed, Google Scholar); book chapters were not included. This review does not aim to cover, compile and describe all the scientific production available under the keywords "passion fruit waste", but aims to highlight only some major research trends regarding the possibilities of valorization of passion fruit waste. Scientific articles that remained for technical or other reasons beyond the scope of the current review paper could be included in a subsequent updated review.

Keywords: Passion Fruit Waste; Valorization; Highlights; Descriptive Approach.

DOI: https://doi.org/10.17268/sci.agropecu.2023.029

Cite this article:
Zhivkova, V. (2023). Recent highlights on passion fruit waste valorization: A review. *Scientia Agropecuaria*, *14*(3), 335-345.

1. Introduction

Passion fruit belongs to the *Passifloraceae* family and it is distinguished by its taste and nutritional properties (Corrêa et al., 2016; Cheok et al., 2018; He et al., 2020; Viganó & Martinez, 2015; Cesar et al., 2022). Among the substances contained in passion fruit are dietary fiber, minerals, vitamins, pectin, antioxidants, flavonoids and other bioactive compounds (Corrêa et al., 2016; He et al., 2020; Biswas et al., 2021; Viganó & Martinez, 2015). Systematized information on chemical and biological activity of different parts of passion fruit could be found in the mini-review article by He et al. (2020); in the work by Viganó & Martinez (2015), the composition and extraction techniques of phytochemicals were considered. Passion fruit can be processed and consumed as juices, dehydrated products, jams, jellies, marmalades, etc. (Biswas et al., 2021); and large amounts of waste are released during processing, including peels and seeds (Corrêa et al., 2016; dos Reis et al., 2018; He et al., 2020; Viganó & Martinez, 2015). Constituent characteristics and functional properties of passion fruit seeds were summarized by Kawakami et al. (2022); possible applications of seed oil were considered by Cesar et al. (2022). According to Cheok et al. (2018), passion fruit peels and seeds account for about 45%-52% and 1%-4% of the total fruit, respectively. Due to the larger amount of peels, they are utilized to a greater extent than the seeds (Cheok et al., 2018).

To the best of the author's knowledge, there is still no published review in the English-language scientific literature in which the opportunities for the valorization of passion fruit waste were considered in general terms. Therefore, the purpose of this review is to present some recent highlights regarding the valorization possibilities of passion fruit waste.

2. Brief bibliographic overview

The current review has been prepared using only scientific publications in English indexed in the most authoritative international databases (Scopus, Web of Science, PubMed, Google Scholar); book chapters were not considered at all and were not included.

Table 1
Systematization of the scientific publications cited in this paper by main words contained in the title and their percentage share

Main words in the title of the article	Share, %	Reference
"waste/wastes"	9.73%	Campos-Flores et al., 2018; Chóez-Guaranda et al., 2017; da Silva et al., 2022; da Silva Francischini et al., 2020; de Barros Júnior et al., 2020; Krambeck et al., 2018; Pavan et al., 2008b; Pereira et al., 2020; Suárez Rivero et al., 2018; Zhang et al., 2023; Zilly et al., 2012
"peel/peels"	28.32%	Abboud et al., 2020; Aisyah & Ngibad, 2022; Almeida et al., 2015; Castañeda-Figueredo et al., 2022; Chutia & Mahanta, 2021; de Oliveira Brito et al., 2019; do Nascimento et al., 2016; Fang et al., 2023; Florêncio et al., 2020; Garcia et al., 2020; Herrera-Ramirez et al., 2020; Huo et al., 2023; Kliemann et al., 2009; Kulkarni & Vijayanand, 2010; Liew et al., 2016; Lin et al., 2022; Liu et al., 2018; Macedo et al., 2023; Moro et al., 2017; Nugraha et al., 2018; Pavan et al., 2007; Pavan et al., 2008a; Ramli et al., 2020; Sampaio et al., 2022; Seixas et al., 2014; Silva et al., 2021; Sun et al., 2021; Teng et al., 2022; Vasco-Correa & Zapata Zapata, 2017; Weng et al., 2021; Wong et al., 2014; Yeo & Thed, 2022
"rind/rinds"	6.19%	Canteri et al., 2012; de Souza et al., 2018; Inayati et al., 2018; Liu et al., 2021; Pereira et al., 2021; Viganó et al., 2016; Zeraik et al., 2012
"shell"	3.54%	Campos-Flores et al., 2019; Chao et al., 2014; Fan et al., 2022; Hu et al., 2021
"bark/barks"	0.88%	Machado et al., 2008
"epicarp"	0.88%	Ghada et al., 2020
"pericarp"	1.77%	Canteri et al., 2010; Talma et al., 2019
"mesocarp"	0.88%	Nascimento et al., 2012
"flavedo"	0.88%	da Silva et al., 2019a
"albedo"	0.88%	de Aguiar et al., 2019
"seed/seeds"	14.16%	Ahmad & Malik, 2023; Antoniassi et al., 2022; Arturo-Perdomo et al., 2021; Barrales et al., 2015; de Santana et al., 2017; Kariuki et al., 2012; Kawakami et al., 2022; Lourith et al., 2017; Muslim et al., 2023; Malacrida & Jorge, 2012; Oliveira et al., 2017; Pereira et al., 2017; Reis et al., 2020; Silva et al., 2015; Surlehan et al, 2019; Vieira et al., 2022
"by-product/by-products"	3.54%	de Toledo et al., 2018; Duarte et al., 2017; Krambeck et al., 2020; Viganó & Martinez, 2015
"residue/residues"	1.77%	Leão et al., 2014; Lima et al., 2018
"valorization"	0.88%	Rodríguez-Restrepo et al., 2020
"waste/wastes" and *"peel/peels"*	5.31%	Kobo et al., 2022; My-Thao Nguyen et al., 2021; Phan & Ngo, 2020; Silva et al., 2019; Tarigan et al., 2022; Wijaya et al., 2017
"waste/wastes" and *"rind/rinds"*	0.88%	Barbalho et al., 2012
"waste/wastes" and *"shell"*	0.88%	Lin & Zheng, 2021
"waste/wastes" and *"seed/seeds"*	0.88%	Regis et al., 2015
"waste/wastes" and *"residue/residues"*	0.88%	Locatelli et al., 2019
"waste/wastes" and *"utilization"*	0.88%	Cheok et al., 2018
"peel/peels" and *"by-product/by-products"*	0.88%	Bussolo de Souza et al., 2018
"peel/peels" and *"albedo"*	0.88%	da Silva et al., 2019b
"peel/peels" and *"seed/seeds"*	1.77%	da Costa et al., 2023; González et al., 2019
"peel/peels", *"by-product/by-products"* and *"valorization"*	0.88%	Martins et al., 2018
"rind/rinds" and *"albedo"*	0.88%	de Oliveira & de Resende, 2012
"skin", *"by-product/by-products"* and *"utilization"*	0.88%	Gerola et al., 2013
*"seed/seeds"*and *"residue/residues"*	0.88%	de Almeida et al., 2021
"seed/seeds", *"residue/residues"*And *"utilization"*	0.88%	dos Santos et al., 2021
"seed/seeds" and *"utilization"*	0.88%	Viyona et al., 2019
"by-product/by-products" and *valorization"*	0.88%	Oliveira et al., 2016

This review does not aim to cover, compile and describe all available scientific production in the above databases under the keywords "passion fruit waste", but aims to systematically summarize and highlight, with the help of the descriptive approach, only some major research tendencies regarding valorization aspects about possibilities of passion fruit waste. Scientific articles that remained for technical or other reasons beyond the scope of the current review paper could be included in a subsequent updated review.

Among the selected publications after the literature survey was done, it is noticeable that the author teams in just over half of them are entirely Brazilian or individual members of international author teams are Brazilian. This confirms what has been stated in almost all the articles about who are the leading passion fruit growers worldwide and about the importance of passion fruit as an agricultural crop. In one-third of the publications used here, the number of authors is five or more.

The intention of this paper was to give an overview and to provide a general framework on the stated subject, not to retell statements, conclusions, generalizations done by other authors that can be found in their respective works.

In Table 1 the scientific publications cited in the present review paper were systematized by some main words contained in the title and their percentage share.

The most common words were *"peel/peels"*, presented in just over a quarter of the titles used here; in second and third place were the words *"seed/seeds"* and *"waste/wastes"*, respectively, which confirms what was stated in the article by Cheok et al. (2018) that the peels were utilized to a greater extent than the seeds. This was also shown by the present descriptive study: in most of the research studies, the object of investigation was the peels.

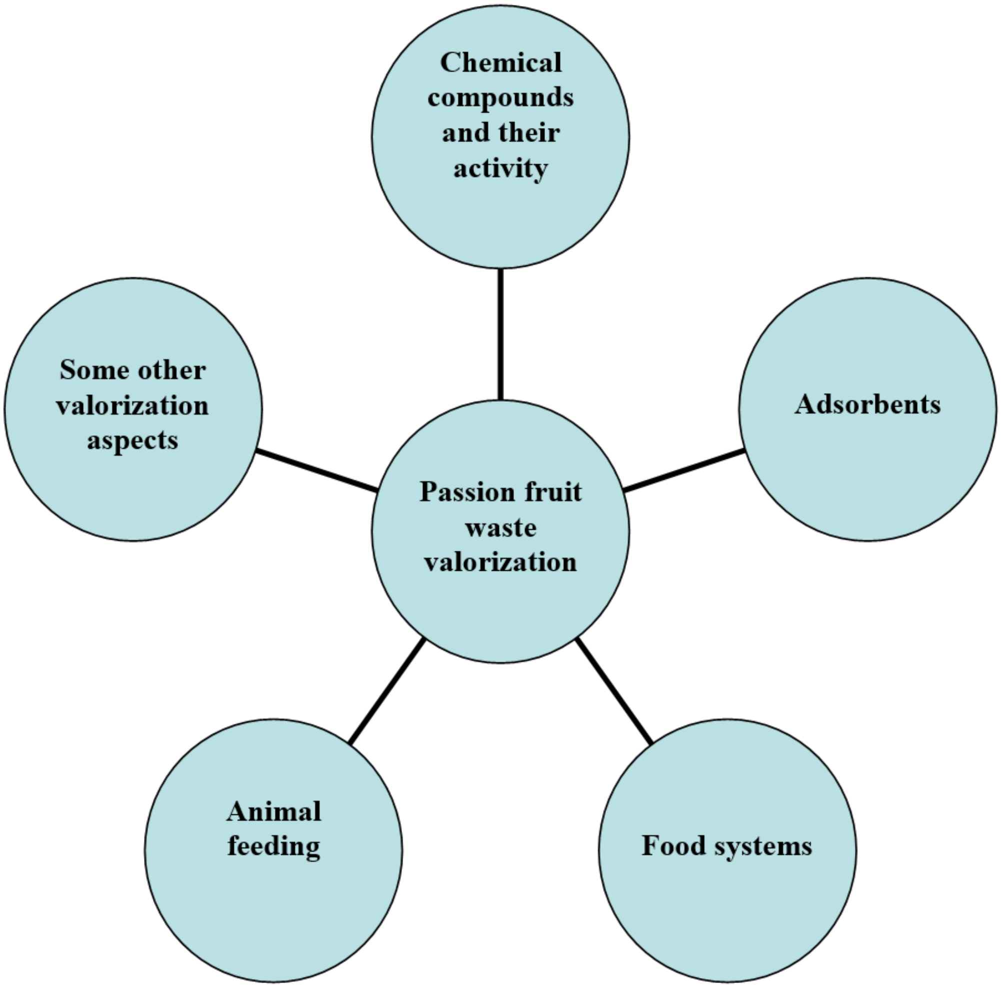

Figure 1. Main areas of passion fruit waste valorization

Next were the terms *"rind/rinds"*, the simultaneous presence in the title of the words *"waste/wastes"* and *"peel/peels"*, followed by *"by-product/by-products"*, *"shell"*, *"residue/residues"*, *"pericarp"*. The words *"bark/barks"*; *"epicarp"*; *"mesocarp"*; *"flavedo"*; *"albedo"*; *"valorization"*; *"waste/wastes"* and *"rind/rinds"*; *"waste/wastes"* and *"shell"*; *"waste/wastes"* and *"seed/seeds"*; *"waste/wastes"* and *"residue/residues"*; *"waste/wastes"* and *"utilization"*; *"peel/peels"* and *"by-product/by-products"*; *"peel/peels"* and *"albedo"*; *"peel/peels"* and *"seed/seeds"*; *"peel/peels"*, *"by-product/by-products"* and *"valorization"*; *"rind/rinds"* and *"albedo"*; *"skin"*, *"by-product/by-products"* and *"utilization"*; *"seed/seeds"* and *"residue/residues"*; *"seed/seeds"*, *"residue/residues"* and *"utilization"*; *"seed/seeds"* and *"utilization"*; *"by-product/by-products"* and *"valorization"* were included in almost one percent of the titles, respectively.

3. Passion fruit waste valorization highlights

The performed descriptive literature review gave reason to conclude that the main areas of valorization of passion fruit waste can be grouped into several main directions, which the author of this review considered appropriate to be systematized and presented in Figure 1.

It is clear from the Fig. 1 that the main directions for valorization of passion fruit waste, which are being worked on in modern conditions, are: determination of composition, isolation of chemical compounds and characterization of biological activity; development of adsorbents for the removal of various pollutants; attempts at embedding and application in food systems; use in animal nutrition; as well as some other areas of valorization.

The articles used in this review paper were systematized by valorization aspects and some main highlights were presented in Table 2.

Table 2
Systematic overview of used in this paper scientific publications on passion fruit waste valorization

Valorization highlights		Waste used	Reference
Chemical compounds and bioactivity characterization	Soluble dietary fibres; high methoxyl pectin	Peel	Abboud et al., 2020
	Enzymes production	Rinds	Zilly et al., 2012
	β-glucosidases production	Peel	Almeida et al., 2015
	Xylanase production	Peel	Martins et al., 2018
	Seed oil: physical and chemical characterization	Seeds	Malacrida & Jorge, 2012
	Supercritical CO_2 extraction of seed oil assisted by ultrasound	Seeds	Barrales et al., 2015
	Polar lipids of seeds oil extracted by supercritical CO_2	Seeds	Arturo-Perdomo et al., 2021
	Oil extraction	Seeds	Pereira et al., 2017
	Oil extraction	Seeds	Surlehan et al, 2019
	Oil quality	Seeds	Regis et al., 2015
	Oil quality	Seeds	Antoniassi et al., 2022
	Dietary fibres: pectin and (hemi)cellulose	Peels	Bussolo de Souza et al., 2018
	Physicochemical composition	Pericarp	Canteri et al., 2010
	Essential oils	Shells and seeds	Chóez-Guaranda et al., 2017
	Carotenoids extraction	Peel	Chutia & Mahanta, 2021
	Fiber pectin	Waste	Contreras-Esquivel et al., 2010
	Flour: physico-chemical characterization	Peel and albedo	da Silva et al., 2019a
	Production of flour by drying	Peel and albedo	da Silva et al., 2019b
	Production of functional flour	Residues	Lima et al., 2018
	Flour: development and characterization	Peels	Macedo et al., 2023
	Flavonoids and pectin extraction	Rind	de Souza et al., 2018
	Flavonoid extraction	Peel	da Silva Francischini et al., 2020
	Flavonoid content of ethanol and ethyl acetate extract	Peel	Aisyah & Ngibad, 2022
	Pectin	Albedo	de Aguiar et al., 2019
	Pectin and phenolics – simultaneous extraction, physicochemical properties, and antioxidant activity	Peel	Huo et al., 2023
	Albedo flour; pectin content	Rind	de Oliveira & de Resende, 2012
	Antioxidant polyphenolic compounds extraction	Seeds	de Santana et al., 2017
	Phenolic compounds extraction	Rinds	Pereira et al., 2021

	Pericarp fractions characterization	Rind	Talma et al., 2019
	Antioxidant properties	Peel	Wong et al., 2014
	Antioxidant activity	Peel	do Nascimento et al., 2016
	Extraction methods – antioxidant activity	Seed	Ahmad & Malik, 2023
	Phenolic compounds – antioxidant activity	Peel and seed	da Costa et al., 2023
	Lipids and antioxidants	Seeds	Reis et al., 2020
	Seeds oil as a source of fatty acids and bioactive substances	Seeds	dos Santos et al., 2021
	Physicochemical and technological properties	Peel	Duarte et al., 2017
	Physicochemical and antioxidant evaluation	Peel and seed	dos Reis et al., 2018
	Anthocyanins	Epicarp	Ghada et al., 2020
	Anthocyanins extraction	Peels	Liu et al., 2018
	Anthocyanins extraction	Peel	Herrera-Ramirez et al., 2020
	Anthocyanins extraction	Rind	Liu et al., 2021
	Mesocarp flour in flexible films	Mesocarp	Nascimento et al., 2012
	Cellulose nanocrystals as drug carrier	Peels	Wijaya et al., 2017
	Ag- and Au-nanoparticles: antibacterial and catalytic activities	Peels	My-Thao Nguyen et al., 2021
	Cellulose nanofibers; immobilization of trypsin	Stalks	Rodríguez-Restrepo et al., 2020
	Extraction and biological activity	Seeds and seed cake	Oliveira et al., 2016
	Antibacterial activity	Pericarp	Nugraha et al., 2018
	Some chemical and bioactive investigations	Peel and seed	González et al., 2019
	Pectin for edible coating	Rind	Inayati et al., 2018
	Pectin extraction	Peel	Kliemann et al., 2009
	Pectin extraction	Peel	Kulkarni & Vijayanand, 2010
	Pectin extraction	Rind	Canteri et al., 2012
	Pectin extraction	Peel	Seixas et al., 2014
	Pectin extraction	Peels	Liew et al., 2016
	Pectin extraction	Peel	Vasco-Correa & Zapata Zapata, 2017
	Pectin and cellulose extraction	Peel	Phan & Ngo, 2020
	Novel pectin polysaccharides	Peel	Teng et al., 2022
	Antioxidant activity of seeds oil	Seeds	Krambeck et al., 2018
	Stilbenes (piceatannol and resveratrol) in seeds oil	Seeds	Krambeck et al., 2020
	Aromatic oil	Seeds	Leão et al., 2014
	Seeds and oil: chemical characteristics	Seeds	Silva et al., 2015
	Isoorientin	Rinds	Zeraik et al., 2012
	Bioactive compounds extraction	Rinds	Viganó et al., 2016
	Bioreduction of carbonyl compounds	Barks	Machado et al., 2008
Adsorbents	Adsorption of Pb, Cr, Cu	Shell	Campos-Flores et al., 2018
	Adsorption of Cr (III)	Shell	Campos-Flores et al., 2019
	Removal of Pb and Cr	Peels	Castañeda-Figueredo et al., 2022
	Removal of Cu(II), Cd(II), Pb(II), Ni(II)	Shell	Chao et al., 2014
	Adsorption of Pb(II)	Skin	Gerola et al., 2013
	Eriochrome black adsorption	Peel	de Oliveira Brito et al., 2019
	Methylene blue removal	Peel	Pavan et al., 2007
	Adsorption of methylene blue	Peel	Pavan et al., 2008a
	Methylene blue adsorption	Peel	Pavan et al., 2008b
	Removal of methylene blue and methyl violet	Peel	Lin et al., 2022
Food systems	Flour in drinkable yogurt	Peels and seeds	de Toledo et al., 2018
	Peel flour in dietary cookies	Peel	Garcia et al., 2020
	Peel flour in biscuits	Peels	Weng et al., 2021
	Peel flour in cookies	Peel	Sampaio et al., 2022
	Dark chocolate	Seeds	Yeo & Thed, 2022
	Meat products preservation	Peels	Ramli et al., 2020
Animal feeding	Meat quail	Pulp waste	de Barros Júnior et al., 2020
	Quail in the laying phase	Waste from pulp extraction	Pereira et al., 2020

Some other valorization aspects	Peel flour: bibliometric analysis	Peel	Florêncio et al., 2020
	Activated carbon	Seed	de Almeida et al., 2021
	Activated carbon for methylene blue removal	Seeds	Vieira et al., 2022
	Fe and N dual doped catalyst	Peels	Zhang et al., 2023
	Production of solid biofuels by torrefaction	Peel	da Silva et al., 2022
	Sunscreen products	Seed	Lourith et al., 2017
	UVB-protection	Peels	Fang et al., 2023
	Effect of 3% purple passion fruit seed extract cream on facial skin aging	Seed	Muslim et al., 2023
	Peel flour in starch bioplastics	Peel	Moro et al., 2017
	Biochar	Shell	Hu et al., 2021
	Biochar production by microwave-assisted wet co-torrefaction	Shell	Lin & Zheng, 2021
	Ratiometric fluorescent molecularly imprinted sensor for tetracycline detection	Peels	Sun et al., 2021
	Fat content prediction	Seed	Viyona et al., 2019
	Dehydration of thin-layer foods: semiempirical models	Peels	Vega-Castro et al., 2023
	Potential use as biomass	Exocarp	Suárez Rivero et al., 2018
	Biodiesel from seed oil	Seed	Kariuki et al., 2012
	Waste peel as a catalyst for biodiesel production	Peel	Tarigan et al., 2022
	Cellulase production to obtain biogas	Peel	Silva et al., 2019
	Biochemical evalution	Rinds	Barbalho et al., 2012
	Corrosion inhibition	Shell	Fan et al., 2022
	Seed oil encapsulation	Seed	Oliveira et al., 2017
	Micro-encapsulation of peel powders rich in polyphenols	Peel	Kobo et al., 2022
	Pectin as a substrate for the cell growth	Peels and bagasse	Locatelli et al., 2019
	Substrate for pigment production	Peel	Silva et al., 2021

The largest was the valorization direction (more than two-thirds of the articles cited here), dedicated to the study of the chemical composition of passion fruit waste, the extraction of various compounds from them and the evaluation of their biological activity with the aim of their potential further application as functional components for various industrial purposes. The author is of the opinion that it is completely explainable and understandable that this valorization direction was the most extensive and that the largest number of studies have been devoted to it, because before outlining specific guidelines for practical application and utilization of waste resources, it must first to be determined and known their chemical composition. The presence of various valuable components in passion fruit waste necessitates the development and application of various techniques for their extraction, isolation, as well as determination of their content.

Almost one-tenth of the research focused on the possibilities of using passion fruit waste as adsorbents for the removal of various inorganic and organic pollutants from water. In the works used here, the adsorption mechanisms and the efficiency of the adsorption process with respect to both metal ions and organic dyes presented in various aqueous media were studied and discussed.

The opportunities and challenges of incorporating passion fruit waste components into food systems after appropriate processing was the next area of research. The author of the present review believes that this is a very interesting and promising direction of valorization in which investigations could be intensified.

The number of studies using passion fruit waste in animal feed was surprisingly small. One possible reason for this may lie in the fact that such researches (including non-English-language ones) were indexed in other scientific databases not used in this review.

The areas united here under the term "other valorization aspects" were quite diverse and include the development of activated carbon, biochar, biofuels, etc. In this way, the scope of research on the potential application of passion fruit waste is greatly expanded, and the advantages, effectiveness and challenges of each of the developed and proposed methods are indicated.

As this paper presented only the general framework for the directions regarding the valorization aspects of passion fruit waste, and did not consider in detail one specific area of potential application itself, quantitative data from the individual articles cited here were not compared and commented on.

4. Current and future challenges

The possibilities and prospects for possible valorization of passion fruit waste for non-food purposes can be seen as a perspective and promising direction. Of particular importance is the creation, development and implementation of easily biodegradable materials from environmentally friendly waste resources, which will significantly reduce the accumulation of fruit waste and limit its harmful environmental impact if it is not managed properly. The challenges could be deepening the research regarding the possibilities and prospects for the possible use of passion fruit waste in animal nutrition, as well as the inclusion of individual valuable components of these waste resources in food systems. In order to be developed first on a laboratory scale, and at a later stage implemented on a larger scale, such products must be categorically proven and established to be safe for the health of consumers. This necessitates conducting in-depth intensive interdisciplinary research in the long term. It would be interesting and useful to periodically conduct surveys on consumer awareness of the possible marketing of products containing passion fruit waste components, to study and track consumer attitudes, their propensity and willingness to consume such products, as well as researching user satisfaction and establishing the opinion of consumers about these products after their use.

5. Conclusions

It can be concluded that the numerous intensive studies that were being carried out worldwide, regarding the possibilities of valorization of passion fruit waste, prove in an indisputable way the importance and relevance of the subject considered in the present review. Among the promising areas of potential application could be the creation and development of readily available, affordable, environmentally friendly materials and products for non-food purposes. From the point of view of the development of products with potential application for food purposes, the first priority should be given to the safety of consumers, which should be demonstrated in a clear, definite, indisputable and unequivocal way. Last but not least, after establishing and proving the safety of the products, is to investigate and analyze consumer attitudes regarding their receptivity and propensity to use such products.

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