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REVIEW ARTICLE

The way forward to produce nutraceuticals from agri-food processing residues: obstacle, solution, and possibility

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Abstract Food matrices contain bioactive compounds that have health benefits beyond nutritional value. The bulk of bioactive chemicals are still present in agro-industrial by-products as food matrices. Throughout the food production chain, there is a lot of agro-industrial waste that, if not managed effectively, could harm the environment, company, and how nutritiously and adequately people eat. It's important to establish processes that maximise the use of agro-industrial by-products, such as biological technologies that improve the extraction and acquisition of bioactive compounds for the food and pharmaceutical industries. As opposed to non-biological processes, biological procedures provide high-quality, bioactive extracts with minimum toxicity and environmental impact. Fermentation and enzymatic treatment are biological processes for obtaining bioactive compounds from agro-industrial waste. In this context, this article summarises the principal bioactive components in agro-industrial byproducts and the biological methods employed to extract them. In this review efficient utilization of bioactive compounds from agro-industrial waste more effectively in food and pharmaceutical industries has been described.

Keywords Nutraceuticals · Fermentation · Agri-processing residues · Solid state fermentation

Introduction

Any food component that offers additional health advantages in addition to its basic nutritional value is referred to as a nutraceutical (Musto et al. 2022). In general, agro-industrial residues have large quantities of components including fibres, lipids rich in polyunsaturated fatty acids, polysaccharides, bioactive polypeptide, phytochemicals, polyphenols, and other substances that can be used as ingredient in neutraceticals and have a variety of bioactivities (Kumar et al. 2022). Large quantities of agro-industrial raw materials are produced worldwide and are primarily used for human and animal use as well as the generation of energy. It is estimated that up to half of the raw resources are lost, with the majority of these losses occurring during the harvest, post-harvest, slaughter, transportation, manufacturing, preservation, and consumption (de Oliveira Filho et al. 2022). According to

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Dora et al., the losses might amount to 680 billion USD per year, which is equivalent to 25–35% of the global food production (Dora et al. 2020). These lost raw materials which account approximately 1.3 billion tons annually are generally not used or handled properly (Ishangulyyev et al. 2019). Depending to their content, residues sometimes exhibit sluggish degradation, which can lead to accumulation and have a harmful influence on the environment. Therefore, finding new uses for these residues to turn them into high-value products is important (Irmak 2017).

India generates over 234.5 MT of excess agricultural wastes annually (Hiloidhari et al. 2014). The management of these residues is one of the most challenging issues in agriculture and the agro-industry. This waste causes substantial management challenges, both financially and environmentally, since it also represents a significant loss of important commodities like feed, food, and fuel, as well as a number of chemicals and bioactive compounds. These residues are not viewed as "trash," but rather as raw materials for the creation of new products because of their high nutritional content. Through fermentation processes, microorganisms have the capacity to reuse source materials (Finkenstadt 2005).

Some constituents of agro-industrial waste are seen as important raw material for production of varied industrial products. Agro-industrial wastes such as peels, seeds, pits, pulps, press cakes and leaves are foundation of a massive variety of secondary plant metabolites (Kumar et al. 2022).

Phytochemicals, antioxidants, amino acids, fatty acids, probiotics, and other bioactive molecules having functional properties can be supplied as dietary supplements or functional foods are known as nutraceuticals. They have positive benefits in addition to the essential nutritional components. Due to the existence of adverse or side effects caused by a few pharmaceutical medications and the rise in resistant pathogens, nutraceutical compounds have attracted enough attention to be recognised as an alternative therapeutic and preventive approach, as well as the benefits of being more readily available and less expensive. Numerous studies have demonstrated the positive benefits of nutraceutical substances on immune system operations. These include strengthening the immune system's ability to respond to infections, raising immunological modulatory activity, and helping to lessen the consequences of autoimmune diseases and hypersensitivity. Additionally, antioxidant, anti-inflammatory, and anti-cancer efficacy of nutraceuticals has been demonstrated (George et al. 2004; Ahluwalia et al. 2021).

During industrial processing, wastes and byproducts are produced in enormous quantities, which is a severe concern because they have a negative influence on the environment. Therefore, they need to be monitored or trained. According to the current study data, it is apparent that the majority of the wastes and by-products produced by the fruit business occur after the juice is extracted or the highest-quality goods are created.

Numerous studies have been done on the conversion of fruit processing byproducts into products with additional value. To improve the amount of nutritional fibre and natural antioxidants in bakery and dairy products, fruit pomace from fruits like those berries and apples has been suggested as an ingredient. Utilizing recent developments and cutting-edge scientific methods, the study of nutraceuticals has been receiving increasing recognition. The primary goal of this study is to highlight contemporary research on nutraceutical substances and their medical applications, which includes a description of several types of nutraceuticals.

Effective use of agro-industrial materials requires the production or collection of phytochemical compounds first utilising sustainable methods as instead of conventional ones, followed by the optimization of process variables (Soquetta et al. 2018; Sik et al. 2020). In this perspective, biochemical systems stand out because they can enhance the synthesis, extraction, and application of agro-industrial matrix components in a more alluring manner. The selectivity of biological processes results in the production of extracts with high quality and bioactivity, as well as minimum toxicity (Ballesteros-Vivas et al. 2019).

Generation of agro-industrial waste

Depending on the biochemical nature of the wastes that are rich in nutraceuticals can be divided into two types that are briefly discussed in this section.

The extraction of different kinds of antioxidants and dietary fibre from fruit and vegetable processing residues is extensively studied. Research has revealed that a variety of food processing by-products, including peel and pulp of citrus, carrot, beet root, tomato, red beet, and others, are sources of bioactive compounds (Elik et al. 2019). Biologically active substances with demonstrated antioxidant and antibacterial activities are abundant in fruits and vegetables. Since bioactive substances are needed for food packaging, fruit, seeds, and leftover pulp from processing provide an intriguing source (Jiang et al. 2021). Numerous studies have demonstrated that compared to the edible tissue, the peel and seeds contain a larger concentration of phytochemical substances. The by-products' total phenolic and flavonoid contents were higher than those of the finished goods, with mango seeds and peel having the highest levels.

Asparagus (*Asparagus officinalis*) is an important, expensive and popular crop worldwidedue to its health benefits with production of more than 70 lakh tons worldwide, although the exact quantity of production is not documented. It is estimated that approximately 50% of the crop is used for human consumption and rest is considered as waste which

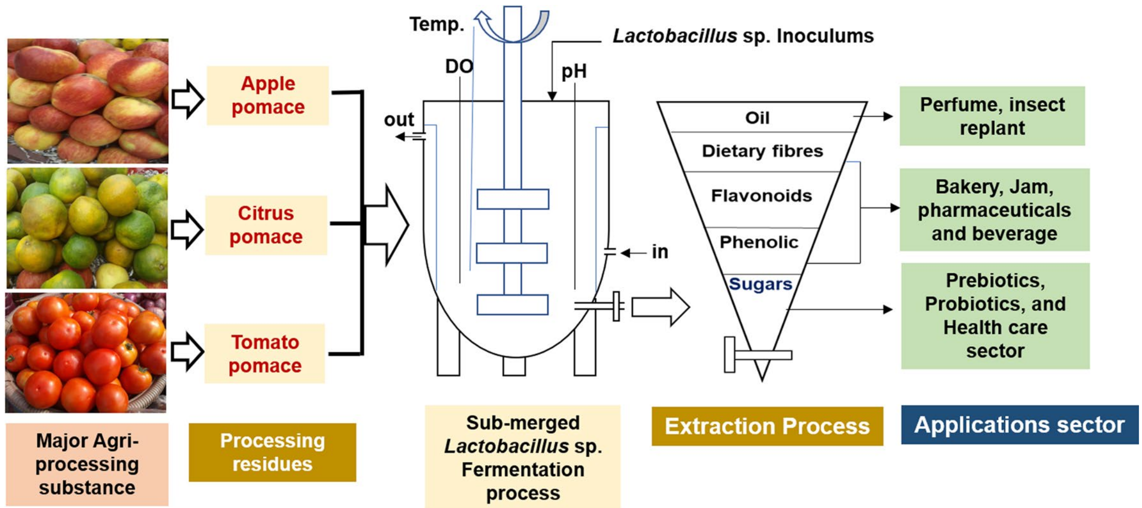

Fig. 1 Summary of *Lactobacillus*sp. Submerged fermentation

is commonly used for creation of low value-added products. This waste is richest source in quality and quantity of bioactive compounds which can be used for recovery and production of value-added compounds and phytochemicals like phytosterols, saponins, flavonoids, and hydroxycinnamates (Jiménez-Moreno et al. 2020). Cholesterol lowering properties of phytosterols provide them a good nutraceutical value (Majeed et al. 2022). Studies have established cytotoxic, antimicrobial, anti-inflammatory, anticarcinogenic and antioxidant properties of saponins with wide application in food, cosmetic, and pharmaceutical sectors (El Aziz et al. 2019; Sharma et al. 2021).

Numerous research articles have established importance of phenolic compounds and carotenoids for human due to their recognized activity against diseases like cancer, inflammatory and cardiovascular diseases (Rahman et al. 2022).

It is estimated that approximately 50% of citrus fruit weight is wasted as peels, pulp, seeds and membranes. Orange peels is a good source of d-limonene (DL), or (+)-limonene, a hydrophobic compound besides using peel waste in bio-refineries as feedstock for fermentation. Orange peel waste is also a good source of carbohydrate polymers and enzymes (Siddiqui et al. 2022).

According to Gorinstein et al. (2001), the total phenolic chemicals in lemon, orange, and grapefruit peel were 15% greater than those in the pulp (Gorinstein et al. 2001). It was discovered that the amount of total phenolic compounds in fruit peel was twice that of fruit pulp for apples, pears, peaches, and nectarines with yellow and white flesh. It was discovered that the number of phenolic compounds in apple peel was up to 3300 mg/100 g of dry weight. Bananas' edible pulp (*Musa paradisiaca*) has 232 mg of phenolic compounds per 100 g of dry weight, which is roughly 25% less than the peel's concentration (Someya et al. 2002). Utilising a combination of solvents was more productive, and they came to the conclusion that while pomegranate peel contain 249.4 mg/g of phenolic chemicals, the pulp only contains 24.4 mg/g (Li et al. 2006). In comparison to the edible product, the total phenolic components of seeds from a number of fruits, including mangos, longans, avocados, and jackfruits, were higher. Ascorbic acid, lycopene, total flavonoids, ascorbic acid, and antioxidant activity are all much higher in tomato peel than they are in tomato pulp and seeds in the tomato peel by-products (George et al. 2004) (Fig. 1). Ellagic acid, a polyphenol has nutraceutical values which play a major role in anti-aging anti-cancer, anti-inflammatory activities (Muthukumaran et al. 2017).

Due to escalating industrial oily effluent creation and sporadic oil spills, there is an increasing need for effective, affordable methods that can remove oils from water bodies in an environmentally friendly way (Ahmad et al. 2020). Wasted cooking oils and by-products of animal slaughter are the main sources of industrial hydrophobic waste produced by the food sector. Due to the abundance of restaurants and other commercial food and beverage establishments, waste cooking oil (WCO) is a serious issue in metropolitan regions (Andler and Goddard 2018). When this WCO is dumped and disposed of into drains unchecked, significantly reduces the effectiveness of wastewater treatment plants (Patel et al. 2022). Additionally, when used oil enters natural water sources, it seriously harms aquatic and marine species. It is challenging to treat highly saline and oily wastewater using traditional physicochemical and biological techniques. Such waters have a negative impact on agriculture, drinking water supplies, and aquatic life without previous treatment.

There is still a dearth of information on the topic of valuing hydrophobic substrates in order to produce goods with additional value. Only the synthesis of lipids adequate for

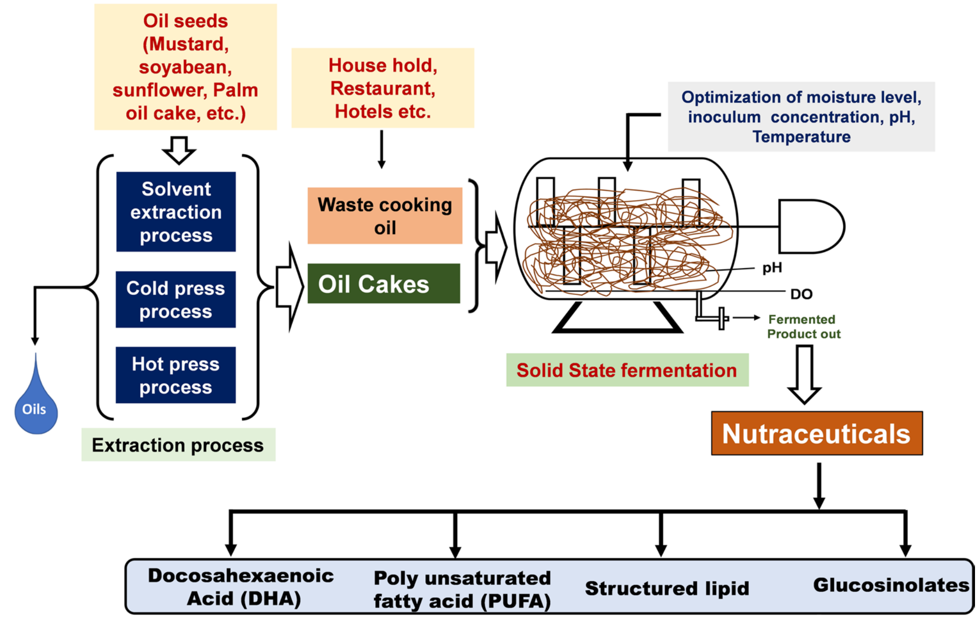

Fig. 2 Importance of oil cakes for production of nutraceuticals through solid state fermentation

making biodiesel using oleaginous yeasts has ever been done utilising hydrophobic substrates (Papanikolaou and Aggelis 2003; Jatav et al. 2019). Only a few researchers have examined the utilisation of acetic acid in thraustochytrids' manufacture of DHA; typically, feedstock must be a combination of VFAs from anaerobic digestion. In the current study, low-value WCO and VFAs produced by anaerobic digestion were simultaneously converted into DHA-rich oils and squalene by the thraustochytrid *Aurantiochytrium limacinum* SR21 (Ishibashi et al. 2019) (Fig. 2).

Types of nutraceuticals and applications

Depending on how they are understood and used, nutraceuticals can be arranged in many ways, such as for the design of clinical trials, academic training, the creation of functional foods, or nutritional advice. Nutraceuticals can be categorised in a variety of ways, such as according to their dietary origins, chemical constitution, and mode of action.

Dietary fibre

Dietary fibre is a wide phrase that is described as a dietary substance, or more specifically, a plant-derived food, that is neither digested nor absorbed by various digestive tract enzymes but is instead broken down by gut microflora. Along with other plant substances like cellulose, hemicellulose, lignin, resistant dextrins, inulin, pectin, beta-glucans, and resistant starch, it contains non-starch polysaccharides (Tucker and Thomas 2009). Dietary fibres can be divided into two groups based on how easily they dissolve in water: - a: Poorly fermented insoluble dietary fibre (IDF), which is comprised of lignocellulose. b: Dietary fibre that dissolves in water, like glucans, pectins, gums, mucilages, and hemicelluloses, and is broken down more quickly in the colon (Das et al. 2012; Pandey et al. 2022).

The majority of recent studies on dietary fibre have concentrated on plant-based sources, such as dietary fibre from wastes from post-harvesting agri-processing, such as fruit and vegetable wastes, oil seeds residues and many more sources (Sagar et al. 2018; Jatav et al. 2022). After harvesting, supplemental sources will be gradually utilised; for instance, it has been reported that residue may be a source of nutritional fibre. In the post-harvesting process, fruits and vegetables generate about 33% of the processing wastes. Even before they are ready for consumption, about 50% of the fruits and vegetables that are grown are wasted (Elik et al. 2019). High volumes of trash are produced as a result of the post-processing extraction of the pulp (to produce juice, jams, etc.) (Wadhwa et al. 2016). The food processing industry is currently continually looking for new ways to extract dietary fibre from underutilised agri-processing wastes for use as a nutritious ingredient with additional value.

Increased consumption of high-dietary fibre foods decreases blood pressure, enhances blood glucose control, promotes weight loss, and raises serum lipoprotein values (Tucker and Thomas 2009). Reduced absorption of vitamins, minerals, proteins, and calories is one of the many negative impacts of dietary fibre. Numerous case studies have revealed that consuming too much dietary fibre causes diarrhoea (Das et al. 2012).

Probiotics

Probiotics are a used as food/feed supplement containing living microorganisms that, when consumed in adequate quantities, can improve the intestinal microflora balance of the host (He et al. 2021). Over 2000 years ago, the first fermented milks were consumed, marking the beginning of probiotic history. In probiotics, the following bacteria are typically found: such as *Lactobacillus acidophilus*, *L. Casei, L. delbrueckii* subsp. *L. bulgaricus*, *L. brevis*, and *L. cellobiosus*. Additionally, yeast *Saccharomyces cerevisiae* and *Bacillus* species are utilised as probiotics. Since ancient times, lactic acid bacteria (LAB), which are employed for food fermentation, have had the ability to give both health benefits and food fermentation. Currently, there is a growing interest in the creation of probiotic products derived from fruit juice. The beneficial ingredients in fruit juices make them a great substrate for probiotics (Monteiro et al. 2022). Fruit juices are regarded as refreshing and healthful, and they offer a pleasing flavour profile for all age groups. Fruits that are nutrient-dense and free of dairy allergies that can deter some populations from eating them include those that are high in dietary fibre, minerals, vitamins, and antioxidants. These traits enable the selection of the proper probiotic strains to produce delicious, healthful fruit juice. Since fermented fruits and vegetables include some lactic acid bacteria such *Lactobacillus* sp., they may be utilised as a source of probiotics. There are many different ways to take probiotics, including in liquid, powder, gel, paste, granule, and capsule form. Certain probiotics are typically used to treat a variety of gastro-intestinal tract (GIT) issues, including acute diarrhoea, lactose intolerance (Doron et al. 2005). Some research shows that taking probiotics can lower your risk of getting allergies, asthma, cancer, and a number of ear and urinary tract infections.

Prebiotics

Prebiotics are nondigestible food ingredients that, in the digestive tract, foster the development of particular probiotic microbes, in addition to triggering bacterial metabolites in the intestines (Davani-Davari et al. 2019). These sources typically contain polysaccharides, and recent research has explored their potential application as prebiotics. These substances serve as substrates for the human gut microbiota and have the ability to modify its composition through a variety of processes (Rajan et al. 2021). After the coconut kernal's coconut milk has been extracted, coconut residue is a waste by-product. As this by-product is nutrient-rich, growing defatted on it might be a way to turn it from an unusable waste product into one with significant market value. A way to reducing environmental pollution is to make use of such by-products, which present a significant disposal issue for the coconut sector and its economic potential (Nor et al. 2017). Similar advantages have also been observed for hemicellulose oligosaccharides (HOS) made from lignocellulosic biomass. HOS, a substance made up of xylooligosaccharides and arabino glucuronoxylan extracted from Norway spruce and birch wood, has been shown to specifically encourage the growth of *Bifidobacterium*, which enhances the production of short chain fatty acids (La Rosa et al. 2019). Similar to this, it has been observed that Xylo oligosaccharides made from Miscanthus support the growth of *Lactobacillus brevis* and encourage the generation of lactic and acetic acids (Hong et al. 2019).

Various lignocellulosic feedstocks that are locally accessible will be used by different biorefineries; in fact, switching between feedstocks would be necessary for a sustainable year-round operation (Baral et al. 2019; Kumar et al. 2021). Therefore, it is important to look into the effectiveness of producing prebiotics from various sources. The dedicated energy crops hybrid poplar (HP) and switchgrass (SG), whose field trials in the United States averaged 15 tonnes per hectare per year (Volk et al. 2018). Aside from that, using agricultural wastes is advantageous because it is a cheap and widely available substance.

Polyunsaturated fatty acids (PUFAs)

With more than one double bond in its backbone, PUFAs are the "essential fatty acids," and they are crucial for healthy cell development and brain function (Bellou et al. 2016). Depending on where the initial double bond is in relation to the methyl end of the fatty acid, PUFAs can be either omega-3- (n-3) or omega-6- (n-6) fatty acid (AA). Alpha-linolenic acid (ALA), docosahexaenoic acid (DHA), and eicosapentaenoic acid are the three main omega-3 fatty acids (EPA). The building blocks of EPA and DHA are ALA and alpha-linolenic acid (ALA) (Li et al. 2021).

Fish oils and fatty fishes like salmon, mackerel, herring, trout, and blue fin tuna are the principal sources of EPA and DHA. ALA is mostly obtained from plant oils, particularly from red/black currant seeds, flaxseed oil, flax seeds, soybeans, and canola oil (Yamagata 2017). Fish processing waste from marine and fresh water sector have shown to be a potential source of PUFA in particular ALA, EPA and DHA. Fermentation and enzymatic hydrolysis have been applied for recovery of PUFA rich lipids from fresh water fish visceral waste. Further, lipids from fish processing waste were shown to be safe and exhibit similar beneficial effects in comparison to fish oil at same concentration of PUFA (Rai et al. 2015).

In accordance with Pandey et al., production of biomass that is rich in PUFAs can be applied in the nutrition of animals as functional feed and nutraceutical. The use of agro-industrial waste as substrates has greatly increased in recent years. One of the major agricultural producers in the world, Brazil, has created technologies that employ waste from the starch-producing agro-industry, such as cassava, corn, potatoes, and rice, as a substrate for fermentation processes to reduce contamination issues and save money on waste treatment. These cheap raw materials have economic value due to the possibility of producing nutraceuticals from agricultural byproducts (Pandey et al. 2000).

Docosahexaenoic acid (DHA)

Due to increased knowledge of DHA as a crucial dietary component, commercial manufacturing of DHA (docosahexaenoic acid) has increased. Regular DHA consumption is known to have a number of positive health effects, including the prevention of arteriosclerosis and coronary heart disease as well as the relief of inflammatory disorders like asthma, depression, and rheumatoid arthritis (Patel et al. 2022).

The majority of time that thraustochytrids have been cultivated, or "de novo" fermented, has been on hydrophilic substrates. In "de novo" mode, the fatty acid composition of thraustochytrids oil is richer in docosahexaenoic acid and saturated palmitic acid. The fatty acid composition of the generated oil was altered by the "ex novo" fermentation of a new *Aurantiochytrium mangrovei* RCC893 with waste acid oil. Dairy liquid waste produced from the production of cheese that has no actual use and is intended for disposal, causing environmental problems and representing a significant expense of disposal of dairy liquid, according to a research working on media formulation for DHA production (Russo et al. 2021). Another promising food waste that results from brewing operations is spent brewery yeast (SBY), which may be reused in fresh biotechnological procedures. An aquatic protist called *Aurantiochytrium mangrovei* is well recognised for producing bioactive lipids including DHA and long chain polyunsaturated fatty acids. In an effort to valorise dairy effluents, for the cultivation of *A. mangrovei*, unique sustained growth medium and DHA production have been developed. Response surface techniques were also used to optimise the unique sustained growth medium from hydrolysed dairy waste liquid, yielding 10.14 g L^{-1} of biomass and 1.21 g L^{-1} of DHA in the optimised medium.

As demonstrated, a marine thraustochytrid strain was able to endure and consume a record 120 g/L of waste cooking oil (WCO) under highly salinized circumstances. The thraustochytrid strain could also improve the microbial triglycerides in this low-quality oil, making them more squalene and docosahexaenoic acid rich (DHA). The quantities of DHA and squalene were further improved by the co-utilization of hydrophilic and hydrophobic substrates by de novo and ex novo fermentation (Patel et al. 2022).

For the industrial production of DHA, the price of the growth medium and the costs associated with creating artificial sea water account for a sizeable amount of the production costs (Nazir et al. 2018). Because of this, developing novel biotechnological techniques based on the reuse of inexpensive by-products from the food industry would be an intriguing option to generate omega-3 oil more cheaply. Due to their excellent metabolic flexibility and bioremediation capabilities, aquatic protists are receiving more attention from the scientific community for the treatment of food waste (Hamilton et al. 2015). When tested on several types of food waste, *Aurantiochytrium* sp. shown a high degree of metabolic adaptability to utilising various types of organic and nitrogen sources (Yin et al. 2019).

Polyphenols

Due to the structural chemistry of polyphenols, these compounds are typically recognised for their antioxidant properties. Plants create polyphenols, a broad family of phytochemicals, as secondary metabolites to shield them from the damaging effects of reactive oxygen species (ROS) during photosynthetic stress (Metsämuuronen and Sirén 2019; Singh et al. 2019). All plant phenolic molecules, including the 8,000 or so various groups of polyphenols, start out as the same precursor called phenylalanine or shikimic acid. Flavanols, flavonoids, flavones, flavan-3-ols, flavanones, anthocyanins, and many more compounds are polyphenols. The majority of the polyphenols are produced by their highly branched phenylpropanoid route (Tsao 2010). In addition, polyphenols develop anti-inflammatory, anti-microbial, antioxidant, and cardio protecting capabilities. Additionally, play a significant part in preventing diabetes mellitus and neurological disorders (Scalbert et al. 2005). Fermentation approaches can be applied for production as well as transformation of polyphenols. Therefore, fermentation approached need to be explored more for transformation of polyphenols rich waste into high value products.

Proteins and peptides

There are several agrifood processing byproducts that are rich in protein that can be essential source of essential amino acids. The protein rich byproducts can be biotransformed to protein hydrolysate and bioactive peptides that can exhibit diverse range of functional properties including antioxidant, immunomodulatory, antihypertensive, antimicrobial and antidiabetic properties (Chourasia et al. 2022a). The amino acid composition and their sequence in the chain of amino acids define the functional properties of the peptides. Animal and fish processing byproducts, legume processing industry byproducts and selected vegetable waste has been the source of protein and therefore have been transformed to protein hydrolysate having selected functionsl properties. The production of bioactive

Table 1 Summary of production of nutraceuticals from agri processing residues

S. no	Source of waste	Process for extraction	Nutraceuticals	References
1	Apple pomace	Enzymatic process	Polysaccharides (pectin), flavonoids, phytochemicals	Picot-Allain et al. (2021)
3	Whey	enzymatic hydrolysis	Bioactive peptides from protein hydrolysate	Corrêa et al. (2019)
4	Mango seeds/kernel	Green pressurized-liquid extraction (PLE)	Bioactive compounds like polyphenols, flavonols, phytosterols (stigma-sterol, campe-sterol), and tocopherol	Ballesteros-Vivas et al. (2019)
6	Raspberry pomace	Solvent Extraction method Solvent: Acidified hydroethanolic mixture (60% ethanol) Processing time: 10–50 min Temperature: 40–60 ◦C	phenolic compounds, flavonoids and anthocyanins	Xue et al. (2021)
7	Carrot waste	Ultrasound enzyme-assisted extraction	Dietary fibres, phenolic compounds, carotenoids	Encalada et al. (2019)
8	Peach pomace	Solvent Extraction method Solvent: Hydroethanolic mixture (70% ethanol) Processing time: 20–120 s Temperature: 25–55 ◦C	Anthocyanins, Polyphenols	Plazzotta et al. (2020)
9	Fig peel	Microwave Assisted Extraction Solvent- Acidified hydroethanolic mixtures (0–100% ethanol) Irradiation time: 5–35 min Temperature: 40–115 °C Microwave power: 400 W	Maximum anthocyanin extraction was achieved at 5 min, 64.21 °C, and 100% ethanol;	Backes et al. (2018)
10	Eggplant peel	Microwave Assisted Extraction Solvent: Acidified hydroethanolic mixtures (55–95% ethanol) Irradiation time: 5–15 min Microwave power: 100–300 W	Anthocyanin extraction improved as the microwave power increased and irradiation time and ethanol concentration reduced;	Doulabi et al. (2020)
11	Black rice bran	Microwave Assisted Extraction Solvent: Acidified water Irradiation time: 13–147 s Microwave power: 298–800 W	Maximum anthocyanin extraction was achieved at 648 W and 83 s;	Halee et al. (2020)
13	Sour cherry peel	Microwave Assisted Extraction Solvent: Acidified hydroethanolic mixtures (20–80% ethanol) Irradiation time: 0.5–1.5 min Microwave power: 350–500 W	Maximum anthocyanin extraction was achieved at 500 W, 1.5 min, and 80% ethanol.	Kurtulbaş Şahin et al. (2021)

peptides depends on the specificity of the proteases or the microbial strain used for hydrolysis (Chourasia et al. 2022b). Therefore there are possibility for producing novel bioactive peptides from unexplored protein rich by-products.

Biotechnological procedures and chemical transformations: new strategies and availabilities

Chemical and biotechnological techniques are the two major ways utilised to produce a range of high-value chemicals from agricultural processing waste. While using biotechnological methods, living organisms or microorganisms are used under specified conditions, as opposed to the chemical method, which uses catalysts to produce a variety of unique molecules (Tables 1 and 2).

Chemical process for extraction of nutraceuticals from Agri processing residues

Traditional and cutting-edge solid-liquid and liquid-liquid separations are used to extract chemicals of interest from agricultural wastes and by-products. Traditional methods based on the extraction potential of different solvents and utilising heat factors and/or disintegration include maceration, infusion, Soxhlet extraction, and hydro-distillation. These methods have some limitations, though, such as a protracted solid-liquid extraction process with poor extraction specificity and selectivity, the decomposition

Table 2 some important patent on nutraceuticals from agri bioprocessing residues

S. no.	Patent title	Years	Remarks	Inventors
1.	PROCESS OF BIOMASS RICH PRODUCTION IN PIGS FOR USE IN ANIMAL NUTRITION AND / OR FISH EMPLOYING AGRICULTURAL WASTE AMILACE	BR102015018119A2 2017	The present invention is the use of high starch agro-industrial waste for the production of microbial biomass or oil rich in polyunsaturated fatty acids, for use in animal feed and / or fish.	Ricardo Soccol CarlosDaniel Goyzueta Mamani LuisCesar De Carvalho Júlio
2.	Processing of biomass	WO2009134791A2 ; 2010	The invention relates to the processing of biomass, to compositions comprising saccharide elements organized in a molecular chain, to methods for producing amino acids or antibiotics, to methods for producing food or immunostimulating material, and to products obtained by such methods.	Marshall Medoff
3.	Methods for producing fertilizers and feed supplements from agricultural and industrial wastes	US-6,497,741-B2; 2002	Integrated waste treatment and fertilizer and feed supplement production methods to be implemented at organic waste source sites, at remote treatment sites, or partially at the organic waste source site and at a remote location, whether in small or large scale operations.	SOWER LARRY P (US)
4.	Purification of Pomegranate Ellagitannins and Their Uses Thereof	US 7,919,636 B2, 2011	Current studies on elagitannins include antioxidant prop erties, anticancer potential, the inhibition of COX-1 and COX-2 enzymes; anti-athersclerotic activity; inhibition of the nuclear transcription factor NF-kB, repression of glutathione expression, and anti-adhesion effects; and the like.	Seeram, and Heber,
5.	PROCESS FOR EXTRACTION OF NUTRACEUTICALS	India; 201,621,016,371, 2017	Process for extraction of bioactives and nutraceuticals and more particularly to a process for extraction of solvent and heavy metal free bioactives and nutraceuticals such as curcuminoids in a powder form which can be in micro or nano size range.	Rajendra Sham Deshpande and Roshan Rajan Kulkarni

of thermolabile compounds, low product purity after the purification process, high processing pressure, energy requirements, and a need for a sizable quantity of solvent with high quality (Naviglio et al. 2019). The use of various nonthermal energies or the substitution of molecular solvents with ionic liquids, eutectic solvents, and supercritical fluids (Pitchaiah et al. 2019), on the other hand, have been recommended as innovative extraction strategies (ultrasound, microwave, and pulsed electric field). However, some compounds may be challenging to extract due to the plant cell walls' cellulose, hemicellulose, starch, pectin, lignin, and proteins.

Biotechnological approaches

There have been numerous advancements made in the use of agro-industrial wastes to create bioactive chemicals through fermentation techniques. One of them makes reference to co-production, which is economical and fits the circular economy's sustainable environment.

The optimization of the fermentation process, which becomes more challenging when producing the highest yield of all the target compounds is the goal, the treatment of waste, which occasionally favours the production of only the target compound, and the separation of the produced compounds, which raises questions about the use and purity of the target compounds and whether they should be used together or separately, are some of the challenges that must be overcome in co-production.

A possible method for creating their biomass and active metabolites is submerged fermentation of the mycelial form of fungi. Research was focused on the biotransformation of ferulic acid from pomegranate peel into biovanillin utilising *Enterobacter hormaechei* through submerged fermentation. The process variables, including substrate concentration, incubation time, pH, temperature, and agitation speed, were improved by RSM to increase biovanillin yield. The biotransformation of 9 g/L of ferulic acid produced the maximum amount of biovanillin, or 4.2 g/L, after 8 h at pH 7, 30 °C, and 100 rpm of agitation (Saeed et al. 2022).

Wheat straw and pinewood sawdust were investigated as low-cost feedstocks for *Paracoccus* cultures that produce carotenoids. For the successful release of fermentable sugars from both substrates, an alkali pre-treatment method followed by enzymatic saccharification was found to be efficient (Pyter et al. 2022). The maximum carotenoid production was achieved during the fermentation of the pre-treated sawdust hydrolysate by *Paracoccus aminophilus* CRT1 and *Paracoccus kondratievae* CRT2, producing 631.33 and 758.82 g/g dry mass, respectively. The biotransformation of dairy products yields health benefits from probiotic-fermentation (Lee et al. 2021). In order to enhance secondary metabolites, rice or other grains are typically utilised as substrates for *Monascus* fermentation. *Monascus*-fermented soybean extracts exhibit antioxidant properties and function as an inhibitor of aging-related enzymes (Jin and Pyo 2017). In Monascus-fermented coix seed, the antioxidant properties of scavenging free radicals have been demonstrated.

By enhancing effectiveness, lowering toxicity, saving resources, and creating new chemical components, medicinal plant bioconversion through fermentation might improve medicinal benefits. Agro-industrial wastes can be used in both fermentation techniques as a nutritional supply for microorganism species to produce bioactive chemicals. Pre-treatments are done before to fermentation in order to improve the microorganisms' access to nutrients in the case of the complex matrices of some wastes (Jiang et al. 2020).

The substrate that is chosen will rely on the dietary requirements of the microbial species that will be producing the target chemicals. The nutritional needs for microbial development can also be met by combining wastes from various sources. Additionally, some methods, such as response surface methodology and one factor at a time, can be used to optimise the fermentation of wastes to produce bioactive chemicals. The key bioactive substances that can be created utilising a biological method, as well as the unique characteristics of each process, were highlighted.

One-step fermentation from wastes can be used to produce protein hydrolysates with biological abilities. Using the *Bacillus subtilis* strain, a fermentative procedure was developed to transform tomato waste proteins into antioxidant and antibacterial hydrolysates (Moayedi et al. 2016). Lactic acid bacteria have also been applied for recovery of protein hydrolsate, Lipids and carotenoids from fish and shrimp processing waste. In their study, Mechmeche et al. (2017) explored the bioconversion of tomato seed meal extract into antioxidant peptides. *Lactobacillus planetarium* demonstrated a promising ability to breakdown and convert tomato seed proteins into peptides, also contributing to the antioxidant activity of the hydrolysates (Mechmeche et al. 2017). The keratinolytic ability of *Chryseobacterium* sp. and *Bacillus* sp. to transform feathers into protein hydrolysates with better in vitro nutritional properties was investigated, suggesting a promising future for their usage in animal feed (Maciel et al. 2017). Similar to this, SmF of feathers with *Chryseobacterium* sp. was used to produce protein hydrolysates with antioxidant characteristics (Fontoura et al. 2019).

Solid state fermentation approach

The use of SSF as a technique to boost the production and/or extractability of nutraceutical components in order to raise their concentration. The use of solid-state fermentation is primarily due to the fact that microbes can easily

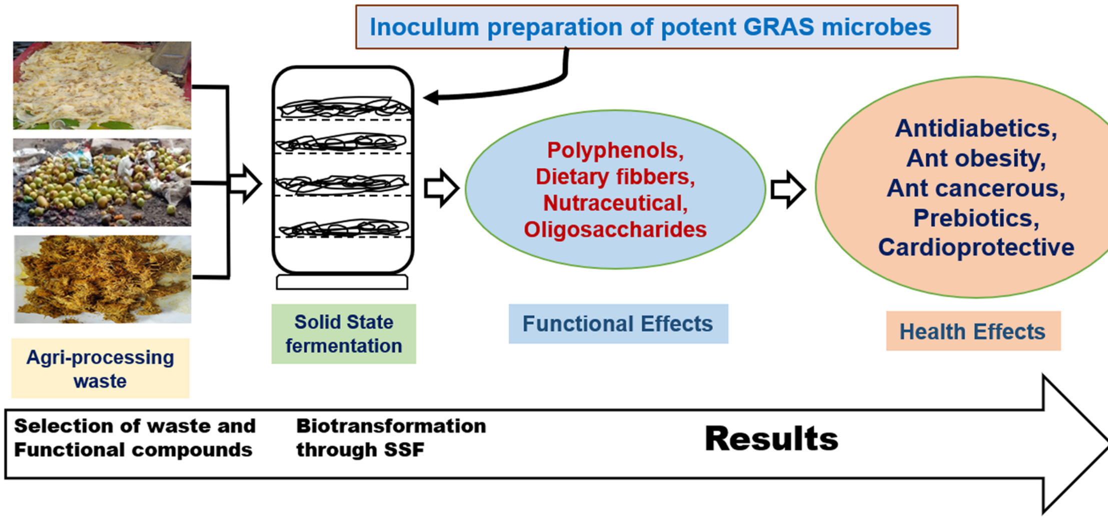

Fig. 3 Systematics representation of productions of nutraceuticals through solid state fermentation

grow on solid Agri processing residues, that many hydrolytic enzymes are produced as a result of fermentation, which aids in the release of many nutraceuticals, and that several microorganisms also produce nutraceuticals as a result of solid support fermentation.

An enzymatic fermentation with the goal of producing enzymes at the substrate's surface is the major focus of the novel applications of SSF in the first two situations. Due to the fact that enzymes increase the extraction yield of secondary metabolites by releasing them from complicated substrates, these enzymes are typically recovered through a separate process and afterwards employed as a pre-treatment in a SmF (Verduzco-Oliva and Gutierrez-Uribe 2020). As a novel strategy, hydrolytic enzymes synthesised in an SSF act directly on the utilization solid substates, releasing the nutraceuticals substances linked to the solid matrix and boosting their extractability. In contrast, in SSF conditions, bacteria and fungi are capable of enhancing the bioactive and nutritional content of the substrate through biosynthesis.

Phenolic chemicals may also be transported by ATP-binding cassette transporters into the cell matrix, where they may form covalent bonds with larger molecules like pectin or cellulose. As a result, there are three different ways that phenolic molecules can be detected inside the matrix of plants: free, insoluble-bound, and soluble-bound (conjugated). While the insoluble fraction is reported to be esterified to more complex cell wall components, the conjugated fraction is esterified to soluble molecules such some low molecular weight carbohydrates, lipids, or proteins. Due to their huge potential for altering the gut microbiota and their therapeutic role in gastrointestinal illnesses, various nutraceuticals are also being developed with SSF, such as polysaccharides and dietary fibres, as well as carotenoids, which primarily have antioxidant properties (Hurtado-Romero et al. 2020). However, there are issues with product recovery and purification, particularly when using agro-industrial waste or by-products, which represent a highly heterogeneous matrix with a variety of distinct substances. SSF does not significantly disadvantage other biosynthetic processes if the substrate can be used as a new and improved product without the requirement for extensive transformation. The right and effective procedures must be used if an extraction phase is necessary, as the conventional extraction employing solvents tends to be incompatible with food industry health laws and could hinder the commercialization of the created antioxidant and nutraceutical components contained in the substrate. Therefore, to ascertain whether an SSF process is feasible, an economic evaluation of the entire process should be carried out. Submerged fermentation (SSF) uses a matrix with little water in it, which is clearly different from SSF (SmF). As a result, considering that the process is subject to slight alterations, many parameters must be carefully considered. A maximum yield of nutraceuticals will actually be greatly dependent on proper optimization, which includes the appropriate selection of the microorganisms and their substrate or solid matrix composition, the correct selection of moisture, the correct selection of temperature, as well as the effective selection of extraction and purification techniques (Baker et al. 2019).

In fact, SSF can improve the production of a range of nutraceuticals by using agricultural and food waste. This opens the door to a wide range of useful items that could be produced with the added benefit of being environmentally friendly and utilising readily available, low-cost raw materials (Fig. 3**)**. Additional efforts are required to automate and optimise the SSF process, which could result in SmF-like efficiencies.

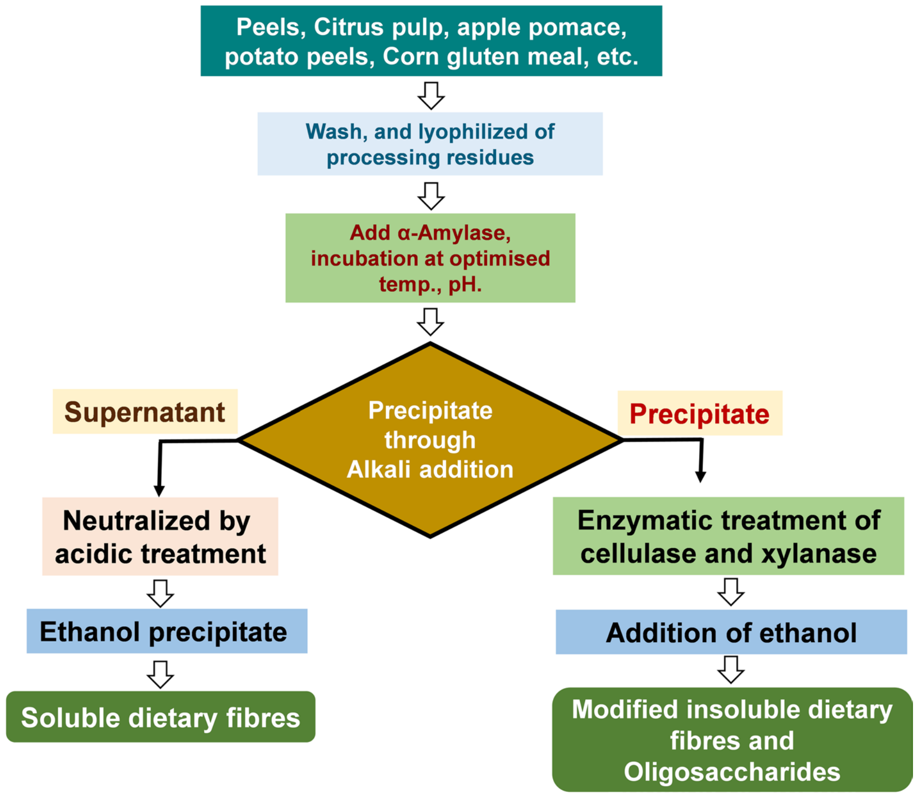

Fig. 4 Flow diagram of enzymatic treatments of processing residues for production of nutraceuticals (dietary fibres, modified fibres and oligosaccharides)

Enzyme-assisted bioactive constituent extraction from agro-industrial wastes

In comparison to traditional extraction procedures, the enzyme-assisted extraction approach can be used to pretreat raw materials, reducing production costs while increasing extraction time, solvent use, and product quality and purity. Cellulases, hemicellulases, pectinases, amylases, proteases, and lipases, in free or immobilised forms, might all be used. The behaviour of the enzyme is influenced by operational factors such pH, temperature, the concentration of the enzyme and substrate, the solid/liquid ratio, the size of the substrate particle, and the reaction time (Hernández Becerra et al. 2021).

Combining enzymes with ultrasound, microwave, and alternative solvent-based extraction techniques has also been suggested as a way to create greener processes that can produce products of higher quality, use fewer solvents during production, or increase the efficacy of enzymatic treatment and extraction yields. These complementing treatments have shorter extraction times, nontoxicity, nonflammability, the use of recyclable solvents, overall streamlined procedures, and programmable process parameters. They can be used in conjunction with the process or before or after EAE (Picot-Allain et al. 2021). Examples of how enzymes are used to extract and recover these bioactive chemicals from agro-industrial wastes are shown in Fig. 4.

Current uses of agro-industrial waste

Industrialization and development of new processing techniques in the food industry lead to generation of agro-industrial waste. In distant past, removal of this agro-industrial waste was considered as big problem by food production industries due to high cost. Also, disposal was creating negative environment impact. Composting and production of animal feed was seen as a good alternative by industries as an alternative to deal with negative impact of agro-industrial waste. Recently, with development of new technologies agro-industrial waste is utilized by adding value to it. Valorization of waste by recovery of added-value resources has economic impact on food industries along with added benefit of environment sustainability (Freitas et al. 2021).

The agro-industrial waste has complex biochemical composition which hinders its complete utilization in a single production process. Bioeconomy concept with integrated production processes can be utilized for complete utilization of waste for multiple products. The pretreatment steps, fermentation process and downstream processing are important steps towards valorization of waste (Yaashikaa et al. 2022).

The agro-industrial waste containing high lignocellulosic residues can be utilized for production of bio-oil, biochar and pyrolysis gases by thermochemical processes pyrolysis process. Lignocellulosic waste is utilized for the production of biomaterials, biofilms, bionanocomposites, hydrogels, tissue engineering (Freitas et al. 2021) Recently, biorefinery route has been explored for conversion of agro-industrial waste into value-added production of biofuels, specific chemicals with high pharmacological potential.

In food industries, new product development and separation of molecules like polysaccharide, aromatic compounds, polyols, enzymes from agro-industrial waste has been explored as resource recovery (Ballesteros-Vivas et al. 2019). In recent times, different agro-industrial wastes are also explored as ingredient for food production. Fruit peel waste like red grapes, pomegranates, dragon fruit, citrus etc. has been explored as natural colorant or dye with additional health benefits as they contain compounds having antioxidant properties (Harivaindaran et al. 2008; Wedamulla et al. 2022). Functional foods have recently gained momentum by health conscious population due health benefits. Different agro-industrial wastes like soybean, grape seed, olive mill wastewater etc. are formulated in food products as functional ingredients. High content of bioactive compounds makes waste an important source for its use in foods (Caporaso et al. 2018; Lemes et al. 2022).

Future prospects

During the production, handling, and processing of agricultural products, agricultural companies produce a sizable number of wastes and byproducts. Due to these pollutants' negative environmental consequences, disposal is a severe financial and ecological challenge. Therefore, finding new ways to recycle and reprocess these wastes is a major goal that is taken into account globally. These wastes and byproducts hold enormous potential that hasn't been completely realised, resulting in a missed business opportunity. Therefore, it's important to pinpoint the causes of the underuse of agricultural byproducts so that they may be addressed with the right methods and legislative changes. A lack of knowledge about the qualities and possible financial advantages of agricultural byproducts contributes to their underutilization. It is important to do thorough research and analyses before integrating various manufacturing processes for value-added products. By opening up new agricultural markets, providing alternatives to the production of low-cost commodities, providing new perspectives for the management of resources, and by creating economic opportunities and environmental advantages, value addition of by-products creates economic value. For agricultural byproducts to be commercialised, added value added, and used effectively, markets are necessary. The use of crop residue to make biofuels is constrained due to a lack of markets for the by-products. Therefore, it is necessary to create markets and maintain operational costs of value addition at levels that will promote the creation and consumption of value-added products. These by-products are potentially potential remedies for the issues with animal nutrition. Technologies that deliver products that are safe for human consumption as well as the usage as animal feed must be developed, taking into account elements like the characteristics of particular wastes and the environment in which they are created, reprocessed, and utilised.

A whole industry could be supported, more money could be made, more worthwhile jobs could be created, rural regions could be developed, and the waste and pollution issues could be resolved with the right use of agricultural wastes and by-products.

Conclusion

The processing of animal and vegetable resources produces significant volumes of agro-industrial leftovers, making it imperative to create strategies for their integrated usage or even for conversion into higher-valued products. When opposed to nonbiological processes, biological methods offer a number of benefits, such as the provision of extracts with high quality, high bioactivity, and low toxicity. The biological technique of obtaining bioactive molecules from byproducts can be used to create foods, active or smart agents for biodegradable materials, and packaging while promoting consumer health, food safety, and sustainable resource usage. Because of the diversity of components that can be produced, the potential interactions, and the wide range of activities, the biological approach is an important tool that must be constantly improved and encouraged; each component must be properly evaluated to ensure maximum potential in the applications.

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Declarations

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