Naik *et al.*
Food Production, Processing and Nutrition (2023) 5:30
https://doi.org/10.1186/s43014-023-00143-2

Food Production, Processing and Nutrition

REVIEW **Open Access**

Agro-industrial waste: a cost-effective and eco-friendly substrate to produce amylase

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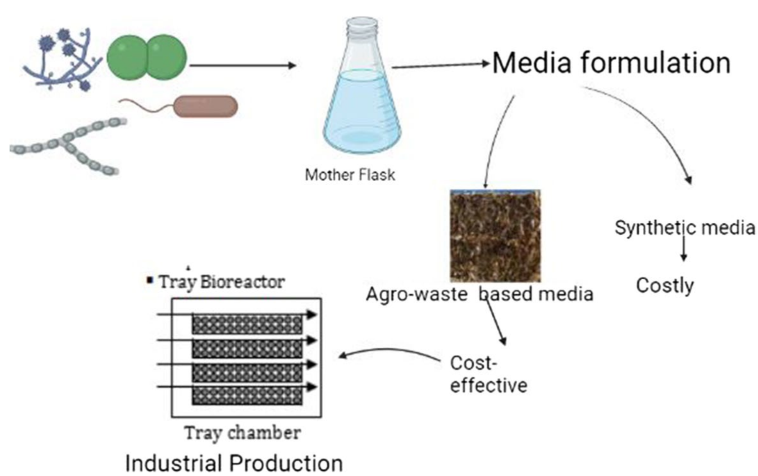
Abstract

The increase in the global population has led to a substantial increase in the demand for food supply as well as food manufacturing industries that regularly produce large amounts of food waste. Agro-industrial waste has attracted tremendous attention all over the world since ancient times, such waste is usually dumped or burned and poses a threat to human health and the environment, which has always been a matter of serious concern. However, food waste is a major source of complex carbohydrates, proteins, lipids, vitamins, minerals, fibers, and helps in the manufacture of raw materials for a variety of industrial purposes such as the production of biofuels, enzymes, bioactive compounds, biodegradable plastics, surfactants. Hence it is necessary to convert food waste into value-added products that reduce environmental problems. The present review paper attempts to outline and analyze the potential of agro-industrial residues as cost-effective substrates to produce the enzyme amylase using a wide range of microbial strains.

Keywords Amylase, Agro-industrial waste, Substrates, Starch processing, Bioprocessing, Enzyme

Graphical Abstract



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Introduction

Enzymes have gained great interest worldwide due to their wide variety of biomedical, scientific, and industrial applications (Singh et al. 2016). The production of enzymes traditionally used in food is considered safe. However, some of the characteristics exhibited by its chemical nature and origin, such as the allergic, toxic nature, activity of microbiological residues, and the toxic potential of chemicals, are highly regarded. These properties regarding their nature must be dealt with in the context of increasing enzyme complexity and uncertainty in the techniques used in the production of food-grade enzymes. To guarantee consumer health, a regular health assessment of all the enzymes even the ones produced by genetically modified microbes is necessary (Deckers et al. 2020). Enzymes that are widely distributed in nature have been used in the production of several commodities for instance cheese, wine, beer, and vinegar as well as in the development of products such as leather, indigo, linen, etc. All these processes were dependent on either enzyme synthesized by randomly grown microbes or enzymes existing in additional preparation such as the rumen of calves or papaya fruit. Consequently, enzymes were not utilized in any pure or characteristic form. The discovery of fermentation processes over the later part of the previous century, explicitly aimed at the production of enzymes utilizing selective growth strains which enabled the production of enzymes as processed, well-characterized preparations even on a massive scale (Muthusamy et al. 2022). Enzymes are the desirable metabolic catalyst that gives different endogenous biochemical reactions through a well-defined pathway. Enzymes enhance various biological reactions that are essential in maintaining human life by reducing the activation energy of the reaction without any significant alteration. Enzymes, varying from a minute microorganism to plants and livestock are found in all naturally occurring species and hence can be exploited for industrial purposes. Moreover, multiple microbial enzymes are well-identified catalysts for the synthesis of several products from a diverse range of substrates under regulated conditions (Singh et al. 2019). Out of all the enzymes proteases and amylases are of high industrial significance. Amylase in total accounts for 30% of the production of industrial enzymes worldwide (Bamigboye et al. 2022).

Amylases

Carbohydrases also termed glycosidase (glycoside hydrolases) are a group of enzymes that represents different enzymes involved in the hydrolysis and synthesis of carbohydrates (Contesini et al. 2013). Amylases are comprised of this group along with other enzymes like xylanases, cellulases, etc. It is one of the main industrially important groups of the enzyme (de Castro et al. 2018). The types of amylases are shown in fig. 1.

It finds a wide range of applications as a processing aid in the food and beverage industries such as in the preparation of different types of sugar syrups, prebiotics, and isomaltulose and to reduce lactose content in milk (Contesini et al. 2013). Other than these it is highly applied in the feed, textile, and pharmaceutical industries (de Castro et al. 2018). The increasing industrial applications further demand for carbohydrase in the enzyme market \(Srivastava & Srivastava 2018). Amylolytic enzymes like α-amylase and glucoamylase are industrially important enzymes among the different enzymes in the carbohydrase group. The amylolytic enzymes degrade the substrates like pullulan, glycogen, starch, and other complex polysaccharides (Jafari et al. 2022). Most of the amylolytic enzymes are belonging to glycosidase or glycoside hydrolases (GHs) and are classified into individual GH families and subfamilies based on structural differences and sequence similarity. These enzymes are classified as exo-glycohydrolase and endo (glycanohydrolase) enzymes based on the position of the bond cleavage. Exo-enzymes (β-amylase, EC 3.2.1.2), break a terminal, non-reducing-end glycose from a glycan like di-, tri- or oligosaccharides, and produce glucose, maltose, etc. and endo enzymes (α-amylases, EC 3.2.1.1) hydrolyze internal α-1, 4 glycosidic bonds of polysaccharides and give oligodextrins (de Castro et al. 2018).

Further, these α-1,4 and α-1,6 glycosidic bond hydrolyzing enzymes are categorized into three types based on the types of bond cleavage, such as; the first one that hydrolyzes only α-1,4 glycosidic bond, e.g. α-amylase and β-amylase (Fig. 1); the second group comprises the pullulanase and isoamylases which breaks α-1,6 glycosidic bonds, and the third group of enzymes included in this category is glucoamylases hydrolyzing both α-1,4 and α-1,6 glycosidic bonds (de Castro et al. 2018). Amylases catalyze the hydrolysis of starch molecules into different products including dextrin, oligosaccharides, and glucose molecules which are among the most hydrolytic enzymes of high industrial significance (Far et al. 2020; Movahedpour et al. 2022). Amylolytic enzymes incorporate a vast range of enzymes and α-amylases, β-amylases, and glucoamylase are the most common among them and are known more widely. Alpha amylases catalyze the α-1,4- glycosidic bond division as a result, the molecular weight of the substrate falls rapidly as well as its viscosity. These enzymes act on the starch to produce polymers composed of glucose

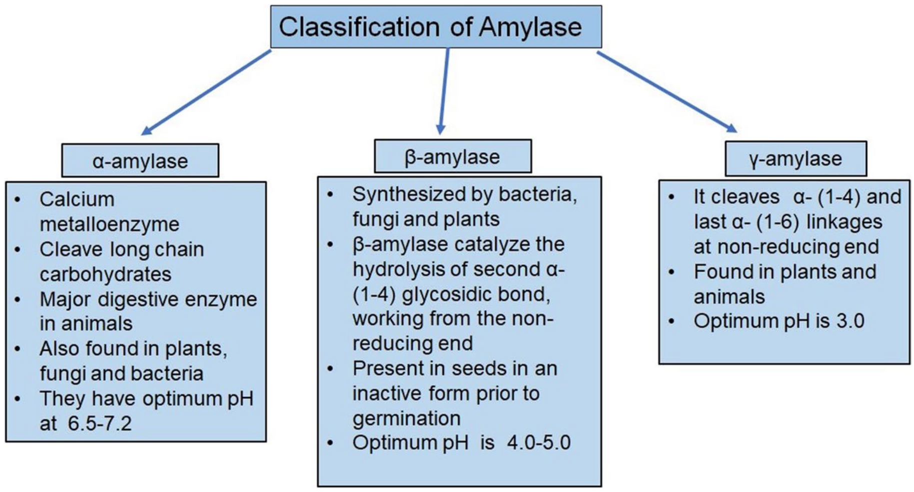

Fig. 1 Classification of amylase (Saranraj & Stella 2013)

units. β-amylases and glucoamylases are the two most widespread forms of extractive amylases in starch saccharification. They function on glycosidic bonds at the non-reducing ends of amylose, amylopectin, and glycogen molecules, providing low molecular weight carbohydrates in the β-anomeric form. Maltose is the principal product of β-amylase catalyzed hydrolysis and glucoamylases produce glucose (Babbar & Oberoi 2001). Amylase is widely used to liquefy starch, and paper, in the preparation of starch coatings for paints, removal of wallpaper, brewing industry, and for the processing of starch sugar syrups consisting of glucose, maltose, and higher oligosaccharides, in pharmaceutical industries. A low-cost medium is necessary for the synthesis of amylase to meet the demands of these industries (Bhatt, Lal, et al. 2020). Over the past few years, researchers have developed a significant interest in the potential of using microorganisms to synthesize amylases. Furthermore, bacterial amylases owing to their rigid stability conditions enhance the enzymatic activity for controlled potential variables, easy handling, high productivity, and cost-effectiveness as well as the availability to acquire genetic modification providing enzymes with desirable characteristics that dominate as bioresources in industries. Amylase has been examined and characterized in past years from several novel bacterial strains such as that *Bacillus subtilis* (Almanaa et al. 2020), *Bacillus thuringiensis* (Smitha et al. 2013), *Aeromonas veroni*, *Stentrophomonas maltophilia* (Sen et al. 2014), and *Chryseobacterium* sp. (Khusro et al. 2017; Bhatt, Prajapati, et al. 2020). There two main methods to produce amylase enzymes are Submerged fermentation (SmF) and Solid-State Fermentation (SSF) (Far et al. 2020). SmF targets the production of microorganisms in an environment where surplus water is flowing. Batch type or continuous type are the two modes over which it operates. Soluble substrates are readily dissolved in the liquid phase whilst the non-soluble substrates get suspended. The reaction conditions are successfully handled due to this efficient setup with a lesser rate of production, potential inhibitory compounds also possess a great threat to the process, and the process requires a great amount of energy (Kumar et al. 2021). Solid-state fermentation is a substitute for submerged fermentation because it resembles the environment in which microorganisms naturally exist. SSF is practically better than SmF regardless of its simplicity, low capital expenditure, low energy consumption, lower water output, and less foam (Couto & Sanromán 2006). The solid substrate in the SSF cycle not only provides the culture with all the vital nutrients but also protects the microbial cells. The optimum moisture content of the substrate is necessary because the water content of the medium changes during fermentation due to loss of water and metabolic activity (Zehra et al. 2020). The best substrates for the solid-state fermentation process are the agro-industrial residues or by-products (Leite et al. 2021).

Agro-industrial residues as substrates

Throughout the twenty-first century, the global agriculture and food industries had major problems to address. Food safety and the adequate disposal of waste materials and by-products stand out among them. Food waste dominates a rapidly increasing space in the management of waste plants and disposal sites. Numerous residual wastes derived from the food supply chain nowadays denominate essential resources as well as cause serious environmental damage. On one side, food waste has profound socio-economic repercussions for low-income and third-world countries (Gustavsson et al. 2011). Whereas on the other side, the behavior of customers and the extensive use of products or services allow a large quantity of household waste to be generated in medium and high-income countries (Usubiaga et al. 2017). In food industries waste is generated by the removal of desirable products from unwanted by-products (Kwan et al. 2018). Waste from fruits and vegetables is the primary cause of environmental degradation (Garg & Ashfaque 2010). Agro-industrial waste is generated throughout the industrial processing of agricultural or livestock products. The main advantages of using these agro-wastes are that they are organic and cost-effective. The sources of energy and moisture present in these wastes provide an ideal basis for microbial growth, and thereby such wastes can be used as a source of fuel, energy, or nutrients for the development of a range of compounds of huge importance (Foyle et al. 2007). Significant research attempts have been carried out in recent times to approve waste produced from food processing to generate bioproducts of substantial quality. Table 1 shows the major agro-waste usage area and the components that could be procured for further use. Renewable conversion of biomass to food waste producing valuable products not only offers profitable benefits but in addition reduces environmental and landfill hazards generated by the decomposition of food waste (Bilal et al. 2018; Hegde et al. 2018). The primary products that can be manufactured are sugar, glucose, furfural, protein, and amino acids, secondary metabolites, fats, lipids, phenols of surfactants, activated carbon, gasoline, composites of degradable plastics, cosmetics, raisins, medications, foods, and feeds, biosorbents, biopesticides, fertilizers along with other miscellaneous products (Mtui 2007; Ubalua 2007; Galbe & Zacchi 2007; Demirbas 2007). Agriculture waste is a starch-based substrate and provides the requisite carbon and nitrogen supplies for the metabolism of bacteria. Agro-industrial wastes or leftovers include a high concentration of nutrients and bioactive substances. As a result of the heterogeneity in the content of such wastes, such as minerals, sugars, and proteins, they should be regarded as “raw material” rather than “wastes” for other industrial operations. It can be utilized as solid support in fermentation processes to produce cost-effective and eco-friendly substrate to manufacture amylase which could be further used as a source of carbon in the culture medium. Specific agriculture waste such as millet starch, potato, and wheat bran are mostly used to produce amylase (Fig. 2) (Sajjad & Choudhry 2012).

Fruit processing industry waste

Mangifera Indica

Mangoes are frequently eaten as sweets, although consumption of mango commodities such as canned, frozen, concentrates, juices, jams, mashed, dehydrated products, and minimally processed mangoes has increased recently. Byproducts from mango fruit processing include peels (13–16%) and seeds (9.5–25%) in substantial amounts. Mango seed kernels have a starch yield of 20% and possess properties resembling those of commercial starch (tapioca). The mango seed has a high concentration of oleic and stearic acids and is a vital source of carbohydrates (58–80%), protein (6–13%), and lipids (6–16%) (Torres-León et al. 2016; Torres-León et al. 2017; Torres-León et al. 2018). Kumar et al. (2012) produced amylase from the kernel of mango using *Fusarium* species. Similarly, the mango kernel has been used by Rizk et al. (2019) to produce amylase by using *Aspergillus niger.*

Ananas comosus

Pineapple is mainly known for its sweet and sour flavour, and contains vitamins A, B, and C, minerals, and antioxidants. It also contains bromelain, one of the important enzymes in food processing. During the processing of pineapples, many by-products are generated mainly consisting of peel and pomace which are rich in dietary fiber. Pineapple stem is an agricultural waste that is rich in starch. Its starch is unique compared to corn, rice, and cassava starch. It has the highest concentration of amylose, which leads to the highest pasting temperature, gelatinization enthalpy, and gelatinization temperature as well as the lowest paste consistency when cooking normally (Nakthong et al. 2017a, b). Cyprian et al. (2017) used pineapple waste to produce amylase by *Aspergillus niger*.

Banana

Due to their nutritive value, affordability, and digestion, bananas are among the most consumed fruits in the world. With over 100,000 ha of farmed land, it is the most popular fruit in South Asia. As a result, the home and food industries generate thousands of tonnes of banana peel waste that is not properly exploited. BP is rich in lignin (6–12%), pectin (10–21%), cellulose (7–10%), and hemicelluloses (6–9.4%%), hence has been used as s substrate to produce various enzymes (HappiEmaga et al. 2008). Alpha-amylase by *Bacillus subtilis* and *Penicillium* species is one of the studies that have been designed to accomplish industrially important enzymes using BP

Table 1 Agro-waste usage area and the components that could be procured for further use

Agriculture produces	Agro-waste	Major components	Usage area	Value-added other products	Enzymes	Reference
Apple	Pomace	Carbohydrates, phenols, flavonoids, Anthocyanins, Dihydrochalcones, Triterpenoids	Fermentation for production of enzymes, prebiotics, hypo-cholesterolemic effects, Antimicrobial, anticancer, anti-diabetic, bone-forming ability, anti-inflammatory	Bread, cake, muffins, cookies, Extruded Food Products, meat products, dairy products, alcoholic beverage	Amylase, cellulase	Barreira et al. 2019; Othman et al. 2020
Mango	Peel	Cellulose, lignin, protein, reducing sugar, polyphenols, carotenoids, and vitamins	Cellulase production, pectin enzymes, Single-cell proteins, antioxidants, lactic acid production, ethanol production	Noodles, bread, biscuits, sponge cakes, and other bakery products	Amylase, Pectinase, glucoamylase	Siddiq et al. 2017
Orange	Peel	sugars, flavonoids, carotenoids, folic acid, vitamin C, pectin and essential oils, c flavanone glycosides (mainly naringin, hesperidin, narirutin, and neo hesperidin, e cellulose, hemicellulose, pectin, b-glucans, gums, and lignin	Naringinases, pectinase, antioxidants, Food additives, designing of functional foods, and biological properties, such as anti-carcinogenic, and antiatherosclerotic effects, reduce coronary diseases	SCP, dietary fiber powder, c Production of Prebiotic Oligosaccharides, Bio-sorbents for Heavy Metal Removal, organic acid production, bioethanol production, enzyme production, extraction of pectin, essential oils	Cellulose, pectinase, amylase glucoamylase	Mamma & Christakopoulos 2014; Abd El-ghfar et al. 2016
Grape	Grape marc, skin, pomace, seeds	Lignin, sugar, protein, soluble and insoluble fiber, fructose, glucose, K, Mg, Ca, Mn, Fe, Zn, Cu, P	Antioxidants, food preservatives, food fortification,	Fortification of foodstuffs, fortification of meat and fish products, fortification of dairy products,	Amylase, glucoamylase	Antonić et al. 2020
Banana	Peel	Starch, pectin, cellulose, fat, proteins, K, Mn, Fe, Zn, Na, P, Ca	Antioxidant, Antimicrobial,	Food thickeners, gelling agents, edible films, enzyme production	Amylase, glucoamylase, pectinase, xylanase	Padam et al. 2014; Aboul-Enein et al. 2016
Rice	Husk	Carbon, nitrogen, lignin, silica, K,	Purification, poultry feed, food additives,	Poultry feed	Glucoamylase, amylase	Bodie et al. 2019
	Bran	Carbohydrates, protein, fiber, lipids, E- complex enzymes, B complex vitamins (niacin, thiamine, pantothenic acid, and pyridoxine), caffeic acid, cycloartenol ferulate, and ferulic acid, γ-oryzanol	Anticancer, prevent chronic disease, lower cholesterol, and lower blood pressure in humans. Reduce the risk of coronary heart disease	Value-added products, e used to produce acceptable low-fat, high-fiber products, d protein concentrate, cookies, muffins, pastries, rice bran wax as an edible coating to candy, feed ingredients for broilers, production of enzymes	Amylase, glucoamylase, protease	Bodie et al. 2019
Wheat	Bran	Starch, fat, proteins, arabinoxylan,	Biosorbent material, antioxidant, anticancer, nutrition, amino acids, the solid substrate for fermentation, production of metabolites, biofuel	Heavy metal removal, minimizes the risk of chronic disease, food enrichment, feed additive, cheap raw material for metabolite production	Amylase, glucoamylase, pullulanase	Katileviciute et al. 2019

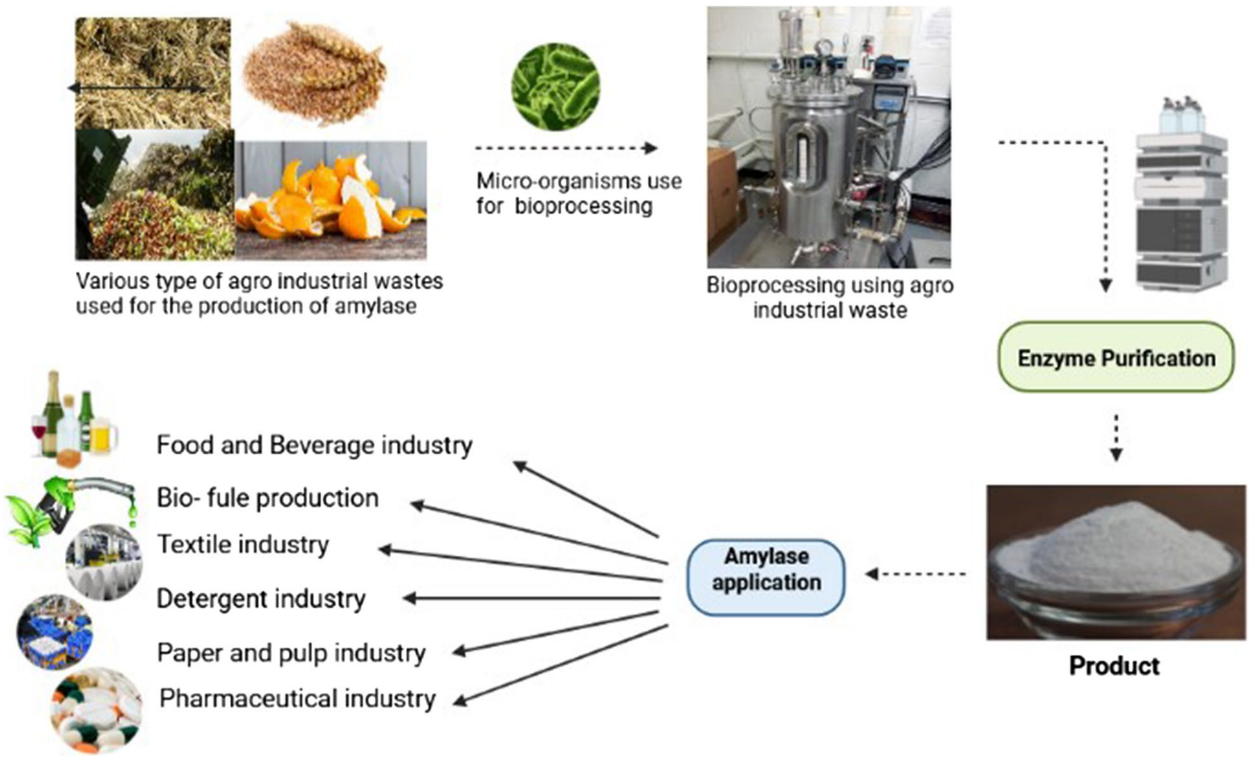

Fig. 2 Amylase bioprocessing and its applications

(Akkarachaneeyakorn et al. 2018). Similarly, Sulong et al. (2022) used BP to produce microbial amylase by bacterial isolate.

Grapes
Both fresh and processed grape products, including wines, jams, juices, jellies, grape seed extract, dried grapes, vinegar, and grape seed oil, are consumed by humans. 51,801.0 tons of waste, or 45.53% of total production, are produced. Grape by-products include the seeds and pomace that remain after the juice has been extracted. Grape waste including seeds has been attempted by various authors to produce enzymes such as Laccase, β-glucosidase, endoglucanase, and other cellulosic enzymes (Díaz et al. 2012; Levin et al. 2012). Iram et al. (2021) used grape peel to produce amylase by using *Bacillus licheniformis.*

Pomegranate
Pomegranate fruit consumption has surged recently due to its exceptional health benefits and the production of large amounts of byproducts that are generally discarded or used improperly (Gullón et al. 2020). These by-products and residues are rich sources of biomolecules and serve as carbon and nitrogen sources for microorganisms. Recently, pomegranate peel waste has been used to produce amylase by *Aspergillus terreus* (Ahmed et al. 2020).

Cereal waste
One of the most important sustainable development techniques that can aid in utilizing waste to create new commodities is the circular economy. Cereal food waste and leftovers are a substantial worldwide resource that may be used as a substrate for solid-state fermentation, an eco-friendly method of producing enzymes (SSF) (Teigiserova et al. 2021). Out of all the waste types, cereal waste ranks in the second position and is utilized for enzyme production. These wastes are also referred to as agro-industrial waste or agricultural residues (Sadh et al. 2018). It includes wastes from wheat, rice, maize, oat, millet, barley, rye, and sorghum. In terms of lignocellulosic biomass, cereal waste is ideally suited as a cheap carbon source for solid-state fermentation. According to the hierarchy of food waste that has recently been modified (Sanchez et al. 2020), material recycling of unavoidable inedible waste takes precedence over energy and nutrient recovery. A recent report from the Knowledge Center for

Bioeconomy of the European Commission lists enzymes as one of the principal products from cereal waste, along with acid and polysaccharides. Enzymes are regarded as high-value compounds (90–2479 USD/kg) (Teigiserova et al. 2019). These are used to breakdown the cell components to increase the availability of desired compounds such as the enzymatic hydrolysis in the manufacture of biofuel, enzyme-assisted extraction of polyphenolics, colourants, and other substances (Boluda-Aguilar & López-Gómez 2013; Strati & Oreopoulou 2014; Gharib-Bibalan 2018).

Wheat bran

It is the byproduct of the wheat processing industry. Wheat bran is a portion of the outer pericarp layer that is left behind after milling. Wheat bran has several bioactive and volatile chemicals with health advantages, along with being high in minerals, fiber, and vitamin B (Apprich et al. 2013; Curti et al. 2013). It also contains soluble and insoluble fiber and complex polysaccharides including cellulose, hemicellulose, and pentosan (Andersson et al. 2014). In SSF wheat bran has been used as a substrate to produce amylase by using *Bacillus* species (El-Shishtawy et al. 2014). Similarly, Almanaa et al. (2020) used wheat bran as the substrate to produce hydrolytic enzymes by using *Bacillus subtilis.*

Rice bran

When paddy rice is milled to obtain polished rice, rice bran, a solid byproduct of agriculture, is produced (Moongngarm et al. 2012). Rice bran contains many nutrients such as carbohydrates (34–62%), lipids (20%), protein (11–15%), crude fiber (7–11%), and ash (7–10%) (Alauddina et al. 2017). Rice bran has been successfully used by Singh et al. (2012) to produce amylase. Similarly, Paul et al. (2020) used rice bran residue from agricultural waste to get a high production of amylase by *Bacillus tequilensis* TB5.

Sugarcane bagasse

The main by-products of the sugar and ethanol industries are sugarcane bagasse and straw, which can be valuable sources of sugar for use in biotechnological processes to produce high-value goods (de Albuquerque Wanderley et al. 2013). A by-product of the sugarcane industry called sugarcane bagasse (SCB) is a substantial source of cellulose (45%), hemicellulose (32%), and lignin (17%) with little ash. Because it is often burned outside or disposed of incorrectly, creating environmental contamination, the huge amounts that sugar factories produce offer a significant environmental concern. It serves as a substrate for the synthesis of microbial enzymes and biofuels since it is a rich supply of fermentable sugars (Yadav et al. 2020). Rajagopalan and Krishnan (2008) used sugarcane bagasse extract to produce amylase by *Bacillus* species while sugarcane press mud has been used by Rajesh et al. (2020). Díaz et al. (2020) produced a cocktail of enzymes by *Aspergillus niger* by using sugarcane bagasse and cassava bagasse as a substrate. Table 2 summarizes the potential usage of several agricultural industrial residues or by-products in the production of the enzyme amylase.

Other industrial attributes

Laundry, dishwashing, textiles, and other sectors are now using enzyme-based detergents. The amylase in the detergent primarily transforms leftovers of starchy foods like potatoes, oatmeal, gravies, chocolate, custard, and others into dextrins (Fig. 2). Starch is the most commonly used sizing agent due to its simplicity of availability, low cost, and ease of removal. Amylase holds huge benefits in the paper and pulp industry to modify the starch-coated paper. Starch is the most popular substrate for the production of bioethanol since it is widely accessible and reasonably priced (Balakrishnan et al. 2019).

Amylases are used in the textile industry to help in the design process. Desizing is the removal of starch from fabric, which acts as a strengthening agent to keep the warp thread from breaking during the weaving process. Amylases remove the size of the fibers but do not affect the fibers themselves (Souza & Magalhães 2010).

Amylases are used in a variety of food processing industries, including brewing and baking, as well as the manufacture of fruit juices and starch syrups. Bread toughness is reduced when low molecular weight dextrins are present. *B. stearothermophilus,* α-amylase has been used as an anti-staling agent in the baking industry (Patil et al. 2021). Amylolytic enzymes convert starch from low-cost resources into the sugar syrup. Chocolate syrup is made by dextrinizing chocolate starch in cocoa slurries using amylases, resulting in a thin syrup (Balakrishnan et al. 2019).

Conclusion

Food processing industries produce a large amount of waste in the form of peels, seeds, straws, stalks, etc. Due to the lack of commercial usage of such waste, they are ultimately dumped leading to environmental pollution. Hence, there is an urgent need to change the perception of the utilization of agro-waste residues as they can

Table 2 Potential usage of Agricultural industrial residues in the production of amylase

Agro-waste	Organism	References
Babassu cake	*Aspergillus awamori*	de Castro et al. 2010
Banana peel	*Bacillus subtilis*	Almanaa et al. 2020
Banana waste	*Rhizopus stolonifer, Bacillus subtilis*	Unakal et al. 2012
Beetroot peel Powder	*Monascus sanguineus*	Tallapragada et al. 2017
Biomass of *Cynara cardunculus*	*Anoxybacillus amylolyticus*	Finore et al. 2014
Cassava bagasse	*Bacillus* sp.	Gois et al. 2020
Cassava waste	*Aspergillus niger*	Kamaraj & Subramaniam 2020
Coconut oil cake	*Aspergillus oryzae*	Ramachandran, Patel, Nampoothiri, Chandran et al. 2004
	Aspergillus niger	Sheela et al. 2021
Corn bran	*Bacillus subtilis*	Pranay et al. 2019
Corn cob	*Aspergillus niger*	Aliyah et al. 2017
Cotton seed cake	*Thermomucorindicae seudaticae*	Kumar & Satyanarayana 2003
Cow dung	*Bacillus cereus*	Vijayaraghavan et al. 2015
Goat dung	*Glutamicibacter arilaitensis*	Aarti et al. 2017
Ground nut oil cake	*Aspergillus oryzae*	Ramachandran, Patel, Nampoothiri, Francis et al. 2004
Groundnut shell and cassava waste	*Bacillus* sp.	Selvam et al. 2016
Moong husk	*Bacillus velezensis*	Bhatt, Lal, et al. 2020
Kitchen waste	*Bacillus amyloliquefaciens*	Bhatt, Prajapati, et al. 2020
Palm kernel Oil cake	*Aspergillus oryzae*	Ramachandran, Patel, Nampoothiri, Chandran et al. 2004
Potato peel	*Anoxybacillus rupiensis*	Tuysuz et al. 2020
Rice flake waste	*Aspergillus* sp.	Mukherjee et al. 2009
Rice bran	*Bacillus* sp.	Anto et al. 2006
Rice flour	*Bacillus subtilis*	Pranay et al. 2009
Sal deoiled cake	*Aspergillus flavus*	Dash et al. 2015
Soyabean husk	*Aspergillus oryzae*	Melnichuk et al. 2020
Spent brewing grain Brewery waste	*A. oryzae* *Bacillus subtilis*	Francis et al. 2003; Sahnoun et al. 2015
Sugar beet molasses	*Paenibacillus chitinolyticus*	Blanco et al. 2016
Sunflower oil cake	*Bacillus licheniformis*	Mihajlovski et al. 2016
Sweet Sorghum Bagasse	*Nesterenkonia* sp.	Ashraf et al. 2003
Wheat bran	*Bacillus lichenformis,* *Bacillus amyloliquefaciens* *Bacillus subtilis* *Aspergillus oryzae*	Lolasi et al. 2018; Kannan & Kanagaraj 2019; Mojumdar & Deka 2019; Almanaa et al. 2020
Wheat straw	*Bacillus* sp.	Fadel et al. 2020
Yam peel	*Aspergillus niger*	Qureshi et al. 2016
Pomegranate peel	*Aspergillus terrus*	Ahmed et al. 2020
White bread waste	*Rhizopus oryzae*	Ahmed et al. 2020
Food waste	*Bacillus licheniformis, Bacillus subtilis*	Msarah et al. 2020
Wheat Bran	*Aspergillus* sp.	Naik et al. 2019

be effectively used as sources of carbon and nitrogen to produce the enzyme amylase which in turn helps in the bioconversion of waste products into commercially important products. The utilization of such raw materials can assist to lower production costs while also contributing to trash recycling and making the environment more eco-friendly.

For diverse biotechnological and bio-anatomy-related applications, starch-based amylases and nano-structured metal-oxide-based amylase sensors should be created with high sensitivity, rapid reaction time, and stability/shelf-life. Food, pharmaceutics, and starch-based sectors will be the main targets for these biocatalysts and biosensors in the future.

Acknowledgments
Not applicable.

Authors' contributions
Conceptualization, VK, and BN.; validation, VK., Vivek K, BN, RS, MC and AKG, SR, SG.; formal analysis, VK, BN, Vivek K, MC, RS writing—original draft preparation, VK, BN, writing—review and editing, VK, BN, Vivek K, AKG, SR, SG, RS, supervision, BN, VK; project administration, BN, VK. The author(s) read and approved the final manuscript.

Funding
None.

Availability of data and materials
The datasets used and analyzed during the present study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
None.

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Received: 2 October 2022 Accepted: 14 February 2023
Published online: 03 May 2023

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