International Journal of Frontline Research in
Science and Technology
Journal homepage: https://frontlinejournals.com/ijfrst/
ISSN: 2945-4859 (Online)

(REVIEW ARTICLE)

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Valorization of agro-industrial wastes using fungi for industrial enzymes production

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International Journal of Frontline Research in Science and Technology, 2023, 02(02), 001–023

Publication history: Received on 13 October 2023; revised on 26 October 2023; accepted on 29 November 2023

Article DOI: https://doi.org/10.56355/ijfrst.2023.2.2.0055

Abstract

Huge quantities of the agricultural wastes are produced from practices related to industrial processing, which are mainly burned and thrown in landfills, becoming a threat to the human health and causing environmental pollution. Agro-industrial residues, such as sugarcane bagasse, orange peel, wheat bran, corn straw, barley, rice straw, corn cob, husk, soy bran, and coffee husk were considered as valuable raw materials that can be converted into products of biotechnological interest using microorganisms. Agro-industrial wastes rich in nutrients, such as proteins, minerals, and sugars that, used as possible low cost substrates, for the fungal cultivation, thus considered as an alternative eco-friendly tool for many biological products of economic value, such as enzymes. Fungi organisms are capable of synthesizing a wide range of relevant oxidative and hydrolytic extracellular enzymes, such as peroxidases, laccases, xylanases, and cellulases. The enzymes secreted fungi, are proteins that function as bio-catalysts, responsible for carrying out various biochemical reactions, which applied in food, detergent, cellulose, paper, cosmetics and textile industries, etc. Thus, the replacement of raw materials with lignocellulosic-sources can result in reducing environmental problems and resolving the pollution associated with their disposal, in addition a higher investment will be gained. Therefore, a review was carried out on the important value of agro-industrial wastes, and the cultivation of fungal isolates for economic production of the industrially important enzymes, based on submerged and solid-state fermentation processes, as well as the important application of these enzymes.

Keywords: Agro-industrial wastes; Fungi; Enzymes; Fermentation; Application

1 Introduction

Increasing industrialization of the agricultural sector, directly increase the waste generation which represents a significant environmental challenge. Agro-based food industries generated large amounts of wastes with high nutrient value and can form breeding medium for disease-causing microbes, if it inadequately treated and left unprocessed. Interestingly, the most of agro-industrial wastes are lignocellulosic in nature, containing high amounts of poly-saccharides such as cellulose, hemicellulose and, lignin (an aromatic polymer) [1,2]. In addition, these wastes containing other nutrients such as lipids, proteins, polyphenol and pectin, therefore, these wastes can serve as raw materials for the production of value-added products or as a source of renewable energy. This can achieve by applying the fermentation strategies such as hydrolysis of wastes, followed by fermentation and simultaneous saccharification [3]. In this context, a new directive by the European Union demonstrated the concepts of the 'Biorefinery' and 'Bioeconomy', where the wastes of an industry can be used as the raw material for another industry [4].

Utilization of agro-industrial wastes as substrates, for fungal cultivation intended to produce cellular biologically important primary and secondary metabolites, like; enzymes, proteins, organic acids, prebiotic oligosaccharides, and using it as sources of fermentable sugars in the bio-ethanol production has been reported [5]. Such residues are superior substrates for the cultivation of filamentous fungi, and inducing the fungal cells to produce cellulolytic, hemicellulolytic and ligninolytic enzymes such as; laccase, amylase, glucose oxidase, glucosidase, protease, pectinase, invertase,

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ligninase, xylanase, lipase, cellulose, and chitinase to meet out their nutrient requirement by solid state fermentation (SSF) and submerged fermentation (SMF) techniques [6,7].

The filamentous *Aspergillus* and *Trichoderma* species, and white-rot fungi are the most appropriate for production of industrial enzymes by fermentation of agro-wastes [8, 9].

Fungal enzymes are large group of complex proteins, which potentially used in different fields, of pulp and paper industry, food industry, pharmaceutical industry, textile industry, bio-fuel production, agriculture field, and bio-remediation. These enzymatic processes have more advantages, over the conventional chemical methods, because enzymatic processes cause a gentle reaction, have advanced specificity and selectivity, usually produce lower amount of waste materials by products during the reaction and its superior characters [10]. Also applying fungal enzymes in the industrial field, contributes to the sustainable growth concept where it gives more efficient and clean industrial processes [11-13]. As a result, the production of cost effective enzymes using agricultural waste fermentation optimized, and the need of variable enzyme production from fungal sources has been increased nowadays [14-15].

In the current review, we will describe the potential application of agro-industrial wastes as substrates for the growth of fungi organism, which able to synthesis multitude of hydrolytic and oxidative enzymes, to breakdowns the complex organic waste materials into simple products, and fermentation characteristics. It will be emphasized the different sources of the industrially important fungal enzymes and highlighted with their production conditions, properties, and its various industrial applications.

2 Wastes of agricultural and food-industry

Agro-industry usually produced large amount of residues with different properties and characteristics. The researches indicated that, accumulation of agricultural waste is in the excess of 2-billion-tons worldwide [16]. These agro-based industries can be classified into field-residues, process-residues and nonfood-wastes**.** The field-residues are usually defined as the waste materials that remain in the field after harvesting the crops such as (leaves, stalks, seed pods, and stems). Where the processed-residues, on the other hand, are the wastes generated after processing the raw products, and it can be grouped into food-based agro-industries such as, the by-products of sugar industries, fermentation-based-industries, food and fruit processing and grain-mills. The nonfood-based agro-industries usually produce waste effluents which are highly bio-degradable in nature like paper and pulp industry. But the effluents released from textile industries are mainly toxic, and threat to animal and human health as well as environment **Table (1)**

Table 1 Valuable wastes of agro-based industries as potent by-products

Category	Industry	Valuable wastes	References
Food-based agro-industries	Sugar industry	Molasses, Bagasse	[17]
	Edible oils	Crude olive pomace, Sunfower stalks, Oil cakes, Groundnut stalks/shells	[18-21]
	starch products, Grain and four mills	Barley straw, Rice straw, Rice bran, Corn stalks, Wheat straw, Oat straw , and cobs Soya stalks Soy meal	[22-29]
	Fruits and vegetables processing	Potato peel waste, Orange peel, artichoke leaf wastes, Banana peel, Cashew shells, Spent cofee waste	[17] [30-32]
Non-food based agro-industries	Paper and pulp industry	Solid cellulosic wastes, Effluent sludge	[33]
	Textile industry	Solid wastes, Effluent	[34]
	Jute/ coir retting units	Lignocellulose residues	[35]

3 Health and environmental problems of agro-industry wastes

Huge amounts of agro-industrial wastes are considered one of the major concern in all countries, and results in different problems, that become worse every year [18]

These agro-wastes and processing-effluents (contains variable chemical characteristics and metal contents) are usually discharged into water bodies or on land which directly harmful to environment, such as wastes from mills of pulp and paper, mills of textile, mainly contain hazardous that can pollute water, air, and soil [36]. In addition, the burning of agro-industrial waste under uncontrolled conditions, releases high amounts of toxic gases like; SO2, nitrogen oxides, dioxins, polycyclic aromatic hydrocarbons, and smoke, which directly contribute to excess haze and global warming, that harms the human health [37].

Agro-wastes are normally having high nutrient value, but they can become source of pathogenic diseases, if left without treatment [31]. Also disposal of such wastes on land without any treatment, increasing the concentrations of herbicide and pesticide residue in soil, which directly harm the beneficial soil microflora [38].

Throwing nutrient rich wastes in water surfaces, can enhance a massive algal-blooms and a disruption hazardous in the aquatic ecosystem [39], also the water soluble wastes sometimes end up in drinking water, causing severe problems in human health, as cancers, Alzheimer's disease, and birth defect problems [40]. Repurpose of agro-industrial wastes as raw materials for making valuable products is an excellent solution to avoid all previously mentioned health risks, and important for the environmental challenges [41].

4 Effective valorization of agro-industry wastes

Agro-industrial waste can be converted to valuable products majorly by biochemical, thermochemical and microbial biotechnology pathways. This section includes significant highlights for the role of microorganisms in using agro-wastes as raw materials for potential industrial enzymes production.

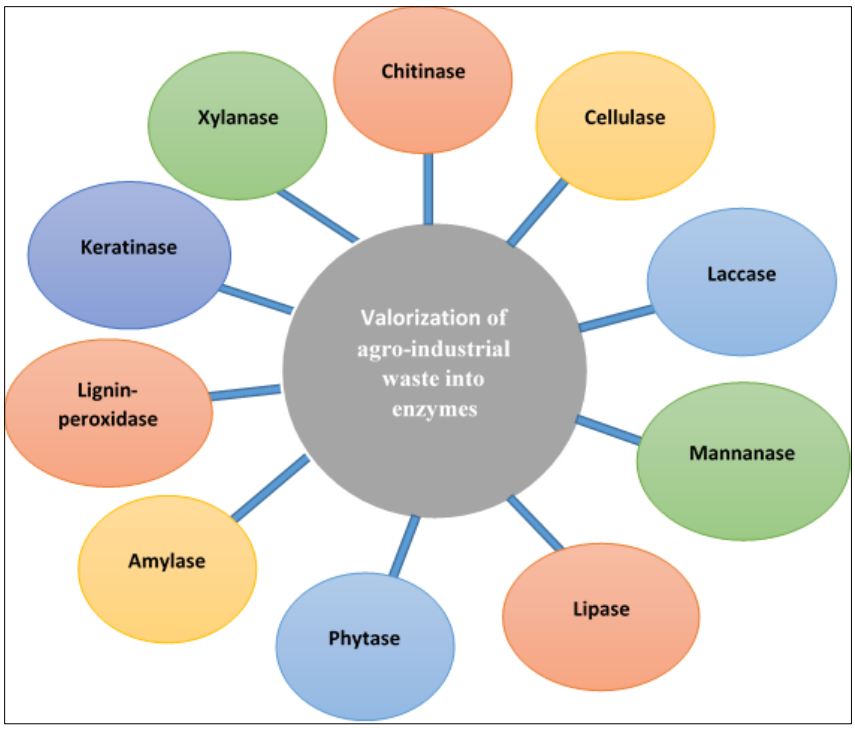

Figure 1 Enzymes produced by degradation of agro-industrial waste

In order to use the plant-biomass as raw material for production of valuable products using microbial fermentation, the ligno-cellulose structure (the main component of plant-biomass which is mainly contains hemicellulose, cellulose, and lignin) must be pretreated for easier degradation and production of fermentable sugars, including arabinose, glucose, galacturonic acid, xylose, etc. [42].Chemical methods can be applied for hydrolysis process using acids (sulphuric acid,

hydrochloric acid, etc.), but they show several drawbacks, including, the corrosion of the reactors, the production of inhibitory compounds for the subsequent fermentation step and the high temperatures needed. On the other hand, using enzymes like (cellulases, hemicellulases, pectinases, etc.), showing several save advantages but the cost of the enzymes is a limiting factor because it need high costs for the enzymes preparation [42].

The enzymes production cost is mainly affected by the used substrate of fermentation process, where the cost could be greatly decreased by using low-cost substrates such as the agro-food residues [43].

Many successful efforts have been made applying biotechnology as a tool to get valuable products, such as enzymes, from biodegradation of lingo-cellulosic materials for industrial uses at a low cost [44]. Enzymes including; phytase, amylase, chitinase, etc. are biocatalysts can be used in different industrial processes and produced from agro-industrial waste by microbial fermentation, hemicellulose-degrading enzymes such as xylanases, arabinanases, mannanases, and galactanases, also can be obtained from microbial biodegradation of the plant cell wall hemicelloses. In addition, lignin-degrading enzymes including lignin peroxidase, laccase, and manganese peroxidase, induced in microorganisms to decay lignin-based woody substrates into phenolic compounds, and enzyme keratinase produced by using keratinous wastes from sectors of meat production [44]. Fig. (1)

5 Hydrolytic activity of fungal cultures

Fungi are heterotrophic-microorganisms which could obtain nutrients only through breakdown of various external organic matters [46]. Fungi able to breakdowns different complex organic materials into simple forms depending on the extracellular production of multitude of hydrolytic and oxidative enzymes such as; proteolytic, glycolytic, and lipolytic enzymes [47]. Fungal cultures able to secrete these enzymes extra-cellular (exoenzymes) and intracellular (endoenzymes).

Exo-enzymes diffused into the environment, can breakdown complex polymeric compounds and predigest the food prior to absorption, as the fungi lack digestive system within their bodies. Endo-enzymes in turn are retained within the cell wall after synthesis and help in further assimilation of absorbed nutrients which is vital for culture growth.

For carbon and nitrogen assimilation by fungal cultures, different genera of fungi synthesized multitudes of enzymes to meet out their nutrient requirements. In this context; the fungal cultures *Aspergillus, Penicillium* and *Trichoderma*, synthesize cellulose and hemicellulose-degrading enzymes such as cellulases, mannanases, xylanases and β-glucosidases (BGL) to hydrolyze and breakdown the hemicellose and celluolytic content of plant cell wall, in plant residues into mono-sugars of xylose and glucose units [24, 48, 50]. Kantharaj et al. [51] indicated the ability of white rot fungi (*Phanerochaete, Phlebia, Ceriporiopsis*, etc.) and brown-rot fungi (*Fomitopsis, Laetiporus, Gloeophyllum*, etc.) to exudate adequate quantities of lignin-degrading enzymes including lignin peroxidase and laccase that showed high activity in degrading lignin-matter of woody substrates into phenolic compounds; also Abd El Aty et al. [52] enhancement the production of laccase enzyme from the marine-derived *Alternaria tenuissima* KM651985. Extracellular production of amylase enzyme from flamentous fungi like marine *Alternaria alternata* hydrolyzes starch (the plants storage material) into glucose [53, 54]. *Rhizopus* and *Trichoderma* secrete pectinase and polygalacturonase which potentially converts pectin in fruit-residues into galacturonic acid. The filamentous fungi; *Chaetomium globosum, Aspergillus griseoaurantiacus*, *Trichoderma longibrachiatum* potentially produced the industrially important chitinase enzyme using wastes [55-57]. Fungal chitinases, chitosinases and N-acetylglucosaminidases can breach out the chitin-rich cell wall of fungi to access the nutrients [58].

Fungal proteases showed great value in hydrolysis of plant and animal proteins from high-molecular weight form into simple amino-acids which can be easily assimilated by fungal cells [59]. Where other fungal species of *Rhizopus, Candida, Geotrichum, Mucor,* etc. were enhanced by wastes for lipase enzyme production to hydrolyze lipid molecules into fatty acids [60]. Other fungal enzymes like, Inulinase and naringinase were produced by the filamentous *Aspergillus terreus* and *Aspergillus niger* using low cost agricultural wastes [61, 62]. The enzymes such as urea-aminohydrolase, nitrate-reductase, and nitrite-reductase able to hydrolyze urea into ammonia which can be easily assimilated by fugal cells for nitrogen nourishment.

The important fungal enzymes obtained from fungal fermentation of agro-industry wastes are depicted in **Table (2).**

Table 2 Fungal fermentation of agro-wastes to produce variable enzymes

Enzyme	Fungal culture	Agro-industry wastes	References
Chitinase	*Aspergillus griseoaurantiacus*	potato shells	[57]
	Trichoderma longibrachiatum	wheat bran , rice straw , potato peels , artichoke leaves , saw dust , and licorice residue	[56]
Laccase	*Trametes versicolor*	Horticultural wastes	[63]
	Pleurotus ostreatus	Peanut shell	[64]
	Alternaria alternate	Wheat bran	[32]
	Alternaria tenuissima	Wheat bran	[52]
α-Amylase	*Aspergillus oryzae*	Coconut oil cake,	[65]
	Aspergillus niger	black gram bran, and soybean	[66]
	Aspergillus niger	Papaya waste	[67]
	Alternaria alternate	corn cobs, wheat bran, potato shells, wheat straw and rice straw	[53]
Xylanase	*Aspergillus flavus* *Cladosporium sphaerospermum* *Epicoccum purpurascens*	wheat bran - saw dust	[48]
Invertase	*Aspergillus niger*	Fruits peel waste	[68]
Lignin peroxidase	Pleurotus ostreatus, Phanerochaete chrysosporium	Sugarcane bagasse	[69]
Endoglucanase	Trichoderma reesei QM9414	Rice bran	[70]
β-Glucosidase	*Aspergillus sydowii* BTMFS 55	Corn straw,wheat bran,	[71]
	Thermoascus aurantiacus CBMAI 456	soy bran, corncob soy peel	[72]
Manganese peroxidase	*P. chrysosporium*	Wheat straw	[73]

6 Fermentation strategy of agro-industry wastes for enzymes production

Fermentation can be defined as a technique used by microorganisms, such as fungi, for biological conversion of complex substrates into simple products [74].

There are two main fermentation techniques applied for fungal cultivation of agro-industry wastes to produce enzymes, submerged-fermentation (SMF) and solid state fermentation technologies (SSF).

6.1 Submerged fermentation, SMF

In submerged fermentation, known as (liquid fermentation), the nutrients are present in the form dissolved in a large volume of water. This method is useful in the production of some enzymes which suffer from the catabolic -repression caused by very low concentrations of residual substrates like; amino acids and glucose [75].

6.2 Solid state fermentation, SSF

SSF is a good technology for potential waste valorization, in which the insoluble matter serves as nutrients source and physical support in absence of free water. [76, 77].

Using solid state fermentation technology, for biodegradation of agro-industry wastes is preferred over conventional fermentation methods, because the similarity to natural ones and simplicity [78], also it has several advantages of, low energy and water consumption, high product yields and enzymatic extraction facilitated, solving disposal problems, reduction of medium contamination risk, therefore this technology has been proved to be both economical and eco-friendly [79]. Therefore, SSF is often indicated as a promising way to produce higher enzyme yields compared to SMF [80].

Agro-industry wastes are preferred substrates for SSF strategy, which are rich in polymeric sugars, such as hemicellulose, cellulose, and pectin, that can be converted into simple ones to be easily assimilated by fungal colonies [81]. In addition, filamentous fungi are usually preferred for SSF processes, due to their specific ability to colonize the inter-particular spaces of solid waste matrices, and to produce various enzymes that, hydrolyze the solid substrate into fermentable sugars, and valuable products [82]. *Aspergillus, Alternaria, Trichoderma* and *Pleurotus*, were the most genera employed in this technique [52, 83].

Various studies have been indicated, in applying SSF-strategy of the agro-wastes as a substrate for different fungal species, such as *Aspergillus awamori* produce amylase and glucoamylase, with SSF of field-residues such as rice bran and wheat bran as substrates [84]. *Aspergilus niger* and *Alternaria alternata* have been reported to produce α-amylase employing SSF of agricultural wastes like wheat bran [53, 85]. Solid state fermentation of the agro-industrial waste, orange rind was used as a substrate containing naringin for naringinase enzyme production using *Aspergilus niger* [62]. Inulinase enzyme secreted by the fungus *Aspergillus terreus* under SSF of the low cost substrate (artichoke leaves) under solid state fermentation (SSF) [61]. Oil cakes, like; palm kernel oil cakes, were also applied as substrates for lipase enzyme production by *Aspergillus ibericus* [86]. SSF of different agro-industrial wastes, including corn cobs, sugarcane bagasse, and coconut husks, used as substrates for ellagitannase enzyme production, which used for biodegradation of ellagic acid [87]. Fermentation of peanut cake with *Aspergillus oryzae* significantly increase α-amylase, β-glucosidase, lipases, and xylanase enzyme activities for industry [88].

Out of all previously reported results, we can conclude that, SSF-strategy of agro-industry wastes can produce variable industrial enzymes, such as; exo-polygalacturonase and xylanases [89], cellulases, ligninases and cinnamoyl esterases, lignocellulosic enzymes [90], pectin methylesterase and polygalacturonase [91], constitutive extracellular chitinases [56], in addition the enzymes, pectinases, xylanases, cellulases were obtained [92]. **Table (3**) shows an overview on production of enzymes by SMF and SSF of various agro-wastes.

Table 3 Production of fungal enzymes by SSF and SMF strategy of various agro-wastes

Fermentation strategy	**Enzyme produced**	**Agro-industry waste**	**Fungal strain**	**Conditions of cultivation**	**References**
SSF	Cellulase	Green tea waste	*Aspergillus niger*	96h; 30 °C	[93]
	Cellulase	Rice straw	*Trichoderma reesei*	96h; 30 °C	[94]
	Chitinase - Chitosanase	potato shells	*Aspergillus griseoaurantiacus*	7 days ; 28 °C	[57]
	Amylase	Babassu cake	*Aspergillus awamori*	144h; 30 °C	[95]
	Laccase	Wheat bran	*Alternaria tenuissima*	14 day; 28 °C	[52]
	Chitinase	wheat bran, rice straw, potato peels, artichoke leaves,	*Trichoderma longibrachiatum*	7 days ; 28 °C	[56]
	Xylanase	Rice straw	*Trichoderma reesei*	96h; 30 °C	[94]
	Amylase	Soybean husk and flour mill waste	*Aspergillus oryzae*	144h; 30 °C	[96]
	Mannanase	Wheat straw	*Aspergillus niger*	96h; 32 °C	[97]
	Xylanase	Ragi husk	*Aspergillus fumigatus*	120h; 49,9 °C	[98]

	Pectinase	Citrus waste and sugarcane bagasse	*Aspergillus oryzae*	24h; 32 °C	[99]
	Mannanase	Açaí seed	*Penicillium citrinum*	144h; 30 °C	[100]
	Invertase	Wheat bran plus oat mea	*Aspergillus caespitosus*	72h; 40 °C	[101]
	Pectinase	Pomelo peels	*Aspergillus niger*	168h; 50 °C	[102]
	Protease	Wheat bran	*Aspergillus oryzae*	48h; 30 °C	[103]
	Lipase	Sugarcane bagasse	*Rhizopus oryzae*	72h; 45 °C	[104]
	Lipase	Malt bagasse	*Aspergillus brasiliensis*	96h; 32,7 °C	[105]
	Protease	Orange peel	*Aspergillus brasiliensis*	72h; 30 °C	[106]
	Laccase	Apple pomace	*Phanerochaete chrysosporium*	192h; 37 °C	[107]
SMF	**Enzyme produced**	**Agro-industry waste**	**Fungal strain**	**Conditions of cultivation**	**References**
	Cellulase	Coir waste	*Aspergillus niger*	72h; 30 °C; 120 rpm	[108]
	Xylanase	Sugarcane bagasse	*Trichoderma lanuginosu*	96h; 30 °C	[109]
	Amylase	Shorea robusta deoiled cake	*Aspergillus flavus*	72h; 30 °C; 200 rpm	[110]
	Mannanase	Banana stem	*Aspergillus sydowii*	168h; 30 °C; 120 rpm	[111]
	Invertase	Orange peel	*Penicillium sp.*	168d; 28 °C; 180 rpm	[112]
	Invertase	Pomegranate pee	*Cladosporium cladosporioides*	96h; 30 °C; 125 rpm	[113]
	Pectinase	Sawdust	*Aspergillus terreus*	96h; 30 °C; 100 rpm	[114]
	Protease	Peanut meal	*Aspergillus awamori*	96h; 30 °C; 220 rpm	[75]
	Laccase	Wheat straw	*Trametes versicolor*	72h; 30 °C; 150 rpm	[115]
	Lipase	Corn oil	*Trichoderma harzianum*	48h; 28 °C; 180 rpm	[116]

Production of fungal enzymes can be optimized by combination of different substrates from agro-industrial residues, where a single by-product may not provide all the sufficient essential nutrients for microbial growth. In this context, Filipe et al uses a mixture of winery residues and olive mill residues in SSF using *Aspergillus niger* and *A. ibericus*, that results in a production of xylanase (189,1U/g), cellulose (56,3 U/g), and Beta-glucosidase (10,9 U/g) enzymes. Studies of Mostafa et al. [48], also indicated that, the mixing of wheat bran and saw dust in different ratios improved xylanase enzyme production by *Epicoccum purpurascens, Cladosporium sphaerospermum* and *Aspergillus flavus* in the ratio of 22.09, 50.22 and 21.82 %, respectively.

In addition, Rayhane et al [117] showed the production of cellulose (19.36U/g), amylase (15.22 U/g) and lipases (38.73U/g), by *Trichoderma asperellum* using a mix of jatropha, vine shoots, olive oil and olive pomace as substrates.

7 Evaluation and application of the fungal-enzymes

In recent years, conversion of agricultural waste, as well as wastes of food- industries (as renewable resources), to the production of low-cost enzymes using microbial fermentation strategies has attracted the attention of researchers that work in such field [15].

Fungal cells usually produce and release the enzymes to breakdown and digest the high complex components of waste substrates for their own benefit, those synthesized fungal enzymes are exploited for various valuable applications for human. Previous studies conducted in this field, reported that more than 50% of industrially important enzymes are synthesized and extracted from fungal sources [118].

These fungi organism are able to synthesize a wide range of highly effective hydrolytic extracellular enzymes, and oxidative ones, like cellulase, xylanase, laccase, inulinase, mannanase, invertase, pectinase, amylase, protease and peroxidase. All fungal synthesized enzymes have potential application in industrial biotechnology, which directly encourages research study, for the suitable substrates and the best promising enzyme producers, to obtain large amounts of industrial enzymes at a low cost [119].

The enzyme-based economy showed a healthy-upward-trend, Therefore, Government policies now directed to the use of sustainable resources and focusing on Green-technology [15, 31].

7.1 Xylanase

Xylanase (E. C. 3.2.1.8, 1,4-β-xylanxylanohydrolase) is the enzymes that hydrolyze xylan which is a complex polysaccharide of the plants. Xylan is the most abundant non-cellulosic polymer in plants and hard-woods, consists of a xylose-residue backbone, with each subunit linked by a β-1,4-glycosidic bond [120]. Xylanases work by cleaving the β-1,4 glycosidic bonds, and forming the usable products such as xylose [121].

Xylanases are produced by several bacteria, actinomycete and fungi. Where, several studies showed that, the filamentous fungi are of particular interest, because they secrete it into the media in large quantities in comparison to other microorganisms [122]. In this context, numerous research studies have been carried out on the production of xylanases from different species of fungi, such as; *Chaetomium thermophilum, Thielevia terrestris, Paecilomyces thermophile*, *Sporotrichum thermophile* and *Melanocarpus albomyces* [109]. Similarly, the type of lignocellulosic–wastes suitable as a nutrient source for a commercial production of xylanase has been studied by several researchers. Botella et al. [123] Investigated grape pomace as a viable carbon source for the production of a xylanase using *Aspergillus awamori*. In another study, Apple pomace, hazelnut shell, and melon peel were used by Seyis and Aksoz [124]. for xylanase production showing a maximum activity of 26.5 U/mg using *Trichoderma harzianum*. In recent years, *N. intermedia* considered as a potential candidate for production of xylanase through a wheat-based bio-refinery [125].

In addition to the great efficiency of xylanases in biomass degradation process, these enzymes have other commercial applications, where xylanases can be used in improving the quality of animal feed, in the textile and paper industry, as well as being used in food processing industries, and used in production of bioethanol, depending on the transformation of some agro-industrial wastes into fermentable sugars [126, 127]. xylanase has potential advantages over chemical treatments, which can be applied in bio-bleaching of kraft pulp and decreased chlorine requirement, that lower the overall production cost [128, 129]. In textile-industry, xylanase is used for processing of fibers, especially for linen making [130].

In bread-making industry, xylanases break down wheat flour hemicelluloses, results in improvement of dough volume, softness, quantity, and quality of bread [58, 128] [131]. In wine and juice industries, xylanolytic enzymes increased clearance of juices, improved liquefaction of fruit and vegetable juice, and reduce its viscosity [132]. Xylanases of *Fusarium sp.* showed potential application in clarification of orange fruit juice due to degradation of xylan reduces the viscosity [133].

7.2 Cellulase

Cellulolytic enzymes classified into, endoglucanases (E.C. 3.2.1.4), exoglucanases (E.C. 3.2.1.176), and β-glycosidases (E.C. 3.2.1.21) [134]. They are the main enzymes efficient in the hydrolysis of polysaccharide (cellulose), by degrading cellulosic chains found in biomass to its primary products such as glucose and cellobiose [135]. Cellulases can be produced by a wide range of fungal organisms, such as the *Aspergillus, Fusarium, Trichoderma, Penicillium*, *Alternaria* and *Schizophyllum* genera [32, 95]. Simillarly, the fungal species *Myceliophthora thermophila*, *Rhizopus oryzae, and Thielavia terrestris* have been characterized to produce cellulases [136-138].

Cellulases are highly effective in many industrial applications, like; textiles, pulp and paper, detergent, food and agricultural, and biofuel production. In food processing, cellulases were applied for extracting and clarifying fruit and vegetable juices, that enhance the texture stability by decreasing its viscosity [139]. In paper and pulp industry, crude and pure cellulases applied for improving the fiber properties and reducing pulp viscosity, which directly deinking the paper wastes, in addition, improve the fiber strength and brightness properties [140]. In agricultural field, cellulase able to controls plant diseases by degrading the pathogens cell wall [141]. Further, cellulase increased soil fertility by accelerating the straw disintegration rate in field [142].

Cellulases are successfully applied in different steps of industry, i.e., wet processing steps of bio-polishing and bio-stoning of cellulosic fabrics and jeans. Also, acidic cellulases enhanced the softness of the fabric [143]. Results obtained by Imran et al. [144] indicated good application of fungal cellulases from *Penicillium echinulatum* and *Acrophialophora nainiana* in finishing process of knitted cotton fabrics.

Karmakar and Ray, [143] showed that, the addition of cellulases in liquid laundry detergent can remove dirts in the fabric spaces and maintain the clothes quality, also indicated the potential application of cellulases in pharmaceutical-industry, cellulases act as biocatalysts, help to release therapeutic compounds for treating metabolic disorders. In feed-industry, pretreating of agricultural silage and grain with cellulases increased the feed and energy values, also improved their digestibility. In wine industry, cellulases was applied during fermentation process to increase the wine viscosity and stability. The ability of cellulases to deconstruct lignocellulose, with releasing glucose units, which in turn can be converted into ethanol, has made these enzymes very important in biofuel research. The studies of Vázquez-Montoya [145] emphasized significant application of *Cladosporium cladosporioides, Fusarium verticillioides,* and *Penicillium funiculosum* in bioethanol production from moringa wastes, on the other hand, *Aspergillus niger* MK543209 produced cellulases from paper wastes which applied in biofuel production[146].

7.3 α-amylase

Alpha amylases (EC 3.2.1.1) are endoglycosidases, that randomly cleave α-1, 4 linkages between adjacent glucose subunits in polysaccharides (amylose), resulting in the release of short chain oligomers and smaller dextrins [147].

Aspergillus sp. between fungi is considered important amylase producers, like *A. niger, A. oryzae, A. terreus, A. fumigatus, A. awamori, A. favus* [148]. In addition, amylases are produced from the fungi organisms, *Thermomyces lanuginosus, Penicillium brunneum, Paecilomyces variotii, P. chrysogenum, Trichoderma pseudokoningii, Mucor sp.,* and *Rhizopus oryzae* [149]. *Penicillium chrysogenum* HTF24 produce amylase with wide range of biotechnological application [150]. *Paecilomyces variotii* ATHUM 8891 synthesis α-amylase with higher stability [151]. The potential function of amylase in the hydrolysis of the starch into units of simple sugars such as dextrins and oligosaccharides, are the main reason for effective amylases application in food, textile, detergent, paper, and pharmaceutical industries since nineteenth century [152,153]. In addition, amylase has several applications in fermentation, starch liquefaction, sugar syrups production (glucose/maltose), and saccharification process [154]. Further, in textile-industry application of amylase in desizing process breakdown the starch particles from the fabrics without attacking the fibers [155]. Additionally, α-amylase obtained from *Aspergillus oryzae* is applied in digestive medicines which used for indigestion treatment with syrup and capsule formulation. Application of α-amylases in detergent formulation indicated, potential application in washing, because its characteristics of alkalophilic, and oxidant in-sensitive characters [149].

7.4 Inulinase

Inulinases are classified into exo and endo-inulinases (EC 3.2.1.80) and (EC 3.2.1.7) respectively, depending upon their mode of activity [156]. Inulinase acts by converting the polyfructose, inulin (fructan), into fructose and fructo-oligosaccharides. The amounts of fructose syrup obtained by inulinase enzyme action is highly increased compared to the amount produced from starch hydrolysis by combined activities of α-amylase, amyloglucosidase and pullulanase, [157].

Several fungal isolates such as *Chrysosporium pannorum, Penicillium sp.* and *Aspergillus niger* have been known to synthesize inulinase [158]. Inulinase can easily obtained by fermentation of lignocellulosic substrates, such as Abd El Aty et al. [61]. showed the ability of *Aspergillus terreus* to produce adequate amounts of inulinase enzyme using artichoke leaves as a solid substrate. Coconut oil-cake was also used in a study of [159], for production and optimization of inulinase using *Pencillium rugulosum* (MTCC-3487). Sugar cane baggase has also been used as substrate in different studies for inulinase production [160]. The importance of inulinase has arisen from their activity to complete conversion of the substrate to fructose, as consumer-preferred sweeteners, which is highly preferred for human in the food and pharmaceutical industry. Additionally, Inulinase finds application in the production of citric acid, bioethanol, and lactic acid.

7.5 Pectinase

Pectinases are a class of enzymes, which catalyze the decay of pectin-containing materials. Pectin is a major constituent of the plant primary cell wall and contains a variety of polysaccharides especially rich in galacturonic acid [161].

Pectinases hydrolyze the pectin present in varieties of agricultural residue using different microbial species. Among all pectinases, fungi organisms are preferred, with the strains of *Aspergillus spp*. dominating many industrial processes [114]. Recently, *Aspergillus niger, A. versicolor, A. orysae, A. pulverulentus, Fusarium oxysporum, A. favus, Mucor racemous, Rhizopus stolonifer, Mucor hiemalis, Penicillium Jenseni, Trichoderma viride* and *P. citrinum,* were explored to release pectinases, which is favorable for industrial pectinase applications [162].

Pectinases have vital roles in the extraction and manufacturing of fruit juices, vegetable oil, wine clarification, coffee and cocoa fermentation [163]. Additionally, potential application in retting of plant fibers, bleaching of paper, scouring of cotton, bio-energy production, and waste-water treatment [163]. In this context, Sudeep et al. [164] produced highly stable pectinase enzyme by *Aspergillus sp.,* which can be applied in juice clarification, and boosted the flavor and aroma of fruit and vegetable juices. In addition, pectinase from *A. niger* and *Mucor circinelloids* is used for coffee fermentation [165].

In poultry-feed industry, pectinase used as supplement to reduce the feed viscosity [166]. In the textile sectors, pectinases can be applied in the process of gum removal from plant fibers like, sunn hemp, jute and fax [164]. Furthermore, pectinases usually applied in pulp and paper industry, to improve the physical characters of paper, depending on depolymerization of the galacturonic acids polymers [167]. Also, in beverage industry, it is play important role in, improving stability, and aroma of red wines with increasing its clarity [164].

7.6 Invertase

Invertase enzyme, known as (beta-fructofuranosidase), which catalyze the hydrolysis of sucrose, by break down of α-1,4- glycosidic linkage between D-fructose and D-glucose of sucrose [168].

Invertase synthesized by variety of fungal genera, i.e., *Aspergillus, Fusarium, Cladosporium, Aureobasidium, Eremothecium, Trichoderma, Ceratocystis, Sclerotinia, Metarhizium, Paecylomices* and *Penicillium, Rhizopus*.

Invertase has been applied in various industrial applications, i.e., beverages, food and bakery. additionally, invertase has a wide range of application in pharmaceutical industry, depending on its ability to synthesis fructo-oligosaccharides (FOS), an important non-digestible carbohydrate composed of fructose chains. The FOS used for diabetic patients due its characters of short-chain fatty acids and lower caloric value [169].

Invertase is one of the most used enzymes in the food industry, because it is sweeter and does not crystallize easily, especially in the preparation of jams and sweets. They produced non-crystallizable sugar which used in baking industry and preparation of chocolates, candies, jams, cookies and artificial honey for children for more iron absorption [170].

7.7 Mannanase

Mannanases are enzymes that degrade the hemicellulose mannan, which is an integral part of the plant cell wall [171]. Mannans form the largest hemicellulosic fraction of soft and hard wood, which are closely associated with cellulose and xylan as components of the cell wall, being organized in paracrystalline arrangements, adsorbed on the cellulose microfibrillar surface [172]. Therefore, mannanases are the second most important enzymes for the hydrolysis of hemicelluloses after xylanases.

Among fungal organisms, different *Aspergillus spp.* showed good ability to produce mannanase [173], similarly, a mixture of apple pomace and cottonseed powder used by *Aspergillus niger* SN-09 as a raw material for production of β-mannanase [174]. Furthermore, filamentous fungi, such as *Trichoderma reesei,* and *Pencillium* spp. are considered to have great potential for the industry in the production of β-mannanases [97].

Due to its ability to randomly hydrolyze the βD1,4 bonds of mannopyranose and effectively remove hemicellulose, mannanase have found applications in the paper, and textile industries [175]. Mannanases also applied in the food, oil, feed and pharmaceutical industries [176].

7.8 Laccase

Laccases are group of multi-copper proteins, which able to oxidize a variety of phenolic compounds and degrade lignin, received much attention in industrial applications [177].

Among microorganisms, white rot fungi are the best producer for laccase enzyme, like; *Phanerochaete chrysosporium Matei*, because of its capacity to produce adequate amounts of ligninolytic enzymes, grow fast, and easy handling during culture and fermentation [107, 178]. Additionally, the filamentous fungi *Aspergillus tubingensis, R. oryzae, Aspergillus favus, Mucor indicus, Fusarium udum, Mucor hiemalis, Trichoderma viride* and *Peniophora,* were confirmed for higher laccase production [179].

laccases have a broad range of substrate specificity, also able to degrade lignin and phenolic compounds, therefore, laccases have been evaluated in a large number of biotechnological applications, such as pulp biobleaching, biodegradation of toxic chemical residues, bioremediation of dyes, treatment of wastewater and soil. In addition, laccases industrially applied in pharmaceutical, paper and pulp manufacture, food processing, and, textile industries [180]. Lignolytic laccases industrially applied in food processing, for changing color appearance of beverage of food, and clarifying fruits and vegetables juices, wine and beer [181]. Furthermore, laccases play a vital role in the environment sector, depending on its ability in biodegradation of hazardous recalcitrant synthetic substances as, herbicides, fungicides, and synthetic dyes, (i.e. Reactive Blue 15, Congo Red and Remazol Brilliant Blue R) [182].

7.9 Protease

Proteases are proteolytic enzymes, which catalyze the hydrolysis of peptide bonds and mediated degradation of proteins into their constituent amino acids.

The fermentation of oriental foods by*, Rhizopus oligosporus, Aspergillus awamori* and *Rhizomucor miehei* mostly used for the production of proteases [183]. *Aspergillus fumigatus, Aspergillus oryzae, Aspergillus versicolor, Aspergillus terreus, Aspergillus niger, and Aspergillus favus* also favorable fungal source for protease enzyme production [184, 185].

Interestingly, lingo-cellulosic residues have been used as raw substrate for proteases production in several studies, such as, Chancharoonpong et al. [186] studied the growth of *A. oryzae* in solid-state culture (soybeans) for protease production. Other substrates such as jatropha seed cake and tomato pomace have been applied for protease secretion [187].

The hydrolytic characteristics of protease has great advantages in degradation of proteins in alcoholic liquors and juice, clarification in beer production, gelatin hydrolysis, whey and soy protein hydrolysis, and meat protein recovery. Nowadays, in cheese production, proteases popularly applied as milk-clotting agent, due to high stability and activity at acidic pH and flavors properties [11]. Similarly, protease of *Rhizomucor miehei N*RRL 2034, and *A. niger* FFB1, which were free from aflatoxins and ochratoxin were applied for white soft cheese production [188]. Organoleptic danbo cheese production was preferred using *Aspergillus oryzae* DRDFS 13 proteases than bacterial enzyme [11].

Also, fungal proteases are widely used in detergents, leather, pharmaceuticals and agricultural industries [189, 190]. In this context, alkaline protease from *Aspergillus flavus* and *Conidiobolus coronatus* were successfully replaces the hazardous chemicals involved in soaking and leather tanning process. In cosmetic industries, collagenolytic proteases have used in wound healing, also fungal proteases hydrolyzed the peptide-bonds of keratin [191].

7.10 Lipase

Lipases are a class of enzymes, which catalyzes the hydrolysis of the insoluble triglycerides, to glycerol and free fatty acids. In addition, lipases catalyze esterifcation, alcoholysis, and acidolysis [192].

Fungal lipases gained special industrial attention due to their broad substrate specificity, stability, and selectivity, [193]. *Rhizopus, Rhizomucor, Aspergillus, Geotrichum, Penicillium*, *Mucor* and *Geotrichum* species are good strains for commercial lipases secretion [194]. Lipases can easily have obtained by fungal fermentation of lignocellulose-waste. Similarly, a study of Salihu et al [195] investigated the fungus *A. niger* for lipase synthesis using peanut cake as substrate with addition of 1.0% (v/w) Tween-80. Furthermore, shea-nut cake used for lipase production, applied for the inherent tannin and saponin content reduction in the animal feed to be more suitable [196].

Lipases are highly applicable owing to the type of reactions they can catalyze. *Penicillium chrysogenum* producing active-lipase with several advantages in environmental and industrial sectors [150]. Furthermore, they are used in various

industries such as detergents (for fat hydrolysis), textiles, biofuels, pharmaceuticals, pulp and paper [197]. In food-processing, lipase of *Penicillium roquefortii* can be applied for synthesizing methyl ketones in order to improve blue cheese flavor [198]. High yield of fatty acid methyl esters was obtained by lipase transesterification, which is important for biodiesel production. The capability of lipase to produce biodiesel is a useful approach, depending on waste oils utilization. [199, 200]. Additionally, lipases are widely applied in treatment of fat-containing effluent released from food processing, paper, cellulose and tanneries, industries [201].

7.11 Chitinase

Chitinase enzyme hydrolyzes the polysaccharide chitin (the world's second most polymer after cellulose), and results in the production of N-acetyl d-glucosamines, chitooligo-saccharides [202].

The most known fungi organisms producing chitinase are *Trichoderma harzianum, Penicillium sp. Saccharomyces cerevisiae, Beauveria bassiana, Coprinopsis cinerea, Ustilago maydis,* and *Xenorhabdus nematophila* [203-206]. *Aspergillus flavus, Penicillium monoverticillium,* and *Fusarium oxysporum* were able to produce chitinase enzyme, which can be applied for preparation of certain oligomer chain length and also used to produce chito-oligosaccharides and N-acetylglucosamine from α-chitin, that showed various healthcare benefits [207]. Fungal chitinases can act as biocatalyst for chitobiose, have several applications in various industries [208].

Chitin is the structural component of several organism's cell wall, such as fungi, mollusks, crustaceans, and algae, the chitinase antifungal activity has potential bio-control application [209]. Similarly, Deng et al. [210] obtained chitinase from *Trichoderma harzianum*, which efficiently inhibited the growth of (*Botrytis cinerea*) pathogen. Chitinase also applied in the postharvest biocontrol of *Verticillium dahlia*, as mentioned by Liu et al. [203] In therapeutic application, chitinase has been applied in the antifungal drugs, against various infectious diseases [211].

Shehata et al. [57] showed good production of chitinase and chitosanase enzymes from the fermentation of potato shells as a sole nutrient source, using the marine-derived fungus *Aspergillus griseoaurantiacus* KX010988. Obtained chitinase exhibited antifungal activity against pathogenic *Fusarium solani*, and the hydrolysis of moderate molecular weight chitosan by chitosanase, produced Chitosan-oligosaccharides with good antioxidant and antibacterial activities.

Low cost, non-chitin containing agricultural wastes (artichoke leaves, wheat bran, rice straw, and potato peels), were fermented by *Trichoderma longibrachiatum* KT693225 for exochitinase synthesis. Exochitinase showed highly effective antifungal effects against the pathogenic strains *Aspergillus niger, Fusarium oxysporium* and *Alternaria alternata* [56].

8 Conclusion

Clean technologies are economically advantageous and has been encouraged for solving several environmental issues and obtaining products of industrial interests. Therefore, many different researches dealing with the use of agro-industrial wastes in bioprocesses to avoid the health and pollution problems related to disposal of these residues in the environment. The microbial fermentations of such residues, is a promising way to produce higher enzyme yields can be applied in different industrial sectors.

Fungi considered one of the most active microorganisms, which able to valorize different wastes, producing hydrolytic and oxidative enzymes, i.e., Xylanases, Cellulases, Pectinases, Laccases, Inulinases, Invertases,,,,,,etc. for potential various biotechnological applications. Many other fungal species can still be discovered with better use of agro-industrial residues to obtain higher enzyme yields. Therefore, the future demand is working on more production of fungal enzymes, for new products with new features, functions, and applications.

Compliance with ethical standards

Acknowledgments

The author sincerely acknowledges University of Hafr Al Batin, P.O. Box 1803, Hafr Al Batin, Saudi Arabia.

Disclosure of conflict of interest

The author declares that there is no conflict of interests regarding the publication of this review.

References

[1] Pandey, A.; Soccol, C.R. & Mitchell, D. (2000). New Developments in Solid State Fermentation: I- Bioprocesses and Products. Process Biochemistry, Vol.35, No.10, pp. 1153- 1169, ISSN 1359-5113.

[2] MateiI , J.C., OliveiraI, J.A.D., PamphileI , J.A., Polonio, J.C., (2021). Agro-industrial wastes for biotechnological production as potential substrates to obtain fungal enzymes. Ci. e Nat., Santa Maria, v. 43, e72, https://doi.org/10.5902/2179460X63133

[3] Guan GQ, Zhao PX, Zhao J, Wang MJ, Huo SH, Cui FJ et al (2016) Production and partial characterization of an alkaline xylanase from a novel fungus Cladosporium oxysporum. Biomed Res Int:1–7. Article ID 4575024. https://doi.org/10.1155/2016/4575024

[4] Hassan, S.S.; Williams, G.A.; Jaiswal, A.K. (2018). Emerging Technologies for the Pretreatment of Lignocellulosic Biomass. Bioresour. Technol. 262, 310–318.

[5] Sanchéz, C. (2009). Lignocellulosic Residues: Biodegradation and Bioconversion by Fungi. Biotechnology Advances, Vol.27, No.2, pp. 185–194, ISSN 0734- 9750.

[6] Kour D, Rana KL, Kaur T, Singh B, Chauhan VS, Kumar A et al (2019) Extremophiles for hydrolytic enzymes productions: biodiversity and potential biotechnological applications. In: Molina G, Gupta VK, Singh B, Gathergood N (eds) Bioprocessing for biomolecules production, pp 321–372. https://doi.org/10.1002/9781119434436.ch16

[7] Verma P, Yadav AN, Khannam KS, Mishra S, Kumar S, Saxena AK et al (2019) Appraisal of diversity and functional attributes of thermotolerant wheat associated bacteria from the peninsular zone of India. Saudi J Biol Sci 26:1882–1895. https://doi.org/10.1016/j.sjbs.2016.01.042

[8] Jin X, Song J, Liu GQ (2020) Bioethanol production from rice straw through an enzymatic route mediated by enzymes developed in-house from Aspergillus fumigatus. Energy 190:116395

[9] SOUZA, M. F.; BON, E. P. S.; SILVA, A. S. (2021). Production of cellulases and β-glucosidases by Trichoderma reesei Rut C30 using steam-pretreated sugarcane bagasse: an integrated approach for onsite enzyme production. Brazilian Journal of Chemical Engineering, in press.

[10] de Souza JB, Michelin M, Amâncio FL, Brazil OAV, Maria de Lourdes TM, Ruzene DS et al (2020) Sunfower stalk as a carbon source inductive for fungal xylanase production. Ind Crop Prod 153:112368

[11] Mamo J, Getachew P, Samuel Kuria M, Assefa F (2020) Application of milk-clotting protease from Aspergillus oryzae DRDFS13 MN726447 and Bacillus subtilis SMDFS 2B MN715837 for Danbo cheese production. J Food Qual 1:1–12

[12] Kour D, Rana KL, Kumar R, Yadav N, Rastegari AA, Yadav AN et al (2019) Gene manipulation and regulation of catabolic genes for biodegradation of biphenyl compounds. In: Singh HB, Gupta VK, Jogaiah S (eds) New and future developments in microbial biotechnology and bioengineering. Elsevier, Amsterdam, pp 1–23. https://doi.org/10.1016/B978-0-444-63503 700001-2

[13] Kour D, Kaur T, Yadav N, Rastegari AA, Singh B, Kumar V et al (2020) Phytases from microbes in phosphorus acquisition for plant growth promotion and soil health. In: Rastegari AA, Yadav AN, Yadav N (eds) Trends of microbial biotechnology for sustainable agriculture and biomedicine systems: diversity and functional perspectives. Elsevier, Amsterdam, pp 157–176. https:// doi.org/10.1016/B978-0-12-820526-6.00011-7

[14] Yadav AN, Verma P, Kumar R, Kumar V, Kumar K (2017) Current applications and future prospects of eco-friendly microbes. EU Voice 3:1–

[15] FERREIRA, R. G.; AZZONI, A. R.; FREITAS, S. (2000). On the production cost of lignocellulose-degrading enzymes. Biofuels, Bioproducts and Biorefining, v. 15, p. 85-99.

[16] Singh, H.; Soni, S.K. (2021) Production of starch-gel digesting amyloglucosidase by Aspergillus oryzae HS-3 in solid state fermentation. Process Biochem. 37, 453–459.

[17] Kanwal S, Chaudhry N, Munir S, Sana H (2019) Effect of torrefaction conditions on the physicochemical characterization of agricultural waste (sugarcane bagasse). Waste Manag 88:280–290.

[18] Sadh PK, Duhan S, Duhan JS (2018) Agro-industrial waste and their utilization using solid state fermentation: a review. Bioresour Bioprocess 5:1

[19] Adeniran HA, Abiose SH, Ogunsua AO (2010) Production of fungal β-amylase and amyloglucosidase on some Nigerian agricultural residues. Food Bioprocess Technol 3:693–698.

[20] Leite P, Salgado JM, Venâncio A, Domínguez JM, Belo I (2016) Ultrasounds pretreatment of olive pomace to improve xylanase and cellulase production by solid-state fermentation. Bioresour Technol 214:737–746.

[21] Arora K, Sharma S, Krishna SB, Adam JK, Kumar A (2017) Nonedible oil cakes as a novel substrate for DPA production and augmenting biocontrol activity of Paecilomyces variotii. Front Microbiol 8:753

[22] Agrawal T, Jadhav SK, Quraishi A (2019) Bioethanol production from an agro-waste, deoiled rice bran by Saccharomyces cerevisiae MTCC 4780 via optimization of fermentation parameters. Int J Thai Soc High Educ Inst Environ Environ Asia 12(1):20–24

[23] Sharma K, Garg VK (2018) Comparative analysis of vermicompost quality produced from rice straw and paper waste employing earthworm Eisenia fetida (Sav.). Bioresour Technol 250:708–715

[24] Sharma K, Garg VK (2019) Vermicomposting of waste: a zero-waste approach for waste management. In: Taherzadeh MJ, Bolton K, Wong J, Pandey ZWA (eds) Sustainable resources recovery and zero waste approaches. Elsevier, pp 133–164. https://doi.org/10. 1016/B978-0-444-64200-4.00010-4

[25] Biswas B, Pandey N, Bisht Y, Singh R, Kumar J, Bhaskar T (2017) Pyrolysis of agricultural biomass residues: comparative study of corn cob, wheat straw, rice straw and rice husk. Bioresour Technol 237:57–63.

[26] Kulikowska D, Sindrewicz S (2018) Effect of barley straw and coniferous bark on humifcation process during sewage sludge composting. Waste Manag 79:207–213.

[27] Zhou L, Li L (2016) Novel fungal consortium pretreatment of waste oat straw to enhance economic and efficient bio-hydrogen production. Ecocycles 2(2):36–42.

[28] Li S, Li D, Li J, Li G, Zhang B (2017) Evaluation of humic substances during co-composting of sewage sludge and corn stalk under different aeration rates. Bioresour Technol 245:1299–1302.

[29] Madej JP, Nowaczyk RM, Janeczek M, Chrószcz A, Korczyński M (2017) The efect of dietary supplementation with chromiumenriched soya meal on lymphatic cells in caecal tonsil of laying hens. Anim Feed Sci Technol 223:53–58.

[30] Al-Weshahy A, Rao VA (2012) Potato peel as a source of important phytochemical antioxidant nutraceuticals and their role in human health—a review. In: Rao V (ed) Phytochemicals as nutraceuticals-global approaches to their role in nutrition and health. Intech Open.

[31] Ravindran R, Desmond C, Jaiswal S, Jaiswal AK (2018) Optimisation of organosolv pretreatment for the extraction of polyphenols from spent cofee waste and subsequent recovery of fermentable sugars. Bioresour Technol Rep 3:7–14.

[32] Abd El Aty, A.A., Mostafa, F.A. (2013) Effect of various media and supplements on laccase activity and its application in dyes decolorization. Malaysian Journal of Microbiology, 9(2), 166-175.

[33] Servos MR (2020) Environmental fate and effects of pulp and paper: mill effluents. CRC Press, Boca Raton.

[34] Khan S, Malik A (2018) Toxicity evaluation of textile efuents and role of native soil bacterium in biodegradation of a textile dye. Environ Sci Pollut Res 25(5):4446–4458.

[35] Ansi L (2017) Comparative studies of the efect of diferent microorganisms on coir pith composting. Ind J Life Sci 6(1):55.

[36] Gupta GK, Shukla P (2020) Insights into the resources generation from pulp and paper industry wastes: challenges, perspectives and innovations. Bioresour Technol 297:122496. https://doi.org/ 10.1016/j.biortech.2019.122496

[37] Sharma P, Gaur VK, Kim SH, Pandey A (2020) Microbial strategies for bio-transforming food waste into resources. Bioresour Technol 299:122580.

[38] Ramírez FB, Tamayo DO, Corona IC, Cervantes JLNG, Claudio JJE and Rodríguez EQ (2019) Agro-industrial waste revalorization: the growing biorefnery. In: Abomohra AEF (ed) Biomass for bioenergy—recent trends and future challenges. IntechOpen. https://doi.org/10.5772/intechopen.83569

[39] Smith V, Wood SA, McBride CG, Atalah J, Hamilton DP, Abell J (2016) Phosphorus and nitrogen loading restraints are essential for successful eutrophication control of Lake Rotorua, New Zealand. Inland Waters 6:273–283

[40] Kim KH, Kabir E, Jahan SA (2017) Exposure to pesticides and the associated human health efects. Sci Total Environ 575:525–535.

[41] Yusuf M (2017) Agro-industrial waste materials and their recycled value-added applications: review. In: Martínez LMT (ed) Handbook of ecomaterials. Springer International Publishing, pp 1–11.

[42] Kumar M, Brar A, Vivekanand V, Pareek N (2017) Production of chitinase from thermophilic Humicola grisea and its application in production of bioactive chitooligosaccharides. Int J Biol Macromol 104:1641–1647.

[43] Dias LM, Dos Santos BV, Albuquerque CJB, Baeta BEL, Pasquini D, Baff MA (2018) Biomass sorghum as a novel substrate in solid state fermentation for the production of hemicellulases and cellulases by Aspergillus niger and A. fumigatus. J Appl Microbiol 124(3):708–718.

[44] Leite P, Salgado JM, Venâncio A, Domínguez JM, Belo I (2016) Ultrasounds pretreatment of olive pomace to improve xylanase and cellulase production by solid-state fermentation. Bioresour Technol 214:737–746.

[45] Preczeski KP, Dalastra C, Czapela FF, Kubeneck S, Scapini T, Camargo AF, Zanivan J, Bonatto C, Stefanski FS, Venturin B, Fongaro G, Treichel H (2020) Fusarium oxysporum and Aspergillus sp. as keratinase producers using swine hair from agroindustrial residues. Front Bioeng Biotechol 8:1–8.

[46] Devi R, Kaur T, Kour D, Rana KL, Yadav A, Yadav AN (2020) Beneficial fungal communities from different habitats and their roles in plant growth promotion and soil health. Microb Biosyst 5:21–47.

[47] Kour D, Rana KL, Kaur T, Singh B, Chauhan VS, Kumar A et al (2019) Extremophiles for hydrolytic enzymes productions: biodiversity and potential biotechnological applications. In: Molina G, Gupta VK, Singh B, Gathergood N (eds) Bioprocessing for biomolecules production, pp 321–372. https://doi.org/10.1002/9781119434436.ch16.

[48] Mostafa, F.A., Abd El Aty. A.A., Wehaidy, H.R. (2014). Improved Xylanase production by mixing low cost wastes and novel co-culture of three marine-derived fungi in solid state fermentation. Int.J.Curr.Microbiol.App.Sci. 3(7) 336-349.

[49] Mostafa FA, Abeer, A. Abd El Aty, Hamed ER, Eid BM, Ibrahim NA. (2016) Enzymatic, kinetic and anti-microbial studies on Aspergillus terreus culture filtrate and Allium cepa seeds extract and their potent applications. Biocatalysis and Agricultural Biotechnology, 5, 116–122.

[50] Abd El Aty, A.A., Saleh, S.A.A., Eid,B.M., Ibrahim,N.A., Mostafa. F.A. (2018) Thermodynamics characterization and potential textile applications of Trichoderma longibrachiatum KT693225 xylanase. Biocatalysis and Agricultural Biotechnology 14, 129–137.

[51] Kantharaj P, Boobalan B, Sooriamuthu S, Mani R (2017) Lignocellulose degrading enzymes from fungi and their industrial applications. Int J curr Res Rev 9(21):1–12

[52] Abeer, A. Abd El Aty, Eman, R. Hamed, Ahmed, A. El-Beih, Ahmed I. ElDiwany (2016) Induction and enhancement of the novel marine-derived Alternaria tenuissima KM651985 laccase enzyme using response surface methodology: 12 Application to Azo and Triphenylmethane dyes decolorization. Journal of Applied Pharmaceutical Science. 6, (04), 006-014.

[53] Abeer, A. Abd El Aty and Faten A Mostafa. (2015) Production and Characterization of Fungal α-Amylase from Marine Alternaria alternata Utilizing Lignocellulosic Wastes and Its Application. Research Journal of Pharmaceutical, Biological and Chemical Sciences. 6(3), 813-825.

[54] Rana KL, Kour D, Sheikh I, Yadav N, Yadav AN, Kumar V et al (2019) Biodiversity of endophytic Fungi from diverse niches and their biotechnological applications. In: Singh BP (ed) Advances in endophytic fungal research: present status and future challenges. Springer International Publishing, Cham, pp 105–144. https://doi.org/10.1007/978-3-030-03589-1_6

[55] Shehata, A N and Abeer, A. Abd El Aty. (2015) Improved production and partial characterization of chitosanase from a newly isolated Chaetomium globosum KM651986 and its application for chitosan oligosaccharides. Journal of Chemical and Pharmaceutical Research, 7(1):727-740.

[56] Walaa A. Abdel Wahab, Abeer, A. Abd El Aty, Faten A. Mostafa. (2018) Improvement of catalytic, thermodynamics and antifungal activity of constitutive Trichoderma longibrachiatum KT693225 exochitinase by covalent coupling to oxidized polysaccharides. International Journal of Biological Macromolecules. 112, 179–187.

[57] Abeer N. Shehata , Abeer, A. Abd El Aty, Doaa A. Darwish , Walaa A. Abdel Wahab Faten A. Mostafa. (2018) Purification, physicochemical and thermodynamic studies of antifungal chitinase with production of bioactive

chitosan-oligosaccharide from newly isolated Aspergillus griseoaurantiacus KX010988. International Journal of Biological Macromolecules, 107, 990–999.

[58] Yadav AN (2020) Recent trends in mycological research, Agricultural and medical perspective, vol 1. Springer, Cham.

[59] de Souza PM, Bittencourt ML, Caprara CC, de Freitas M, de Almeida RP, Silveira D et al (2015) A biotechnology perspective of fungal proteases. Braz J Microbiol 46(2):337–346.

[60] Gurung N, Ray S, Bose S, Rai V (2013) A broader view: microbial enzymes and their relevance in industries, medicine, and beyond. Biomed Res Int:1–18. Article ID 329121. https://doi. org/10.1155/2013/329121.

[61] Abeer, A. Abd El Aty, Hala R. Wehaidy, Faten A. Mostafa. (2014) Optimization of inulinase production from low cost substrates using Plackett– Burman and Taguchi methods. Carbohydrate Polymers. 102, 261– 268.

[62] Abeer, N. Shehata and Abeer, A. Abd El Aty. (2014). Optimization of Process Parameters by Statistical Experimental Designs for the Production of 13 Naringinase Enzyme by Marine Fungi. International journal of chemical engineering. Article ID 273523. http://dx.doi.org/10.1155/2014/273523.

[63] Xin F, Geng A (2011) Utilization of horticultural waste for laccase production by Trametes versicolor under solid-state fermentation. Appl Biochem Biotechnol 163(2):235–246.

[64] Mishra A, Kumar S (2007) Cyanobacterial biomass as N-supplement to agro-waste for hyper-production of laccase from Pleurotus ostreatusin solid state fermentation. Process Biochem 42(4):681–685.

[65] Ramachandran S, Patel AK, Nampoothiri KM, Francis F, Nagy V, Szakacs G, Pandey A (2004) Coconut oil cake—a potential raw material for the production of a-amylase. Bioresour Technol 93:169–174.

[66] Akpan I, Bankole MO, Adesemowo AM, Latunde DG (1999) Production of amylase by A. niger in a cheap solid medium using rice bran and agricultural materials. Trop Sci 39:77–79.

[67] Sharanappa A, Wani KS, Pallavi P (2011) Bioprocessing of food industrial waste for α-amylase production by solid state fermentation. Int J Adv Biotechnol Res 2:473–480.

[68] Mehta K, Duhan JS (2014) Production of invertase from Aspergillus niger using fruit peel waste as a substrate. Intern J Pharm Biol Sci 5(2): B353–B360.

[69] Pradeep V, Datta M (2002) Production of ligninolytic enzymes for decolorization by cocultivation of white-rot fungi Pleurotus ostreatus and Phanerochaete chrysosporium under solid-state fermentation. Appl Biotechnol Biochem 102–103(1–6):109–118.

[70] Rocky-Salimi K, Hamidi EZ (2010) Evaluation of the efect of particle size, aeration rate and harvest time on the production of cellulase by Trichoderma reesei QM9414 using response surface methodology. Food Bioprod Process 88(1):61–66.

[71] Madhu KM, Beena PS, Chandrasekaran M (2009) Extracellular B-glucosidase production by a marine Aspergillus Sydowii BTMFS 55 under solid state fermentation using statistical experimental design. Biotechnol Bioprocess Eng 14(4):457–466.

[72] Leite RSR, Alves-Prado HF, Cabral H, Pagnocca FC, Gomes E, DaSilva R (2008) Production and characteristics comparison of crude glucosidases produced by microorganisms *Thermoascus aurantiacus* and *Aureobasidium pullulansin* agricultural wastes. Enzyme Microb Technol 43:391–395.

[73] Fujian X, Hongzhang C, Zuohu L (2001) Solid-state production of lignin peroxidase (lip) and manganese peroxidase (Mnp) by *Phanerochaete chrysosporium* using steam-exploded straw as substrate. Bioresour Technol 80(2):149–151.

[74] SUBRAMANIYAM, R.; VIMALA, R. (2012). Solid state and submerged fermentation for the production of bioactive substances: a comparative study. International Journal of Science and Nature, v. 3, 3, 480-486.

[75] SINHA, S.; SINHA, S. (2009). Studies on the production of acid protease by submerged fermentation. International Journal of Food Engineering, v. 5, n. 1.

[76] Díaz AB, De Ory I, Caro I, et al. (2012) Enhance hydrolytic enzymes production by Aspergillus awamori on supplemented grape pomace. Food and Bioproducts Processing 90: 72–78.

[77] Yazid NA, Barrena R, Komilis D, et al. (2017) Solid-state fermentation as a novel paradigm for organic waste valorization: A review. Sustainability 9: 1–28.

[78] RAVINDRAN, R. et al. (2018). A review on bioconversion of agro-Industrial wastes to industrially important enzymes. Bioengineering (Basel), v. 5, n. 4, p. 93, 2018.

[79] MARZO, C. et al. (2019). Valorization of agro-industrial wastes to produce hydrolytic enzymes by fungal solid-state fermentation. Waste Management Resource, v. 37, n. 2, p. 149-156.

[80] HANSEN, G. H. et al. (2015). Production of cellulolytic enzymes from ascomycetes: comparison of solid state and submerged fermentation. Process Biochemistry, v. 50, n. 9, p. 1327-134.

[81] Díaz AB, Blandino A, Webb C, et al. (2016) Modelling of different enzyme productions by solid-state fermentation on several agro-industrial residues. Applied Microbiology and Biotechnology 100: 9555–9566.

[82] Gutiérrez Rojas M, Auria R, Benet Jean C, et al. (1995) A mathematical model for solid state fermentation of mycelial fungi on inert support. The Chemical Engineering Journal and The Biochemical Engineering Journal 60: 189–198.

[83] Mansour AA, Arnaud T, Lu-Chau TA, et al. (2016) Review of solid state fermentation for lignocellulolytic enzyme production: Challenges for environmental applications. Reviews in Environmental Science and Biotechnology 15: 31–46.

[84] Suganthi R, Benazir JF, Santhi R, Kumar RV, Hari A, Meenakshi N, Nidhiya KA, Kavitha G, Lakshmi R (2011) Amylase production by Aspergillus niger under solid state fermentation using agroindustrial wastes. Int J Eng Sci Technol 3:1756–1763.

[85] Kumar A, Sadh PK, Surekha DJS (2016) Bio-ethanol production from sweet potato using co-culture of saccharolytic molds (*Aspergillus spp*.) and Saccharomyces cerevisiae MTCC170. J Adv Biotechnol 6(1): 822–827.

[86] Oliveira F, Carlos ES, Peclat Veronica ROL, Salgado JM, Bernardo DR, Maria AZC, Armando V, Isabel B (2017) Optimization of lipase production by *Aspergillus ibericusfrom* oil cakes and its application in esterification reactions. Food Bioprod Process. https://doi.org/10.1016/j.fbp.2017.01.007.

[87] Buenrostro J, Ascacio A, Sepulveda L, De la Cruz R, Prado-Barragan A, Aguilar-Gonzalez MA, Rodriguez R, Aguilar CN (2013) Potential use of diferent agro-industrial by products as supports for fungal ellagitannase production under solid state fermentation. Food Bioprod Process 92(4):376–382.

[88] Sadh PK, Chawla P, Bhandari L, Duhan JS (2017) Bio-enrichment of functional properties of peanut oil cakes by solid state fermentation using Aspergillus oryzae. J Food Meas Character 12:622–633.

[89] Marzo C, Díaz AB, Caro I, Blandino A (2019) Valorization of agroindustrial wastes to produce hydrolytic enzymes by fungal solidstate fermentation. Waste Manag Res 37(2):149–156.

[90] Kumla J, Suwannarach N, Sujarit K (2020) Cultivation of mushrooms and their lignocellulolytic enzyme production through the utilization of agro-industrial waste. Molecules 25(12):2811.

[91] Patidar MK, Nighojkar S, Kumar A, Nighojkar A (2018) Pectinolytic enzymes-solid state fermentation, assay methods and applications in fruit juice industries: a review. Biotech 8(4):199.

[92] Díaz AB, Blandino A and Caro I (2018) Value added products from fermentation of sugars derived from agro-food residues. Trends in Food Science & Technology 71: 52–64.

[93] SALDAÑA-MENDOZA, S. A. et al. (2021). Uses of wastes from the tea and coffee industries for the production of cellulases using fungi isolated from the Western Ghats of India. Systems Microbiology and Biomanufacturing, v. 1, p. 33-41.

[94] DHILLON, G. S. et al. (2011). Value-addition of agricultural wastes for augmented cellulase and xylanase production through solid-state tray fermentation employing mixed-culture of fungi. Industrial Crops and Products, v. 34, n. 1, p. 1160-1167.

[95] CASTRO, A. M.; PEREIRA JR, N. (2010). Production, properties and application of cellulase in hydrolysis of residuies agro-industriais. Química Nova, v. 33, n.1, p. 181-188.

[96] MELNICHUK, N. et al. (2020). Valorization of two agroindustrial wastes to produce alpha-amylase enzyme from Aspergillus oryzae by solid-state fermentation. Waste Management, v. 106, p. 155-161.

[97] WU, M. et al. (2011). Bimutation breeding of *Aspergillus niger* strain for enhancing β-mannanase production by solid-state fermentation. Carbohydrate Research, v. 346, n. 14, p. 2149-2155.

[98] Sarajo, P., Manasa, P., Narasimhulu, K. (2020). Assessment and evaluation of cellulase production using ragi (Eleusine coracana) husk as a substrate from thermo-acidophilic *Aspergillus fumigatus* JCM 10253. Bioprocess Biosyst Eng. 2021 Jan;44(1):113-126. doi: 10.1007/s00449-020-02428-z.

[99] BIZ, A. et al. (2016). Production of pectinases by solid-state fermentation of a mixture of citrus waste and sugarcane bagasse in a pilot-scale packed-bed bioreactor. Biochemical Engineering Journal, v. 111, p. 54-62.

[100] LIMA, A. C. et al. (2021). β-Mannanase Production by *Penicillium citrinum* through Solid-State Fermentation using açaí residual biomass (Euterpe oleracea). Journal of Chemical Technology and Biotechnology, in press.

[101] ALEGRE, A. C. P. et al. (2009). Production of thermostable invertases by *Aspergillus caespitosus* under submerged or solid state fermentation using agro-industrial residues as carbon source. Brazilian Journal of Microbiology, v. 40, n. 3, p. 612-622.

[102] JALIL, M. T. M.; IBRAHIM, D. (2021). Partial Purification and Characterisation of Pectinase Produced by *Aspergillus niger* LFP-1 Grown on Pomelo Peels as a Substrate. Tropical Life Sciences Research, v. 32, n. 1, p. 1-22.

[103] CASTRO, R. J. S.; SATO, H. H. (2013). Synergistic effects of agro-industrial wastes on simultaneous production of protease and α-amylase under solid state fermentation using a simplex centroid mixture design. Industrial Crops and Products, v. 49, p. 813-821.

[104] VASEGHI, Z. et al. (2013). Production of active lipase by *Rhizopus oryzae* from sugarcane bagasse: solid state fermentation in a tray bioreactor. International Journal of Food Science & Technology, v. 48, n. 2, p. 283-289.

[105] EICHLER, P. et al. (2020). Lipase production by *Aspergillus brasiliensis* in solid-state cultivation of malt bagasse in different bioreactors configurations. Anais da Academia Brasileira de Ciências, v. 92, n.2, p. e20180856.

[106] CHIMBEKUJWO, K. I.; JA'AFARU, M. I.; ADEYEMO, O. M. (2020). Purification, characterization and optimization conditions of protease produced by Aspergillus brasiliensis strain BCW2. Scientific African, v. 8, p. e00398.

[107] GASSARA, F. et al. (2010). Screening of agro-industrial wastes to produce ligninolytic enzymes by *Phanerochaete chrysosporium*. Biochemical Engineering Journal, v. 49, n. 3, p. 388-394.

[108] MRUDULA, S.; MURUGAMMAL, R. (2011). Production of cellulase by *Aspergillus niger* under submerged and solid state fermentation using coir waste as a substrate. Brazilian Journal of Microbiology, v. 42, n. 3, p. 1119-1127.

[109] ALI, U. F.; IBRAHIM, Z. M.; ISAAC, G. S. (2013). Ethanol and xylitol production from xylanase broth of *Thermomyces lanuginosus* grown on some lignocellulosic wastes using Candida tropicalis EMCC2. Life Sciences Journal, v. 10, n. 1, p. 968-978.

[110] SINGH, S.; GUPTA, A. (2014). Comparative fermentation studies on amylase production by Aspergillus flavus TF-8 using Sal (Shorea robusta) deoiled cake as natural substrate: characterization for potential application in detergency. Industrial Crops and Products, v. 57, p. 158-165.

[111] SIQUEIRA, F. G. et al. (2010). The potential of agro-industrial residues for production of holocellulase from filamentous fungi. International Biodeterioration and Biodegradation, v. 64, n. 1, p. 20-26.

[112] E.A. N, Atalla SM. (2020). Production and immobilization of invertase from Penicillium sp. using orange peel waste as substrate. Egypt Pharmaceut J 19:103-12. http://www.epj.eg.net/text.asp?2020/19/2/103/283855

[113] UMA, C. et al. (2012). Production and properties of invertase from a *Cladosporium cladosporioides* in SmF using pomegranate peel waste as substrate. Asian Pacific Journal of Tropical Biomedicine, v. 2, n. 2, p. S605-S611.

[114] SETHI, B. et al. (2016). Production of ethanol and clarification of apple juice by pectinase enzyme produced from *Aspergillus terreus* NCFT 4269.10. International Journal of Biological Research, v. 4, n. 1, p. 67-73.

[115] BIRHANLI, E.; YEŞİLADA, Ö. (2013). The utilization of lignocellulosic wastes for laccase production under semisolid-state and submerged fermentation conditions. Turkish Journal of Biology, v. 37, n. 4, p. 450-456.

[116] CORADI, G. V. et al. (2013) Comparing submerged and solid-state fermentation of agro-industrial residues for the production and characterization of lipase by *Trichoderma harzianum*. Annals of Microbiology, v. 63, n.2, p. 533-540.

[117] RAYHANE, H. et al. (2019). From flasks to single used bioreactor: scale-up of solid state fermentation process for metabolites and conidia production by *Trichoderma asperellum*. Journal of Environmental Management, v. 252, p. 109496.

[118] Anisa SK, Girish K (2014) Pectinolytic activity of Rhizopus sp. and Trichoderma viride. Int J Res Pure App Microbiol 4(2):28–31.

[119] BAJAR, S.; SINGH, A.; BISHNOI, N. R. (2020). Exploration of low-cost agro-industrial waste substrate for cellulase and xylanase production using Aspergillus heteromorphus. Applied Water Science, v. 10, n. 6, p. 153.

[120] Vogel K (2018) Analytics of enzymes. In: Nunes CS, Kumar V (eds) Enzymes in human and animal nutrition. Academic Press, Amsterdam, pp 441–455. https://doi.org/10.1016/B978-0-1 2-805419-2.00023-X

[121] Harris, A.D., Ramalingam, C. (2010). Xylanases and its Application in Food Industry: A Review. Journal of Experimental Sciences Vol. 1, Issue 7, Pages 01-11.

[122] Knob,A., Beitel,S.M., Fortkamp,D., Terrasan,C.R.F., and de Almeida, A.F. (2013). Production, Purification, and Characterization of a Major Penicillium glabrum Xylanase Using Brewer's Spent Grain as Substrate. Article ID 728735 | https://doi.org/10.1155/2013/728735

[123] Botella C, Id O, Webb C, Cantero D, Blandino A (2005) Hydrolytic enzyme production by Aspergillus awamori on grape pomace. Biochem Eng J 26:100–106.

[124] Seyis, I.; Aksoz, N. (2005). Xylanase Production from Trichoderma harzianum 1073 D3 with Alternative Carbon and Nitrogen Sources. Food Technol. Biotechnol. 43, 37–40.

[125] Shahryari Z, Fazaelipoor MH, Ghasemi Y, Lennartsson PR, Taherzadeh MJ (2019) Amylase and xylanase from edible fungus neurospora intermedia: production and characterization. Molecules 24(4):721.

[126] GOMES, A. F. S. et al. (2016). Substract and temperature effect on xylanase production by Aspergillus fumigatus using low cost agricultural wastes. Bioscience Journal, v. 32, n. 4.

[127] Bala A, Singh B (2019) Development of an environmental-benign process for effcient pretreatment and saccharifcation of Saccharum biomasses for bioethanol production. Renew Energy 130:12–24.

[128] Cunha L, Martarello R, Souza PMD, Freitas MMD, Barros KVG, Ferreira Filho EX et al (2018) Optimization of xylanase production from Aspergillus foetidus in soybean residue. Enzyme Res:1–7. Article ID 6597017. https://doi.org/10.1155/2018/6597017.

[129] Campioni TS, de Jesus Moreira L, Moretto E, Nunes NSS, de Oliva Neto P (2019) Biobleaching of Kraft pulp using fungal xylanases produced from sugarcane straw and the subsequent decrease of chlorine consumption. Biomass Bioenergy 121:22–27.

[130] Abeer, A. Abd El Aty, Shireen A.A. Saleh, Basma M. Eid, Nabil A. Ibrahim, Faten A. Mostafa. (2018). Thermodynamics characterization and potential textile applications of Trichoderma longibrachiatum KT693225 xylanase. Biocatalysis and Agricultural Biotechnology 14, 129–137.

[131] Rana KL, Kour D, Sheikh I, Dhiman A, Yadav N, Yadav AN et al (2019) Endophytic fungi: biodiversity, ecological signifcance and potential industrial applications. In: Yadav AN, Mishra S, Singh S, Gupta A (eds) Recent advancement in white biotechnology through fungi, Diversity and enzymes perspectives, vol 1. Springer, Cham, pp 1–62.

[132] Ahmed SA, Saleh SAA, Mostafa FA, Abeer, A. Abd El Aty, Ammar HAM. (2016). Characterization and valuable applications of xylanase from endophytic fungus Aspergillus terreus KP900973 isolated from Corchorus olitorius. Biocatalysis and Agricultural Biotechnology, 7 134–144.

[133] Li C, Kumar A, Luo X, Shi H, Liu Z, Wu G (2020) Highly alkali-stable and cellulase-free xylanases from Fusarium sp. 21 and their application in clarifcation of orange juice. Int J Biol Macromol 155:572–580.

[134] KUHAD, R. C. et al. (2016). Revisiting cellulase production and redefining current strategies based on major challenges. Renewable and Sustainable Energy Reviews, v. 55, p. 249-272.

[135] BUDIHAL, S. R.; AGSAR, D.; PATIL, S. R. (2016). Enhanced production and application of acidothermophilic Streptomyces cellulase. Bioresource Technology, v. 200, p. 706-712.

[136] Sahay H, Yadav AN, Singh AK, Singh S, Kaushik R, Saxena AK (2017) Hot springs of Indian Himalayas: potential sources of microbial diversity and thermostable hydrolytic enzymes. 3 Biotech 7:1–11.

[137] Kour D, Rana KL, Yadav N, Yadav AN, Singh J, Rastegari AA et al (2019) Agriculturally and industrially important fungi: current developments and potential biotechnological applications. In: Yadav AN, Singh S, Mishra S, Gupta A (eds) Recent advancement in white biotechnology through fungi, Perspective for value-added products and

environments, vol 2. Springer International Publishing, Cham, pp 1–64. https://doi.org/10.1007/978-3-030-14846-1_1.

[138] Yadav AN, Mishra S, Singh S, Gupta A (2019) Recent advancement in white biotechnology through fungi, Diversity and enzymes perspectives, vol 1. Springer International Publishing, Cham.

[139] Carvalho LMJ, De Castro IM, Da Silva CAB (2008) A study of retention of sugars in the process of clarifcation of pineapple juice (Ananas comosus, L. Merril) by micro-and ultra-fltration. J Food Eng 87(4):447–454.

[140] Kuhad RC, Mehta G, Gupta R, Sharma KK (2010) Fed batch enzymatic saccharifcation of newspaper cellulosics improves the sugar content in the hydrolysates and eventually the ethanol fermentation by Saccharomyces cerevisiae. Biomass Bioenergy 34(8):1189–1194.

[141] Verma P, Yadav AN, Khannam KS, Kumar S, Saxena AK, Suman A (2016) Molecular diversity and multifarious plant growth promoting attributes of bacilli associated with wheat (Triticum aestivum L.) rhizosphere from six diverse agro-ecological zones of India. J Basic Microbiol 56:44–58.

[142] Han W, He M (2010) The application of exogenous cellulase to improve soil fertility and plant growth due to acceleration of straw decomposition. Bioresour Technol 101(10):3724–3731.

[143] Karmakar M, Ray RR (2011) Current trends in research and application of microbial cellulases. Res J Microbiol 6(1):41.

[144] Imran M, Bano S, Nazir S, Javid A, Asad MJ, Yaseen A (2019) Cellulases production and application of cellulases and accessory enzymes in pulp and paper industry: a review. PSM Biol Res 4(1):29–39.

[145] Vázquez-Montoya EL, Castro-Ochoa LD, Maldonado-Mendoza IE, Luna-Suárez S, CastroMartínez C (2020) Moringa straw as cellulase production inducer and cellulolytic fungi source. Rev Argent Microbiol 52(1):4–12.

[146] Darwesh OM, El-Maraghy SH, Abdel-Rahman HM, Zaghloul RA (2020) Improvement of paper wastes conversion to bioethanol using novel cellulose degrading fungal isolate. Fuel 262:116518.

[147] Liu X, Kokare C (2017) Microbial enzymes of use in industry. In: Brahmachari G, Demain AL, Adrio JL (eds) Biotechnology of microbial enzymes – production, biocatalysis and industrial applications. Elsevier, Academic Press, London, pp 267–298. https://doi.org/10.1016/b978-0 -12-803725-6.00011-x.

[148] Singh S, Singh S, Bali V, Sharma L, Mangla J (2014) Production of fungal amylases using cheap, readily available agriresidues, for potential application in textile industry. Biomed Res Int:1–9. Article ID 215748. https://doi.org/10.1155/2014/215748.

[149] Samanta S (2020) Enhancement of characteristics and potential applications of amylases: a brief review. Am J Pure Appl Sci 2(2):24–35.

[150] Rafiq M, Nadeem S, Hassan N, Hayat M, Sajjad W, Zada S et al (2020) Fungal recovery and characterization from Hindu Kush mountain range, Tirich Mir glacier, and their potential for biotechnological applications. J Basic Microbiol 60(5):444–457.

[151] Apostolidi ME, Kalantzi S, Hatzinikolaou DG, Kekos D, Mamma D (2020) Catalytic and thermodynamic properties of an acidic α-amylase produced by the fungus Paecilomyces variotii ATHUM 8891. 3. Biotech 10(7):1–12.

[152] Mehta D, Satyanarayana T (2016) Bacterial and archaeal α-amylases: diversity and amelioration of the desirable characteristics for industrial applications. Front Microbiol 7:1129.

[153] Singh G, Verma AK, Kumar V (2016) Catalytic properties, functional attributes and industrial applications of β-glucosidases. 3 Biotech 6:3.

[154] Liu X, Kokare C (2017) Microbial enzymes of use in industry. In: Brahmachari G, Demain AL, Adrio JL (eds) Biotechnology of microbial enzymes – production, biocatalysis and industrial applications. Elsevier, Academic Press, London, pp 267–298. https://doi.org/10.1016/b978-0 -12-803725-6.00011-x

[155] Mojsov K, Andronikov D, Janevski A, Jordeva S, Kertakova M, Golomeova S et al (2018) Production and application of α-amylase enzyme in textile industry. Teks Indus 66:23–28.

[156] Vijayaraghavan, K.; Yamini, D.; Ambika, V.; Sravya Sowdamini, N. (2009) Trends in inulinase production—A review. Crit. Rev. Biotechnol. 29, 67–77.

[157] Zittan, L. (1981) Enzymatic Hydrolysis of Inulin—An Alternative Way to Fructose Production. Starch Stärke 33, 373–377.

[158] Chi, Z.; Chi, Z.; Zhang, T.; Liu, G.; Yue, L. (2009). Inulinase-expressing microorganisms and applications of inulinases. Appl. Microbiol. Biotechnol. 82, 211–220.

[159] Dilipkumar, M.; Rajasimman, M.; Rajamohan, N. (2014). Utilization of copra waste for the solid state fermentatative production of inulinase in batch and packed bed reactors. Carbohydr. Polym. 102, 662–668.

[160] Chesini, M.; Neila, L.P.; Fratebianchi de la Parra, D.; Rojas, N.L.; Contreras Esquivel, J.C.; Cavalitto, S.F.; Ghiringhelli, P.D.; Hours, R.A. (2013). Aspergillus kawachii produces an inulinase in cultures with yacon (Smallanthus sonchifolius) as substrate. Electron. J. Biotechnol. 16.

[161] SHAIKH, R. et al. (2018). Isolation, Screening and Characterization of Microorganisms producing Pectinase Enzyme from the Ipomoea spp. and its Potential Application. International Journal of Microbiology Research, v. 10, n. 9, p. 1355-1359.

[162] El-Rahim WMA, Moawad H, Hashem MM, Gebreil GM, Zakaria M (2020) Highly effcient fungal pectinase and laccase producers among isolates from fax retting liquor. Biocatal Agric Biotechnol 25:101570.

[163] Kubra KT, Ali S, Walait M, Sundus H (2018) Potential applications of pectinases in food, agricultural and environmental sectors. J Pharm Chem Biol Sci 6:23–34.

[164] Sudeep KC, Upadhyaya J, Joshi DR, Lekhak B, Kumar Chaudhary D, Raj Pant B et al (2020) Production, characterization, and industrial application of pectinase enzyme isolated from fungal strains. Fermentation 6(2):59–69.

[165] Rosales E, Pazos M, Sanromán MÁ (2018) Solid-state fermentation for food applications. In: Pandey A, Larroche C, Soccol CR (eds) Current developments in biotechnology and bioengineering. Elsevier, Amsterdam, pp 319–355. https://doi.org/10.1016/B978-0-444-6399 0-5.00015-3.

[166] Hoondal G, Tiwari R, Tewari R, Dahiya NBQK, Beg Q (2002) Microbial alkaline pectinases and their industrial applications: a review. Appl Microbiol Biotechnol 59(4–5):409–418

[167] Rebello S, Anju M, Aneesh EM, Sindhu R, Binod P, Pandey A (2017) Recent advancements in the production and application of microbial pectinases: an overview. Rev Environ Sci Bio 16(3):381–394.

[168] Toledo LET, García DM, Cruz EP, Intriago LMR, Pérez JN, Chanfrau JMP (2019) Fructosyl transferases and invertases: useful enzymes in the food and feed industries. In: Kuddus M (ed) Enzymes in food biotechnology. Elsevier, pp 451–469. https://doi.org/10.1016/B978-0- 12-813280-7.00026-8.

[169] Bhalla TC, Thakur N, Thakur N (2017) Invertase of Saccharomyces cerevisiae SAA-612: production, characterization and application in synthesis of fructo-oligosaccharides. LWT 77:178–18.

[170] Andjelković U, Milutinović-Nikolić A, Jović-Jovičić N, Banković P, Bajt T, Mojović Z et al (2015) Effcient stabilization of Saccharomyces cerevisiae external invertase by immobilisation on modifed beidellite nanoclays. Food Chem 168: 262–269.

[171] Guan, W.; Xu, G.; Duan, J.; Shi, S. (2018). Acetone–Butanol–Ethanol Production from Fermentation of Hot-Water-Extracted Hemicellulose Hydrolysate of Pulping Woods. Ind. Eng. Chem. Res. 57, 775–783.

[172] VAN ZYL, W. H. et al. (2010). Fungal β-mannanases: mannan hydrolysis, heterologous production and biotechnological applications. Process Biochemistry, v. 45, n. 8, p. 1203-1213.

[173] Dhawan, S.; Kaur, J. (2007). Microbial Mannanases: An Overview of Production and Applications. Crit. Rev. Biotechnol. 27, 197–216.

[174] Yin, J.-S.; Liang, Q.-L.; Li, D.-M.; Sun, Z.-T. (2013). Optimization of production conditions for β-mannanase using apple pomace as raw material in solid-state fermentation. Ann. Microbiol. 63, 101–108.

[175] CHAUHAN, P. S. et al. (2012). Mannanases: microbial sources, production, properties and potential biotechnological applications. Applied Microbiology and Biotechnology, v. 93, n. 5, p. 1817- 1830.

[176] Naganagouda, K.; Salimath, P.V.; Mulimani, V.H. (2009). Purification and characterization of endo-beta-1,4 mannanase from Aspergillus niger gr for application in food processing industry. J. Microbiol. Biotechnol. 19, 1184–1190

[177] Singh D, Gupta N (2020) Microbial laccase: a robust enzyme and its industrial applications. Biologia 75:1183–1193.

[178] BIRHANLI, E.; YEŞİLADA, Ö. (2013). The utilization of lignocellulosic wastes for laccase production under semisolid-state and submerged fermentation conditions. Turkish Journal of Biology, v. 37, n. 4, p. 450-456.

[179] El-Rahim WMA, Moawad H, Hashem MM, Gebreil GM, Zakaria M (2020) Highly effcient fungal pectinase and laccase producers among isolates from fax retting liquor. Biocatal Agric Biotechnol 25:101570.

[180] Periasamy D, Mani S, Ambikapathi R (2019) White rot fungi and their enzymes for the treatment of industrial dye effluents. In: Yadav AN, Singh S, Mishra S, Gupta A (eds) Recent advancement in white biotechnology through fungi. Springer, Cham, pp 73–100. https://doi. org/10.1007/978-3-030-25506-0

[181] Bilal M, Jing Z, Zhao Y, Iqbal HM (2019) Immobilization of fungal laccase on glutaraldehyde cross linked chitosan beads and its biocatalytic potential to degrade bisphenol a. Biocatal Agric Biotechnol 19:101174.

[182] Mishra S, Maiti A (2019) Applicability of enzymes produced from different biotic species for biodegradation of textile dyes. Clean Techn Environ Policy 21:763–781.

[183] SINHA, S.; SINHA, S. (2009). Studies on the production of acid protease by submerged fermentation. International Journal of Food Engineering, v. 5, n. 1.

[184] Yadav AN, Mishra S, Kour D, Yadav N, Kumar A (2020) Agriculturally important fungi for sustainable agriculture, Perspective for diversity and crop productivity, vol 1. Springer International Publishing, Cham

[185] Yadav AN, Mishra S, Kour D, Yadav N, Kumar A (2020) Agriculturally important fungi for sustainable agriculture, Functional annotation for crop protection, vol 2. Springer International Publishing, Cham.

[186] Chancharoonpong, C.; Hsieh, P.-C.; Sheu, S.-C. (2012). Enzyme Production and Growth of Aspergillus oryzae S. on Soybean Koji Fermentation. APCBEE Procedia 2, 57–61.

[187] Veerabhadrappa, M.B.; Shivakumar, S.B.; Devappa, S. (2014). Solid-state fermentation of Jatropha seed cake for optimization of lipase, protease and detoxification of anti-nutrients in Jatropha seed cake using Aspergillus versicolor CJS-98. J. Biosci. Bioeng. 117, 208–214.

[188] Fazouane-Naimi F, Mechakra A, Abdellaoui R, Nouani A, Daga SM, Alzouma AM et al (2010) Characterization and cheese-making properties of rennet-like enzyme produced by a local Algerian isolate of Aspergillus niger. Food Biotechnol 24(3):258–269.

[189] PANT, G. et al. (2015). Production, optimization and partial purification of protease from Bacillus subtilis. Journal of Taibah University for Science, v. 9, n. 1, p. 50-55.

[190] Devi R, Kaur T, Guleria G, Rana K, Kour D, Yadav N et al (2020) Fungal secondary metabolites and their biotechnological application for human health. In: Rastegari AA, Yadav AN, Yadav N (eds) Trends of microbial biotechnology for sustainable agriculture and biomedicine systems: perspectives for human health. Elsevier, Amsterdam, pp 147–161. https://doi.org/10.1016/B97 8-0-12-820528-0.00010-7

[191] Chao YP, Xie FH, Yang J, Lu JH, Qian SJ (2007) Screening for a new Streptomyces strain capable of efficient keratin degradation. J Environ Sci (China) 19:1125–1128.

[192] Javed S, Azeem F, Hussain S, Rasul I, Siddique MH, Riaz M et al (2018) Bacterial lipases: a review on purification and characterization. Prog Biophys Mol Biol 132:23–34.

[193] TREICHEL, H. et al. (2010). A review on microbial lipases production. Food Processing Technology, v. 3, n. 2, p. 182-196.

[194] VASEGHI, Z. et al. (2013). Production of active lipase by Rhizopus oryzae from sugarcane bagasse: solid state fermentation in a tray bioreactor. International Journal of Food Science & Technology, v. 48, n. 2, p. 283-289.

[195] Salihu, A.; Bala, M.; Alam, M.Z. (2016). Lipase production by Aspergillus niger using sheanut cake: An optimization study. J. Taibah Univ. Sci. 10, 850–859.

[196] Kanmani, P.; Kumaresan, K.; Aravind, J. (2015). Utilization of coconut oil mill waste as a substrate for optimized lipase production, oil biodegradation and enzyme purification studies in Staphylococcus pasteuri. Electron. J. Biotechnol. 18, 20–28.

[197] Borowiecki P, Justyniak I, Ochal Z (2017) Lipase-catalyzed kinetic resolution approach toward enantiomerically enriched 1-(β-hydroxypropyl) indoles. Tetrahedron Asymmetry 28:1717–1732.

[198] Ornla-Ied P, Sonwai S, Lertthirasuntorn S (2016) Trans-free margarine fat produced using enzymatic interesterifcation of rice bran oil and hard palm stearin. Food Sci Biotechnol 25(3):673–680.

[199] Kaur T, Devi R, Kour D, Yadav N, Prasad S, Singh A et al (2020) Advances in microbial bio-resources for sustainable biofuels production: current research and future challenges. In: Yadav AN, Rastegari AA, Yadav N,

Gaur R (eds) Biofuels production – sustainability and advances in microbial bioresources. Springer International Publishing, Cham, pp 371–387. https://doi. org/10.1007/978-3-030-53933-7_17.

[200] Prasad S, Yadav AN, Singh A (2020) Impact of climate change on sustainable biofuel production. In: Yadav AN, Rastegari AA, Yadav N, Gaur R (eds) Biofuels production – sustainability and advances in microbial bioresources. Springer International Publishing, Cham, pp 79–97. https://doi.org/10.1007/978-3-030-53933-7_5

[201] Sarmah N, Revathi D, Sheelu G, Yamuna Rani K, Sridhar S, Mehtab V et al (2018) Recent advances on sources and industrial applications of lipases. Biotechnol Prog 34(1):5–28.

[202] Poria , V., Rana, A., Kumari , A., Grewal , J., Pranaw , K., Singh, S., (2021). Current Perspectives on Chitinolytic Enzymes and Their Agro-Industrial Applications. Biology 2021, 10, 1319. https://doi.org/10.3390/biology10121319

[203] Liu J, NanGong Z, Zhang J, Song P, Tang Y, Gao Y et al (2019) Expression and characterization of two chitinases with synergistic effect and antifungal activity from Xenorhabdus nematophila. World J Microbiol Biotechnol 35:106.

[204] Yadav AN, Singh J, Singh C, Yadav N (2020) Current trends in microbial biotechnology for sustainable agriculture. Springer, Singapore

[205] Rastegari AA, Yadav AN, Yadav N (2020) New and future developments in microbial biotechnology and bioengineering: trends of microbial biotechnology for sustainable agriculture and biomedicine systems: diversity and functional perspectives. Elsevier, Amsterdam.

[206] Rastegari AA, Yadav AN, Yadav N (2020) New and future developments in microbial biotechnology and bioengineering: trends of microbial biotechnology for sustainable agriculture and biomedicine systems: perspectives for human health. Elsevier, Amsterdam.

[207] Zhou J, Chen L, Kang L, Liu Z, Bai Y, Yang Y et al (2018) ChiE1 from Coprinopsis cinerea is characterized as a processive exochitinase and revealed to have a significant synergistic action with endochitinase ChiIII on chitin degradation. J Agric Food Chem 66:12773–12782.

[208] Le B, Yang SH (2019) Microbial chitinases: properties, current state and biotechnological applications. World J Microbiol Biotechnol 35(9):144.

[209] Le B, Yang SH (2018) Characterization of a chitinase from Salinivibrio sp. BAO-1801 as an antifungal activity and a biocatalyst for producing chitobiose. J Basic Microbiol 58:848–856.

[210] Deng JJ, Shi D, Mao HH, Li ZW, Liang S, Ke Y et al (2019) Heterologous expression and characterization of an antifungal chitinase (Chit46) from Trichoderma harzianum GIM 3.442 and its application in colloidal chitin conversion. Int J Biol Macromol 134:113–121.

[211] Gutiérrez-Román MI, Holguín-Meléndez F, Dunn MF, Guillén-Navarro K, Huerta-Palacios G (2015) Antifungal activity of Serratia marcescens CFFSUR-B2 purified chitinolytic enzymes and prodigiosin against Mycosphaerella fjiensis, causal agent of black Sigatoka in banana (Musa spp.). BioControl 60:565–572.