BRIEF REVIEW ON THERMOPHILIC BACTERIA AND THEIR APPLICATIONS

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Received: 12 Sep 2021, Revised and Accepted: 15 Nov 2021

Enzymes from incredibly thermophilic microorganisms have been of innovative interest for quite a while in view of their capacity to catalyse responses of modern importance at raised temperatures. Most of the potential bioprospecting is at present identified with the investigation of the extremophiles and their likely use in modern cycles. As of late microbial enzymes discover applications in different businesses and comprise a significant gathering of modern enzymes. Present review article reveals basics of thermophilic bacteria and their applications with thermostability.

Keywords: Thermophiles, Ecology, Thermoenzymes, Thermostability, Applications

INTRODUCTION

Organic entities equipped for living at high temperatures have held a specific interest for researcher and natural chemists, as they exist at temperatures where their proteins and nucleic acids would be relied upon to be denatured [1]. Hotness adoring microorganisms, or thermophiles, are among the best examined of the extremophiles. The order of living life forms dependent on their connection to temperature has consistently been considered as the most essential component of organic methodical [2]. For the most part, the ideal temperature for development of earthbound microorganisms is between 25-35 °C. Microorganisms were gathered into three classifications dependent on their ideal temperature, psychrophiles that have a underneath 20 °C, mesophiles that develop ideally over the temperature of protein coagulation (60 –70 °C) and Thermophilic microorganisms have a place with Archaea and creatures or plants have been found to endure temperatures above 50 °C. Thermophiles were arranged as life forms with a temperature most extreme of about room temperature (25 °C), yet additionally develop well at room temperature. Thermophiles are added to different gatherings depending on their temperature necessity. Thermophiles were arranged as life forms with a temperature least of about room temperature (25 °C). Orthothermophiles as microorganisms with a temperature most extreme over the temperature of protein coagulation (60–70°C) and the thermotolerants as life forms with a temperature limit of 50–55 °C, yet additionally develop well at room temperature. Thermophiles are additionally isolated into two gatherings as first is valid thermophiles, which showed ideal development at 60–70 °C and no development, or follow development, under 40 to 45 °C. The second is facultative thermophiles, which showed development at 25 °C and have their ideal temperature for development and endurance is 50–55 °C, and most extreme 60 °C. Thermophiles are likewise named severe thermophiles, which showed development above 55 °C thermotolerant showed ideal development at temperature between 40-50 °C and commit thermophiles showed development at 55 °C; however not at 37 °C [6]. As of now, thermophiles are characterized into moderate thermophiles (ideal development 50–60 °C), outrageous thermophiles (ideal development 60–80 °C) and hyperthermophiles (ideal development 80–110 °C). A few researchers made a solitary gathering of hyper thermophiles and

outrageous thermophiles. In light of their ideal temperature for development, a few thermophilic microscopic organisms also, archaeabacteria have been named moderate thermophiles (Bacillus caldolyticus, Geobacillus stearothermophilus, Thermoactinomyces vulgaris, Clostridium thermohydrodsulfurificans, Thermomanaerobacter ethanolicus, Thermoplasma acidophilum), outrageous thermophiles (Thermus aquaticus, Thermodesulfobacterium collectum, Sulfolobus acidocaldarius, Thermostreum roseum Dicyogloymus thermophilum, Methanococcus vulcanicus, Sulforoccus, mirabilis, Thermitoga maritima) and hyperthermophiles (Methanococcus jannaschii, Acidobium halophiles, Archaeoglobus profundus, Methanopyrus kandleri, Pyrobaclium islandicum, Pyrococcus furiosus, Pyrodictium occultum, Pyrolobus furfurii, Thermococcus littoralis, Igncoccus islandicum, Nannothermaeaeaequans Geobacillus sp.) [7-9]. The greater part of the thermophiles has been sequestred from mariners, sun-warmed soils, earthly underground aquifers, submarine aqueous vents and geothermally warmed oil saves and oil wells. The first extremophile equipped for development at temperatures more noteworthy than 70 °C was a bacterium, presently called Thermus aquaticus that would later make conceivable the inescapable utilization of a progressive innovation the polymerase chain response. Concerning a similar time, the first hyperthermophile [10, 11].

Habitat of thermophiles

Regular geothermal regions are generally conveyed across the globe. Natural aquifers are framed because of the development of boiling water from the world’s outside through shortcomings made by structural development or volcanic ejection. Earthy surface conditions incorporate natural aquifers that are near unbiased pH, or acidic and sulfurous, or rich in iron. Hot underground regions are different and goes from volcanically warmed conditions to those, for example, the Great Artesian Basin in Australia that are warmed by ethnicness of their profundity. Natural aquifers could be fundamental, nonpartisan, or acidic [12]. Be that as it may, the most various are those with soluble pH, normally connected with volcanic or structural movement. Acidic underground aquifers, for example, that of the Yellowstone caldera are related with dynamic volcanoes or shallow magma pools [13]. The pH of geothermal springs mirrors their biodiversity, for example, in acidic underground aquifers, acidophiles such as Sulfolobus flourish and in impartial or moderate natural aquifers a different number of thermophiles like Thermoproteus, Pyrobaculum, Methanothermus, Desulfurococcus and Thermofilum exist. Submarine conditions incorporate volcanic and aqueous vents. The last are frequently portrayed as dark smokers inferable from the precipitation of minerals when hot, mineral-rich
volcanic liquids meet cold sea waters (5 °C). The current record for high-temperature development is held by the archaeon *Pyrolobus fumarii*, which can develop at 113 °C [14].

**Earthbound natural aquifers**

Earthbound geothermal regions can be the most part isolated into two classes as indicated by the nature of the hotness source and pH.

**High-temperature fields**

High temperature fields are situated inside the dynamic volcanic zones and magma chamber fills in as the hotness source [15]. They are for the most part on key position. Torbjörkull east of Helka, Grimsvotn in the Vatnajökull ice sheet, and Hengill close to Reykjavík, Kéringarfjöll, Namafjall close to Myvatn, Kórrkjöl on the north side of Vatnajökull furthermore, Krisuvik south of Reykjavik are the primary high-temperature regions. Around there, steam and volcanic gases are produced at the surface and the water temperature comes to 150 to 350 °C. The most noteworthy, recorded temperature was 386 °C. Icelandic underground aquifers have high sulfide fixations (30 mg/L-) and thick bacterial mats are framed with accelerated sulfur and make fabulous dazzling yellow or white tones [16].

**Low-temperature fields**

The low temperature underground aquifer fields are situated outside the dynamic volcanic zones. The outer layer of low-temperature fields is generally covered with underground aquifers and fountains. The boiling water of these spaces is basic. Generally, the synthetic substance of low-temperature water is like the and fountains. The boiling water of these spaces is basic. Generally, the synthetic substance of low-temperature water is like the

**Underground natural aquifers**

Deep silt, rocks and minerals offer conditions for life that are totally different from earthbound and amphibian territories. Water ordinarily contains H₂, CH₄, and CO₂ that advance chemolithoautotrophic life however microbial development rates are low. Steam and water are gathered in boreholes 1500 to 2000 m profound, and temperatures are running between 50 to 130 °C [18].

**Marine and earthbound oil reservoirs**

Oil fields are considered as new living spaces for thermophiles. Contingent upon the geographic area, reservoirs have temperatures going from 60 to 130 °C and pressures somewhere in the range of 15 and 40MPa sea floor, down to a few kilometres. The liquid is extremely hot (250 to 400 °C), acidic, wealthy in metals (iron), CH₄ and H₂S. In case there is blending of aqueous liquid and cool seawater not long before outflow, its temperature is 5 to 100 °C and in case there is no blending, the temperatures of liquid vents is 350 °C or above. The remote ocean vents are otherwise called dark smokers, because of the steady release of accelerated minerals in seawater that take the part of thick, dark mists [19]. Most of the known aqueous vent can be found at profundities more prominent than 3500 m and as shallow as 400 m.

**Other geothermal natural surroundings**

Steady hot environments other than geothermal are not many in nature. Sunlight based warmed lakes and naturally warmed cultivators, feed and compost might cause high temperature. Man-made, hot conditions, for example, boiling water pipelines consuming coal decline heaps, squanders from treatment plants or modern cycles in the food or fertilizer, geothermal soil, raw petroleum, gold mine and profound sea dregs) announced worldwide and evaluated [7, 8].

**Thermophilic bacteria**

The thermophilic bacterial agents showed ideal development underneath temperature 75 °C, aside from *Thermotoga* and *Aquificae* have ideal temperature above 85 °C. The pH range for bacterial thermophiles is 5-9, with few special cases like *Hydrogenobaculum* spp. or then again *Bacillus* species. The *Aquificae*, *Thermotogae*, Thermodesulfobacteria, Thermo-microbia and Thermales are thermophilic families. *Aquificae* species are thermophilic high impact, chemoheterotrophic chemosynthetic microorganisms. They are Gram negative cells and utilized H₂ or diminished sulfur compounds as energy sources [1]. The *Thermotogae* are anaerobic and fermentative species. They are Gram negative cells with an unmistakable external sheath-like envelope of "frock". The *Thermodesulfobacteria* cells are pole formed, rigorously anaerobic, chemoheterotrophic displaying a unique sulfate-lesser nitrogen. The *Thermomicrobia* cells are only oxygen consuming and become distinctively on complex supplements. The request *Thermales* addresses *Thermus aquaticus*, separated from the Yellowstone Park in the USA. The *Thermales* are transcendentally vigorous and heterotrophic. The *Thermus* sort can be found in different conditions, for example, hot faucet water [3], thermally dirtied streams or fertilizer heaps and normal aqueous regions, marine aqueous vents, and shallow marine underground aquifers. Different genera create the request *Thermales*, for example, *Meiothermus*, and *Marinithermus*, *Oceanithermus* and *Vulcanithermus* all are disengaged from profound marine vents. The thermophilic Gram-up-sides are dispersed up to 22 genera, and 20 are only thermophelic [4, 5]. The *Cyanobacteria* are mesophilic oxygentic photosynthetic prokaryotes with the couple of special cases of moderate thermophiles like *Fischerella* or *Oscillatoria* furthermore, *Synechococcus* which becomes ideally above 55 °C. The genera *Rhodothermus* furthermore, *Thermonema* are the interesting thermophilic delegates among the Archaea. The *Cytophaga/Flexibacter/Bacteroides* bunc. *Rhodothermus* becomes above 70 °C and needs at least 1 % salt focus for development [6]. It has been utilized broadly as a weelspring of new compounds *Thermonema* is a moderate thermo-halophile with at 65 °C. The class has been accounted for from New Zealand, Italy, and Iceland. The purple microbes or *Proteobacteria*, thermophilic genera dissipated among the, β, γ, δ and ε-developments coincide with both mesophilic and psychrophilic agents. The β-proteobacterial genera are becoming stringently under anaerobic conditions. The thermophilic ones are the hydrogen-oxidizing *Hydrogenophilus* and the sulfur-oxidizing *Thermophilic* as well as *Aquificae*, *Thermodesulfobacteria*. Delegates of the ε-development are generally moderate thermophiles with Topt fluctuating around 55 to 65 °C. The *Geobacillus* spp (detached from underground aquifers, fertilizer, geothermal soil, raw petroleum, gold mine and profound sea dregs) announced worldwide and evaluated [7, 8].

**Thermozymes**

Enzymes created by thermophiles and hyperthermophiles are ideally dynamic at high temperatures, somewhere in the range of 60 and 125 °C and impervious to irreversible inactivation at raised temperatures are known as thermozymes. Thermozymes offer different biotechnological and modern benefits over mesophilic proteins. They are simpler to decontaminate by heat treatment, higher protection from synthetic denaturants (solvents and guanidine hydrochloride) and withstand higher substrate focuses [21]. Since of their soundness at raised temperature, thermozyme responses are less powerless to microbial pollution and frequently show higher response rates than mesozyme catalyzed responses. Considering these significant benefits, thermozymes are drawing in much modern interest. Moreover, thermozymes can be utilized as models for comprehension thermo soundness. Consequently, distinguishing underlying highlights associated with strength of thermozymes is fundamental for a hypothetical portrayal of the physico-compound standards adding to protein strength and collapsing [11, 22]. Besides, this data is fundamental likewise for planning more steady proteins for modern cycles. The principle benefit of thermozymes is their high strength at raised temperatures which is valuable for a huge assortment of modern cycles. The increment of temperature impacts the bioavailability and expanded disposability of numerous thermophilic natural substances [12, 23]. The height of temperature likewise related with expansion in dispersion of natural mixtures, decline in thickness, further developed exchange rates and subsequently expanded response rates. Additionally, another benefit is that it likewise decreases the
hazard of microbial pollution as every one of the pathogenic microorganisms and saprophytes are killed at temperature above 70 °C and lessen number of microorganisms which cause defilement of food processes. Variables adding to steadiness incorporate extra intermolecular cooperation (for example hydrogen bond), following, β-turns which cause, to the thermophilic associations, disulfide bonds, metal restricting) and great general conformational structure (for example more inflexible, high pressing thickness; conformational strain discharge [24]; steadiness of a-helical decreased entropy of unfurling, ideal charge example or particle pair and oligomer development). Electrostatic connections increase the stability of self-extended and disulfide bonds, as contrast with mesophilic proteins. In thermophilic proteins, the measure of Glu, Arg and Lys are higher in the helices, which lead to expansion in control build ups, upgrading thermo resistance of proteins in hyper thermophilic microorganisms. Hydrophobic powers are significant supporters of atomic collapsing and thermotability [13, 15]. Most extreme pressing poweing of a catalyst can be accomplished by filling holes in the protein centre and lead to expand the centre hydrophobicity. The ribonuclease HI from Escherichia coli has a pit close to inside the protein centre. Presentation of a methyl bunch in the cavity expanded hydrophobic cooperation inside the protein centre and thusly upgraded protein security. Higher measure of alanine, isoleucine and proline gives additional security to circles and tighter the pressing in hydrophobic centres. Proteins are balanced out by disulfide spans through an entropic impact. Disulfide spans decline the entropy of protein’s unfurled state. The disulfide bond interfaces the C-end of helix1 at 27 positions and 27 potential turning sites, which cause, to the thermophilic soundness of glucomylase. Metals are known to balance out and enact proteins. An investigation of B. licheniformis xylose isomerase (BXLII) showed settling powers are related with the presence of metals in the holoenzyme. The energy of actuation for irreversible inactivation was affected by the presence of metal particle. The actuation energy went from 342 (apoenzyme) to 1166 kJ/mol (Co2+enzyme) [25]. By and large, mesophilic proteins are inactivated at raised temperature due to covalent adjustments. This kind of inactivation might be forestalled by replacement of explicit different sorts of polysaccharide corrupting compounds like amyloses, cellulases, pullulanases, xylanases, mannanase, pectinases and chitinases, lipases, esterases, proteases and phytases have been portrayed from amazingly thermophilic and hyperthermophilic. Countless thermozymes are required by businesses. Starch, material, drug, calfkin, mash and paper, cleaner, food also, feed businesses are the principal client of thermophilic compounds [26]. The starch breaking is perhaps the biggest client of thermophilic and hyperthermophilic proteins. Amylases, glucoamyloses and isoamyloses or pullulanases are utilized in starch ventures for the hydrolysis and adjustment of starch to give glucose and different items. Amylolytic proteins are likewise utilized in baking, material, and paper businesses. Cellulolytic proteins are utilized in cleaners for shading lighting up and mellowing of materials, biostoning of pants, expulsion of polyphenolic substances from juices, mash and paper businesses and pre-treatment of plant biomass [27]. These days, bio cleaners contain proteins like amylyase, protease, cellulase and lipase, utilizing variations that are safe to unforgiving conditions. Lipases are additionally utilized in different cycles, for instance, fat hydrolysis, esterification, interesterification, trans-esterification and normal biosynthesis. Different utilizations of lipase incorporate the expulsion of pitch from mash delivered in the paper business, hydrolysis of milk fat in the dairy business, expulsion of non-cellulose contaminations from crude cotton before additional handling into coloured and completed items, expulsion of subcutaneous fat in the cowhide business and assembling of medications in the drug business [28].

Thermotability

Warm opposition of catalysts is controlled by free energy utilization essential for change of particles from collapsed to unfurled state. Some changes in the surface, for example, example particles, disulfide spans, hydrogen bonds and hydrophobic connections. Notwithstanding sidechain connections, thermophilic and hyperthermophilic microorganisms embrace different procedures for balancing out proteins. This might be accomplished by filling pits in the atomic design of the proteins, shortening of the circles and decrease of open hydrophilic surface region [29]. Different changes include metal particle restricting furthermore, reduced measure of build-up’s helplessness to degradation. Beside these, proteins can additionally contain thermolabile deposits in area in which they are not powerless to debasement. Thermotability of certain proteins can be guaranteed by natural components, e.g., expanded intracellular salts furthermore, protein focuses and combination of various stabilizers. Be that as it may, there are no widespread elements or their mixes that might be utilized to guarantee the steadiness of thermophilic proteins [30]. Besides, some elements engaged with thermostabilization of solvent proteins don’t show up in the event of film proteins. Even though, variation of thermozymes to act at raised temperatures is mostly accomplished by trade of scarcely any amino corrosive build ups and additionally their diverse limitation in particle, the homologously thermotable and thermotable catalysts are comparative and have the equivalent reactant components. Higher obstruction of thermozymes as contrasted and their mesophilic partners is the aftereffect of expanded inflexibility, which jelly their chemically dynamic construction, yet prompts diminished movement at lower temperatures. Moreover, their thermotability is shown and expanded due to their unique dynamic than their mesophilic partners even at low temperatures. Such marvel proposes that their particles show near adaptability in the space of synergist site with generally inflexibility of the remainder of the protein [15,19,21]. It is fascinating to take note of that a large portion of the heat safe catalysts show maximal action about the ideal development temperature of the microorganism from which they are separated.

Applications of thermozymes

As of now, just scarcely any thermostable proteases are commercially accessible. One of them is alcalase disconnected from Bacillus licheniformis [1]. The significant element of this planning is subtilisin, which is an endoprotease of serine type, displaying most elevated action at 60 °C and pH of 8.3. Alcalase discovered numerous applications in the food business, e.g. by reason of their low particularity towards various proteins from plant and creature sources. For instance, this protein is significant in the handling of soy suppur which brings about dissolvable, [2] non-severe hydrolysate, utilized as part of protein-sustained sodas [4] and dietetic food [5]. Alcalase is additionally helpful for recuperation of proteins from results of the meat and fish industry also, from shellfish shell squander during chitin creation [12]. Moreover, thermostable proteases that are impervious to anionic or non-ionic surfactants and are dynamic at temperatures above 60 °C discovered application as part of dishwashing cleansers. Such proteases can be additionally utilized for cleaningultrafiltration layers at high temperatures, expanding the effectiveness of this cycle. The other expected use of hotness safe proteases is meat softening. It is because of the extraordinary contrast of enzymatic action at moderate and high temperatures [6, 9, 11, 21]. The mesophilic proteases infused into the tissue show a lingering action during the entire time of post-butchering stockpiling of the meat slices prompting an unreasonable discontinuity of the protein atoms. The utilization of compounds with a fundamental action as it were during cooking permits the stoppage of proteolysis just by cooking. The steadiness of hotness safe proteases in Fluid/natural and nonaqueous media prompts the adjustment of the response equilibrium, making new peptidic bonds. Such converse responses might be utilized to work on nourishing quality and usefulness of protein hydrolyzates and to lessen their sharpness [3, 7, 9, 13]. It is accomplished by expanded sub-atomic load of peptides just as by presentation of beneficial amino corrosive build ups. Among the thermozymes proteases presently utilized on a modern scale, immobilized thermolysin from Bacillus thermoproteolyticus is engaged with the amalgamation of aspartylphenylalanine-l-methyl ester, known as aspartame. This item is ordinarily utilized as sugar in some low-caloric food and drinks. Enzymatic combination dispenses with tainting of the item by non- sweetening. Poultry industry creates a lot of quills. Customarily, this side-effect is debased by acid hydrolysis and steam pressure cooking. Such method of handling annihilates some fundamental amino acids and lead to development of non-nutritive lysinoalanine and lantionine [16, 19]. By this explanation, an incredible
importance has non-contaminating, biotechnological use of keratin-containing squanders. In any case, the generally created proteases proved unable debase keratin. It is brought about by firmly stuffed fibre design of keratin, settled by an enormous number of disulphide and hydrogen bonds just as by hydrophobic cooperations. This insusceptible protein can be separated by certain microorganisms (16, 19). Contingent upon protease source, keratinolytic catalysts show distinctive movement and substrate particularity. For example, keratinase from B. licheniformis is fit for hydrolyzing ox-like serum egg whites, collagen, and elastin. Despite what might be expected, a thermostable protease orchestrated by Cryptococcus keratinophilum is dynamic just towards keratin. The utilization of keratinolytic proteins from thermophiles prompts expanded pace of keratin degradation. In addition, such keratinases typically have low collagenolytic movement, which are the necessities of enzymatic de-hairing in the calfskin industry. The traditional technique for de-hairing in a basic condition by treatment with sodium sulphide makes issues of natural contamination. Properties of keratinases are reliant upon microorganism and blend of these proteins can be actuated by keratin added to the development media (17, 19, 23). Fundamental for keratinases creation are development conditions, for example, pH, temperature, and media organization. Most of known keratinases are extracellular or external film bound enzymes having a place with the serine protease family, however aspartic-, cysteine- and metallo-proteases are likewise considered. Keratinases delivered by mesophilic microbes and saprophytic growths are generally dynamic at temperatures up to 50 °C. Notwithstanding, in a couple cases, thermoactive protease which keep up with keratinolytic activity at raised temperatures are delivered by a few mesophiles. Such wonder was seen on account of B. licheniformis K-19 creation, during development at 37 °C; keratinolytic protease performed enzymatic action at temperatures from 30 to 90 °C. This protease has most noteworthy activity at 60 °C and pH 7.5-8.0. Interestingly, protease from thermophilic Pseudomonas islandicum AW-1 shows ideal keratinolytic movement at 100 °C and pH 9.0, and has halfLife of 90 min at 100°C. The biodegradation utilizing refined keratinase could be supplanted by the activity of thermophilic microorganisms filling in response media or the utilization of culture filtrates containing the keratinase alone without microorganism cells (24). This process is adequately productive and generally requires gentle conditions and more modest energy input, on the grounds that microbial decay creates heat during development (14, 19, 25). It decreases the expenses of handling and no pathogenic microbes (generally mesophiles) can develop at raised temperature. As of late, the bacterium Methanothermus ruber H-328 was utilized for usage chicken mesophiles) can develop at raised temperature. As of late, the bacterium Methanothermus ruber H-328 was utilized for usage chicken

CONCLUSION

Following quite a while of exploration on thermoenzymes usage, it is currently viewed as that protein-based advancements for biomass changes are generally productive, practical and climate agreeable. Significant advancement has been made looking for extremophiles, yet their actual variety, has not yet been completely investigated. Thermostable enzymes disengaged from these living beings have shown their potential under conditions that are proper for bioconversion processes which play part in enterprises. The future difficulties for thermoenzymes creation incorporate innovations for enzymes biomass pre-treatment for better microbial assault, processes for practical creation of enzymes lastly creature advancement techniques to work on the properties of chemical to build their exercises, process resilience and warm solidness.

FUNDING

Nil

AUTHORS CONTRIBUTIONS

All the authors have contributed equally.

CONFLICT OF INTERESTS

Declared none

REFERENCES

1. Anand SS, Hawkes C, De Souza RJ, Mente A, Dehghan M, Nugent R, Zulayakis A, Weke T, Bernstein AM, Krauss RM, Kromhout D, Jenkins DJA, Malik V, Martinez-Gonzalez MA, Mozaffarian D, Yusuf S, Willett WC, Popkin BM. Food consumption and its impact on cardiovascular disease: importance of solutions focused on the globalized food system: A report from the workshop convened by the World Heart Federation. J Am Coll Cardiol: Basic Transl Sci. 2016;1(4):1590-614. doi: 10.1016/j.jacbts.2015.07.050. PMID 26429085.

2. Mane RS. Therapeutic applications of bioactive compounds obtained by endophytes of Thielaviopsis basica isolated from Ximenia americana, Western Ghats of India. J Microbiol Biotechnol Food Sci. 2020;9(5):870-8. doi: 10.15414/jmbfs.2020.9.5.870-878.

3. Aro N, Saloheimo A, Ilmén M, Penttilä M. ACEII, a novel transcriptional activator involved in regulation of cellulase and xylanase genes of Trichoderma reesei. Appl Environ Microbiol. 2002;68(1):430-3. doi: 10.1128/AEM.68.1.430-433.2002. PMID 11772658.

4. Mane RS. Fungal endophytes: sources and prospects. J Med Plants Stud. 2015;3(2):121-6.

5. Andrade CMMC, Nei P Jr, Antranikian G. Extremely thermophilic microorganisms and their polymer hydrolytic enzymes. Braz J Microbiol. 1999;30:287-98.

6. Aro N, Ilimen M, Saloheimo A, Penttilä M. ACEI is a repressor of cellulase and xylanase genes of Trichoderma reesei. Appl Environ Microbiol. 2002;68(5):256-65.

7. Mane RS, Paarakh PM, Vedamurthy AB. Brief review on fungal endophytes. Int J Second Metabolites. 2018;5(4):288-303. doi: 10.1128/IAIM.68.1.430-433.2002. PMID 11772658.

8. Aro N, Saloheimo A, Ilimen M, Penttilä M, ACEII, a novel transcriptional activator involved in regulation of cellulase and xylanase genes of Trichoderma reesei. J Biol Chem. 2001;276(26):24309-14. doi: 10.1074/jbc.M003624200. PMID 11304525.

9. Dienes D, Egghazi A, Reczey K. Treatment of recycled fiber with trichoderma cellulases. Ind Crops Prod. 2004;20(1):11-21. doi: 10.1016/j.indcrop.2003.12.009.

10. Egorova K, Antranikian G. Industrial relevance of thermophilic Archaea. Curr Opin Microbiol. 2005;8(6):649-55. doi: 10.1016/j.mib.2005.10.015. PMID 16257257.
16. Fangdong Z. Study on the isolation of thermophilic cellulolytic bacteria by using 3 kinds of medium and the determination of its enzyme activity. J Anhui Agric Sci. 2008;36(15):6171-2.

17. Firn RD. Bioprospecting—why is it so unrewarding? Biodivers Conserv. 2003;12(2):207-16. doi: 10.1023/A:1021928209813.

18. Fitter J. A measure of conformational entropy change during thermal protein unfolding using neutron spectroscopy. Biophys J. 2003;84(6):3924-30. doi: 10.1016/S0006-3495(03)75120-0, PMID 12770898.

19. Folan MA, Coughlan MP. The cellulase complex in the culture filtrate of the thermophilic fungus, Talaromyces emersonii. Int J Biochem. 1978;9(10):717-22. doi: 10.1016/0020-711x(78)90038-1, PMID 710680.

20. Fracheboud D, Canevascini G. Isolation, purification, and properties of the exocellulase from Sporotrichum (Chrysosporium) thermophile. Enz Microb Technol. 1989;11(4):220-9. doi: 10.1016/0140-229x(89)90096-3.

21. Grogan DW. Evidence that beta-galactosidase of Sulfolobus solfataricus is only one of several activities of a thermostable beta-D-glycosidase. Appl Environ Microbiol. 1991;57(6):1644-9. doi: 10.1128/aem.57.6.1644-1649.1991, PMID 16348503.

22. Vedamurthy AB, Mane RS. A new RoVe method to purify endophytic fungi from medicinal plants Western Ghats of Karnataka India. PCI-Approved-IJPSN. 2020;13(4):5011-9. doi: 10.37285/ijpsn.2020.13.4.7.

23. Gullo VP, McAlpine J, Lam KS, Baker D, Petersen F. Drug discovery from natural products. J Ind Microbiol Biotechnol. 2006;33(7):523-31. doi: 10.1007/s10295-006-0107-2, PMID 16544162.

24. Hahn Hagerdal B, Galbe M, Gorwa Grauslund MF, Liden G, Zacchi G. Bio-ethanol—the fuel of tomorrow from the residues of today. Trends Biotechnol. 2006;24(12):549-56. doi: 10.1016/j.tibtech.2006.10.004, PMID 17050014.

25. Majamaa H, Isolauri E. Probiotics: a novel approach in the management of food allergy. J Allergy Clin Immunol. 1997;99(2):179-85. doi: 10.1016/s0091-6749(97)70093-9, PMID 9042042.

26. Isolauri E, Arvola T, Sutas Y, Moilanen E, Salminen S. Probiotics in the management of atopic eczema. Clin Exp Allergy. 2000;30(11):1604-10. doi: 10.1046/j.1365-2222.2000.00943.x, PMID 11069570.

27. Bliznakov EG. Lipid-lowering drugs (statins), cholesterol, and coenzyme Q10. The Baycol case—a modern Pandora’s box. Biomed Pharmacother. 2002;56(1):56-9. doi: 10.1016/s0753-3322(01)00150-0, PMID 11905511.

28. Mann GV. Studies of a surfactant and cholesterolemia in the Maasai. Am J Clin Nutr. 1974;27(5):464-9. doi: 10.1093/ajcn/27.5.464, PMID 4596028.

29. Shaper AG, Jones KW, Jones M, Kyobe J. Serum lipids in three nomadic tribes of northern Kenya. Am J Clin Nutr. 1963;13:135-46. doi: 10.1093/ajcn/13.3.135, PMID 14061585.

30. Mane RS, Khatun MJ, Khalequzzaman KM, Neela FA. Fusarium wilt controlling revealed physiological and biochemical variations in tomato cultivar. Bioc Sci Biotech Res Comm. 2020;13(3):1576-80.