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Bio-deterioration and its Management Techniques

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Abstract
Every natural or synthetic product is subject to some form of natural degradation over time under the right enabling environmental conditions. Bio-deterioration is one of the natural means of degradation. It is an unwanted change in the composition of a material influenced by biotic activities. This process of spoilage could either be a chemical or physical spoilage, usually caused by the entry of insects and creating pathways for the growth of identifiable organisms. Bio-deterioration is also complex and the factors that lead to the alterations in the physicochemical properties of an item depend most importantly on the item involved, the mode of action of the biotic agent, and a favourable environmental condition. The scope of bio-deterioration, products affected, causative agents, and mode of action were looked into and methods available to man to tackle this natural phenomenon were also evaluated. Some of the methods were from simply cultural practices to advanced techniques like nanotechnology.
Keywords: Bio-deterioration, Fruits, Cereals, Root and tuber crops, Insect pests, and Microorganisms

Introduction

Bio-deterioration has been generally defined as any adverse effect in the physicochemical property of an item caused by the vital activities of biotic agents thereby making it undesirable (Hueck, 1965, 1968; Zabihi *et al*., 2021). The process of spoilage in bio-deterioration can be a chemical or a physical effect mostly caused by the continuous growth of organisms that are either contained in the food, before packaging or during and on surfaces of packaging materials (Aduroja *et al*., 2018). This process of bio-deterioration is complex; involving alterations in the physicochemical and mechanical properties of the item, the mode of action of the organisms and favourable environmental conditions (Rivera *et al*., 2018). Food spoilage refers to unpleasant changes to food in which the food becomes unpalatable or even poisonous for consumption accompanied by change in smell, bad taste and undesirable appearance or texture (Akinmusire, 2011). In the case of food or agricultural products, these spoilage microorganisms can gain access to the product by using unhealthy or unclean seed before planting, through growth and development in the field, harvesting equipment, harvest/storage of the product and during processing and transportation (Barth *et al*., 2009). Zabihi *et al*. (2021) reported that physical, chemical, and biological factors work together, moving from coexistence to antagonism to cause bio-deterioration. It can apply to diverse types of materials such as agricultural food produce and inedible items like wood, paper, leather, fuels, cosmetics, building materials and building structures and could be a result of the metabolic activities of one of many micro-organisms or may be caused by insect, rodent or bird damage (Featherstone, 2008). The present review aims to reveal different crop produce that are lost through the process of bio-deterioration by providing reports on the factors that influence bio-deterioration. Biotechnological techniques used to control and prevent bio-deterioration were also highlighted. Featherstone (2008) classified bio-deterioration into two;

Chemical bio-deterioration

Chemical bio-deterioration is divided into two with similar results (the material becomes bad or unsafe) but from different causes or biochemistry.

- Biochemical assimilatory bio-deterioration – the organism feeds on the material as food – and derives energy from it.
- Biochemical dissimilatory bio-deterioration – the chemical change in the food is a result of discharges from the organisms.

Physical bio-deterioration

- Mechanical bio-deterioration – This happens when the outer nature of an item is physically damaged/altered by the impact of insects or the growth or activities of the organisms.
- Soiling/fouling – In this kind of bio-deterioration, the item or product is rendered unacceptable due to

its appearance and smell has been compromised. The building up of biofilms on the surface of a material can affect the state and nature of the item.

Causes of bio-deterioration

Materials stored or outside an enclosure have been directly or indirectly exposed to bio-deterioration processes by macro- and micro-organisms commonly known as bio-detergents (Aduroja *et al*., 2018; Zabihi *et al*., 2021). Several ecological factors contribute to the bio-deterioration of a product in the immediate environment apart from the inherent characteristics of organisms (Beimforde, 2011). The growth and colonization of specific biological species in specific materials are dependent on the nature, properties and composition of such products (nutrient composition, the relative percentage of acid, base, salinity, moisture, firmness) and specific environmental factors such as temperature, relative humidity, sun intensity, oxygen, nitrogen, level of atmospheric pollution, wind, and precipitation (Pinna, 2021; Zabihi *et al*., 2021). The bio-deterioration of different materials and substances has been extensively studied across the world.

Oyeyipo (2012) worked on the bio-deterioration of sweet potato (*Ipomoea batatas*) in Port Harcourt, Nigeria and observed that these fungi; *Aspergillus niger*, *Fusarium oxysporum*, *Rhizopus stolonifer, Botryodiplodia theobroma* and *Penicillium* sp. were associated with the spoilage of sweet potato tubers.

Okigbo *et al* (2012) carried out a study on the deterioration of yam chips. The microbial pathogens isolated in this processed form of yam during storage were *Aspergillus niger, Aspergillus flavus, Rhizopus stolonifer and Botryodiploida theobromae.* The study indicated that *Zingiber officinale* and *Vernonia amygdalina* were able to suppress these fungi causing spoilage on yam chips. Spoilage microorganisms easily invade fruits and vegetables during the period of growth, at maturity and mainly during post-harvest handling and storage. These microorganisms thrive easily on these products due to their tender nature with a very high level of moisture in them. Any puncture or wound to the fruit tissue may lead to microbial entry and colonization. According to Oyewole (2012), the living organisms associated with the bio-deterioration of stored banana fruits (*Musa sapientum* and *Musa acuminata* var. dwarf Cavendish) were isolated. Fungi and bacteria isolates such as *Rhizoctonia solani*, *Aspergillus niger* w., *Streptococcus pyogenes*, *Proteus vulgaris*, *Alcaligenes faecalis* and *Streptococcus faecalis* were responsible for the bio-deterioration of banana fruits. The study recommended refrigeration ($4^{o}C \pm 1$) and the use of moist sawdust to be the most appropriate storage condition for delaying ethylene expression, ripening and improving the state of the banana fruits during storage.

Hodges *et al.* (2014) attributed greater post-harvest losses in cereals in sub-Saharan Africa to bio-deterioration. The biotic agents involved are mainly pests (mostly insects such as beetles, moths and mites), microorganisms in the form of moulds, and vertebrates (mostly rodents such as rats and mice but also sometimes birds). The study observed that bio-deterioration was enhanced by inherent changes to the chemicals within the grain itself and extremes of temperature and humidity. The study further observed that the time of harvest and the climate condition are a major issue in avoiding the absorption of moisture or wetting of the product. For example, rotting grain (a special category of bio-deterioration), becomes a major problem when the time of harvest is in the rainy season or close to a wet season. Harvesting should have already been completed before these seasons set in. As a result, the damp cloudy weather type prevents the crop from still in the field, or after harvesting from drying or even drying to optimum moisture content and vulnerable to mould attacks. Postharvest losses due to bio-deterioration may set in as the crop attains the physiological maturity stage (the crop is close to harvest). While the crop is still standing in the field, field-to-store pests may make their first attack at this stage and when unseasonal rains dampen the crop, some mould will start to grow.

Ahuja and Chattopadhyay (2015) carried out e-pest surveillance on fruit trees such as citrus, banana, mango, pomegranate and sapota. The study highlighted major insects and microorganisms that influence bio-deterioration in citrus like citrus rust mite (*Phyllocoptruata oleivora Ashmead*), fruit-sucking moth (*Eudocina materna*), spores of fungi causing citrus scab (*Elsinoe fawcett*), greening disease (*Candidatus liberibacter asiaticus*) transmitted by infected bud woods and citrus canker (*Xanthomonas citri subsp. citri*) which is caused by a bacteria. In bananas, the study revealed thrips (*Chaetanaphothrips signipennis*) as a major insect pest and disease such as anthracnose (*Colletotricum musae*) caused by conidias of fungi found to cause bio-deterioration in bananas. Mango mealy-bug, thrips, and fruit fly (*Bactrocera dorsalis*) are major insect pest that causes bio-deterioration in mango. Fungi diseases such as anthracnose (*Colletotrichum gloeosporioides*), sooty mould (*Capnodium mangiferae / Meliola mangiferae*), powdery mildew (*Oidium mangiferae*), black rot on fruits (*Aspergillus niger*), stem end rot (*Diplodia natalensis/ Rhizoctonia solani*), and bacterial canker (*Xanthomonas campestris pv. mangiferae indicae*) causes bio-deterioration in mango fruits. Insect pests like pomegranate fruit borer (*Deudorix isocartes*), thrips (*Scirtothrips dorsalis and Rhipiphorothrips cruentatus*), fruit piercing/ sucking moth; diseases like bacterial blight (*Xanthomonas axonopodis* pv. *Punicae*) and the fungal attack caused by scab (*Sphaceloma punicae*), *Cercospora punicae* (Cercospora spots), and fruit rot (*Colletotrichum gloeosporioides*); fungal blight (*Phytophthora nicotiane*) and heartrot (*Alternaria alternata*) are all responsible for the bio-deterioration in pomegranate fruit.

Aduroja *et al.* (2018) studied the role of three fungal species (*Neocosmospora ramosa, Aspergillus tamari* and *Aspergillus violaceofuscus*) in the bio-deterioration of onions and cucumbers in Nigeria. The study reported that *N. ramosa* was responsible for the spoilage of cucumber and onions at a very high rate and gained resistance to both the antifungals (voriconazole and fluconazole) applied. The study recommended some effective interventions against these fungal invasions such as good agricultural practices (GAP), harvest and storage hygiene. Due to the biological damages at the pre-harvest level, the effect in the form of wounds/bruises and unhealthy parts of fruits and vegetables results in spoilage, quality and quantity deterioration and postharvest loss. Etana *et al.* 2019 reported that the influence of cutworms is common in most fruit crops like tomatoes at the field level. A pest that influences bio-deterioration in tomatoes includes potato tuber moth, tomato leaf miner/fruit borer, African bollworm, spider mites and whiteflies.

Mohammed and Kuhiyep (2020) also investigated the bacteria and fungi organisms associated with the bio-deterioration of fresh tomatoes, (*Lycopersicum esculentum*) in Kaduna, Nigeria. The study identified *Staphylococcus aureus, Escherichia coli*, *Salmonella sp*, *Aspergillus niger Penicillium* sp and *Aspergillus flavus* to be responsible for spoilage of tomatoes. These isolates were both sensitive and resistant to antibiotics and antifungal agents used. Ano and Nji (2022) reviewed the bio-deterioration of cassava roots, its causes and management techniques. Their study highlighted the two processes involved in the deterioration of cassava; physiological (primary) deterioration which is the main effect on cassava roots and microbiological (secondary) deterioration. Physiological deterioration is an in-house occurrence called Post-harvest Physiological Deterioration (PPD). The microbiological deterioration results from the colonization of rot-causing organisms, softening of the roots or fermentation. Microorganisms such as *Fusarium, Cladosporium, Glomerella, Gloeosporium, Rhizoctonia, Pythium, Mucor, Rhizopus, Penicillium, Aspergillus, Bacillus, Xanthomonas, Erwinia, Agrobacterium* and many saprophytic bacteria are responsible for the deterioration in cassava. Their study highlighted approaches to delay bio-deterioration in cassava; rapid processing, pruning, traditional techniques and modern storage techniques are all mechanical approaches practised by farmers. Conventional breeding (improved varieties, genetic manipulation, speed breeding) and using transgenic approaches are genetic techniques for tackling bio-deterioration.

Sharma *et al*. (2022) studied major microorganisms that affect citrus crops in post-harvest and highlighted the appropriate methods to manage them. In addition to oomycetes, a large number of pathogens are responsible for bio-deterioration in citrus. Among them, *Phytophthora spp*., *Fusarium spp*., and postharvest pathogens particularly *Altenaria citri, Geotrichum candidum, Penicillium spp*., *Aspergillus spp*., etc. have been reported to be the major pathogens of citrus fruits during storage and this post-harvest loss experienced due to spoilage are responsible for declining the growth of citrus industries in some developing countries due to its quality and quantity loss. These micro-organisms have been found to cause diseases such as citrus canker, orange scab, citrus greening, leaf and fruit spot, moulds such as; blue, sooty and grey mould, rot such as; brown rot, phytophthora root rot, collar rot, citrus wither tip, in addition to biological agents that cause bio-deterioration in citrus certain pests including citrus aphid, citrus mealybug, fruit flies and woolly white flies contributes to bio-deterioration thereby limiting citrus production. The easiest control method for such harmful pests and diseases that cause deterioration relies entirely on the use of chemicals such as pesticides and insecticides with the inclusion of sanitation practices, cultural methods and integrated pest management practices.

Prevention and control of Bio-deterioration

Bio-deterioration can be effectively controlled or prevented by a proper understanding of the genetic make-up of the product/material and the possible spoilage organisms and mechanisms that help them thrive on such product (Featherstone, 2008). Bio-deterioration is a result of either separate or combined activities of several organisms on different substrates and under different ecological conditions, therefore the prevention and control require the combined knowledge from different branches of biology, biochemistry, chemistry, physics-chemistry, etc. (Dunca *et al*., 2014). The methods of controlling or preventing bio-deterioration range from simple cultural practices to advanced applications of biotechnology and nanotechnology. Mohammed and Kuhiyep (2020) recommended the removal of dirt's dirt-carrying germs and cooling of the tomatoes after harvest by quickly washing the tomatoes with clean or chlorinated water thoroughly, safe handling during harvest and using the appropriate harvesting tools/equipment to prevent punctures informing of bruises and scars or other mechanical injuries and refrigeration. Refrigeration however is a major challenge in developing countries like Nigeria where the power supply is epileptic. Sridhar *et al.* (2021) studied food wastage as a result of bio-deterioration and reviewed several food preservation techniques including nanotechnology to increase the shelf life of vegetables, fruits, beverages and spices. Heat or thermal treatment was one of the novel techniques listed for food preservation, used extensively in various food sectors; from fruits, vegetables, dairy and bakery (Wurlitzer *et al*., 2019; Gharibi *et al*., 2020; Prieto-Santiago *et al*., 2020; Christiansen *et al*., 2020). Others are cooling and freezing used to maintain all the quality attributes of leafy vegetables, spices and milk products. The freezing techniques used include cryogenic, direct contact and immersion freezing, and air blast, while advanced freezing techniques include electromagnetic disturbance freezing, dehydration freezing, high-pressure freezing and ultrasound-assisted freezing, (Cheng *et al*., 2017; Barbosa de Lima *et al*., 2020). The ultrasound treatment technique is versatile; it involves the passing of high-intensity sound waves and has been applied in different sectors ranging from the food industry, medicine, and to healthcare (Dai and Mumper 2010). Ozone treatment technology has been on the increase since its inception due to ozone's diverse properties and quick disintegration (Sridhar *et al*., 2021). The compound is a good antimicrobial and antiviral agent because of its high oxidation potential (Fisher *et al*., 2000; Nakamura *et al*., 2017). This technique in combination with ultrasound has been used to maintain the quality of cabbages (Mamadou *et al*., 2019). Pulse electric field technology is a pre-drying treatment that could be considered a substitute for thermal drying and could enhance food drying because of its very low-temperature requirement to function and a shorter residence time for the treatment of foods (Barba *et al*., 2015; Wiktor *et al*., 2016; Sridhar *et al*., 2021). The use of pulse electric fields has grown rapidly over the years in all food sector areas, especially in fruits. It has been successfully applied in the preservation of Blueberries (Yu *et al*., 2017), Date palm fruit (Yeom *et al*., 2004; Siddeeg *et al*., 2019), Apple juice (Wibowo *et al*., 2019); Salehi, 2020), Red beet (Luengo *et al*., 2016), Olive paste (Tamborrino *et al*., 2020) and Clover sprouts (Gała̜zka-Czarnecka *et al*., 2020). Nanotechnology is the most recent concept in food preservation and has enhanced the processing and formulation of flavours, additives, preservatives, colourants, sensors and food supplements (nano-encapsulation and nano-emulsion) in both plant and animal products (He *et al*., 2019). The introduction of nano-sensors in food processing industries was a result of its successes in other fields and nano-materials have revealed several electrochemical and optical properties in different beverages, sauces, oils and juices (Sridhar *et al*., 2021). Different nano-materials have been applied as sensors in different food industries - edible oils in bakery industry (Delfino *et al*., 2020), mixed fruit juices (Ye *et al*., 2020), Potato, onion and cabbage (Naser-Sadrabadi *et al*., 2020), skimmed milk (Echegoyen *et al*., 2016; Nguyen *et al*., 2020), soft drinks (Pradela-Filho *et al*., 2020), Milk (Goud *et al*., 2020; Nguyen *et al*., 2020), chilli sauce (Zou *et al*., 2020), water (Tian *et al*., 2020), clove and green tea extracts (Madhusudhana *et al*., 2020) and honey (Ye *et al*., 2020).

In Sridhar *et al*. (2021), pathogen reduction and maintaining the nutritional quality and physicochemical properties of the product were achieved through electro-thermal, freezing and pulse electric field methods. On the other hand, to preserve heat-sensitive foods, ultrasound technology and ozone treatment were recommended suitably while nanoparticles and polymer-based composites have proven to be the best solutions in food and crop preservation (Auffan *et al*., 2009; Joshi *et al*., 2019). Why nanotechnology is preferred because it possesses different properties like precise action on active sites, slow release action, target specific nature, and high surface area (Joshi *et al*., 2019). The reason for the successes recorded with the application of nanotechnology is due to its energy efficient, less space requirements, no pollutant release and a lot of promising results. Nanotechnology has also shown versatile applications in terms of risk assessment in areas of agriculture, food and environment, safety and toxicity (Sridhar *et al*., 2021).

Conclusion

Bio-deterioration is an inevitable natural phenomenon with a huge cost to man. It is capable of frustrating human development, especially global food security and programmes. Bio-deterioration in different facets including scope, products affected, causative agents, mode of action, etc., have been reviewed. Because of the dimension of this natural challenge, man has devised means of minimizing its effects and has also continued to improve upon them. Some of these methods which range from simply cultural practices to advanced techniques like nanotechnology were also reviewed. This review has also shown that man cannot rest on his oars now but keeps on looking for better ways of tackling this problem.

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