CARPATHIAN JOURNAL OF FOOD SCIENCE AND TECHNOLOGY

journal homepage: **http://chimie-biologie.ubm.ro/carpathian_journal/index.html**

MICROORGANISMS RESPONSIBLE FOR DETERIORATION OF FOOD PRODUCTS: REVIEW

Çağla Pınarlı[1], Fatih Tarlak[1]✉

[1]*Istanbul Gedik University, Faculty of Health Sciences, Department of Nutrition and Dietetics, Istanbul, Turkey*
✉*ftarlak@gtu.edu.tr*

https://doi.org/10.34302/crpjfst/2022.14.4.16

Article history:
Received
16 January 2022
Accepted
16 July 2022
Published
December 2022

Keywords:
Food spoilage;
Spoilage microorganisms;
Bacterial spoilage;
Yeast;
Mold.

ABSTRACT
Every year, tons of food is thrown away because of changes in odor, taste, texture or color. Food spoilage has a very important effect at this point. Microorganisms have a significant position in food spoilage. The type of microorganisms seen varies depending on factors such as the amount of water, acidity, carbohydrate, protein or fat ratios of foods, packaging type, and oxygen levels. In this section, basic organisms that cause food spoilage (bacteria, mold, yeast) and microorganisms that are effective in specific food groups (meat products, poultry products, dairy products, seafood products, egg products, cereal products, fruits and vegetables) are covered. Approaches to reduce spoilage organisms are as important as identifying spoilage organisms. Therefore, recommendations for controlling and preventing spoilage organisms are also included in this section.

1.Introduction

People need food to grow, develop, protect and maintain health, and meet their daily macro and micronutrient requirements. At this point, some problems may be experienced in reaching healthy and delicious foods. Food spoilage is one of these problems (Hammond *et al.*, 2015). Food spoilage is a metabolic process that adversely affects food consumption due to changes in sensory properties. Deteriorated foods can be consumed safely, in other words, since there are no pathogens or toxins, consuming these foods may not cause any disease. On the other hand, food spoilage causes the rejection of nutrients by changes in texture, odor, taste, or appearance. It is thought that this situation is created especially by microorganisms. So, the food is rejected by the animals and the microorganisms keep the food source for themselves (Burkepile *et al.*, 2006).

Among the main causes of food spoilage are physical changes that occur in situations such as transportation and storage. Animals such as insects or rodents also cause food spoilage. Exposure to chemicals and autolytic enzymes are also important risk factors for food spoilage. In addition to all these, microorganisms that facilitate the effect of all these factors on the food can also affect the quality and texture of the food. Certain species from different organisms found in food cause this spoilage. At this point, the physical qualities of the food have an important effect. These are water content, pH, temperature, gaseous conditions, texture, and nutrients (Modi, 2009).

Considering the water content, the probability of spoilage of food rises as the number of water increases. Foods with a higher water content are susceptible to spoilage by a wide variety of organisms. Therefore, the drying process is used to prevent food from spoiling (Kayacan Çakmakoğlu *et al.*, 2020). When the water content of different foods is examined, it has been observed that foods such as skim milk, strawberries, watermelon, and spinach have a water content of 90% and above. Foods such as fruit juices, yogurt, oranges, and carrots contain 80-89% water. Foods such as banana, avocado, baked potato, cottage cheese have a water content near 70-79%. Foods such as legumes, pasta, chicken breast, salmon, ice cream contain 60-69% water. Foods such as minced meatballs and sausage contain 50-59% water. Foods such as bread, bagels, cakes, and biscuits contain 20-39% water. Butter and margarine have 10-19% water content, while oils and sugar have 0% water content (Baker *et al.*, 2014).

When the pH is evaluated; the pH value of food limits the microorganisms that can grow. Foods can be spoiled by the growth of a wide variety of organisms, the effect of which is to change the flavor, texture and appearance of the affected item. At this point, the acidity of food with an acidic pH can be changed and microorganisms that can grow in acidic pH can be prevented. Thus, food spoilage can be prevented. The spoilage of canned foods also depends on the pH all contain after heat treatment (Ratzke and Gore, 2018). While more fungal growth in acidic foods, more bacterial growth occurs in fruits and vegetables with pH value above 4.5 (Rawat, 2015).

When the temperature is evaluated; especially molds and yeasts grow best at room temperature. When the tissue is evaluated; fluid and solid-liquid mixed foods spoil quickly. Solid foods begin to degrade from their outer surfaces. When the food is evaluated; foods rich in protein are more attacked by proteolytic organisms. Foods rich in carbohydrates are more prone to attack by fermentative organisms. Fat-rich foods tend to be attacked by lipolytic organisms. In the gaseous conditions; the oxygen tension and oxidation-reduction state of the food directly affect the microorganisms that cause food spoilage. The degradation by aerobic organisms occurs on the surfaces of foods (Modi, 2009).

Food losses from farm to fork have environmental and economic impacts. According to the Food Waste Index 2021 report, 17% of the food produced is wasted before it reaches the consumer. In this case, it is thought that at least 40% of the food produced is wasted. In numerical terms, it is thought that 2.5 billion tons of food are lost or wasted annually. 44% of these foods are fish and seafood, 26% fruits and vegetables, 15% roots, tubers and oil crops, 14% cereals and pulses, 12% meat and animal products and 6% consists of other foods (WWF-UK, 2021). At this point, the importance of food losses in fighting hunger and improving food security comes to the fore, especially in poor countries around the world. It is affected by factors such as food production conditions, transportation, distribution conditions and infrastructure. These preventable food losses directly or indirectly influence the financial situation of both farmers and consumers negatively. Food spoilage and loss also have environmental effects. When a certain percentage of the product is lost, the fertilizer, water and energy used to grow that crop are also wasted at the same rate (Rawat, 2015). While the water footprint spent for the production of 1 kilogram of red meat is more than 15,000 liters on average, the water used for the production of 1 kg of eggs is 3,265 liters, and the water footprint for 1 kg of wheat is 1,827 liters (Mekonnen and Gerbens-Leenes, 2020).

2. Food Spoilage Microorganisms

Spoilage of food; it is defined as the loss of qualitative characteristics in terms of color, taste, texture, smell, or shape in foods. At this point, various microorganisms cause chemical reactions that cause disturbing sensory changes in foods. These microorganisms use food as a source of carbon and energy. Microorganisms that cause food spoilage are bacteria, yeasts, and molds (Gram *et al.*, 2002).

2.1. Yeast

Yeasts are a subset of a large group of organisms, including molds and fungi. These are generally adapted to living in liquid environments. Yeasts can reproduce with or without oxygen. It also plays an important role in the formation of bread and alcoholic beverages through fermentation. It is known that food spoilage caused by yeast does not directly lead to infections or toxic product formation in humans. But the simultaneous growth of other microorganisms can cause these problems (Barnett *et al.*, 2000).

2.1.1. Zygosaccharomyces and related genera

Zygosaccharomyces and its species *Lachancea*, *Torulaspora* and *Zygotorulaspora* generally affect high sugar and high salt foods (Barnett *et al.*, 2000). Yeasts also affect wine and cause significant economic losses as these produce negative organoleptic properties in wine (Kuchen *et al.*, 2021). Because these species can grow slowly, it can take months for food to deteriorate. The most obvious problem seen in spoiled products is the accumulation of carbon dioxide in the package of the product. This species can also cause food staining, foul odor and taste (Grinbaum *et al.*, 1994).

2.1.2. Saccharomyces and related genera

Saccharomyces cerevisiae and *Saccharomyces bayanus* are involved in the fermentation of alcoholic beverages (Parapouli *et al.*, 2020).

S. cerevisiae and *Saccharomyces exiguus* have a position in the fermentation of cereal products (Rose and Harrison, 1993). *Saccharomyces* species generally have positive effects on food. But some species produce high amounts of hydrogen sulfide and acetic acid. In this case, the raw material is wasted. Regrowth of *S. cerevisiae* or *S. Bayanus* in beer or wine causes turbidity and off-flavor (Oda and Ouchi, 2000).

2.1.3 Candida and related genera

Candida is an asexual, imperfect and anamorphic yeast genus. Candida is the nomenclatural type genus of the family *Candidaceae*. Candida species make up about a quarter of all known yeasts. *Candida* is a type of yeast that also causes infections in humans (Blackburn, 2006). It is known that *Candida* species have effects especially on milk and dairy products, fruits and vegetables. Nearly 24 different candida species were affected by the deterioration of milk and dairy products (Tomičić *et al.*, 2017).

2.1.4. Dekkera/Brettanomyces spp:

These mainly cause an undesirable and repellent taste in wines. *Dekkera/Brettanomyces* also play a role in the spoilage of dairy products and fermented foods. Judging by its effect, it produces volatile phenolic compounds that cause bad taste (Couto *et al.*, 2005).

2.2. Molds

Molds are filamentous fungi that are most visible to the naked eye and do not form fruit bodies. Molds are involved in the recycling of dead plant and animal remains in nature. These are well adapted to growth on and through solid substrates. These need oxygen for their metabolic processes to take place. Most molds can grow in both acidic and basic environments. In addition, molds can grow in dry foods in very low levels of water activity. Their spores are resistant to harsh environmental conditions. These are generally sensitive to heat treatment, with some exceptions (Carlile *et al.*, 2001).

2.2.1. Zygomycetes

Zygomycetes reproduce in soil and dead plant material. These are also a good source of fertilizer and generally scavenge simple carbon sources rapidly. Many *Zygomycetes* are associated with living organisms as parasites or mycorrhizal fungi. These can infect many insect species and microscopic creatures as parasites (Martin *et al.*, 2004). *Zygomycetes* are most associated with food spoilage; *Absidia*, *Mucor* and *Rhizopus* genera. Ecologically, these reproduce in soil, plant residues and manure. *Rhizopus* and *Absidia* species are found in cereals, fruits and vegetables, and meat and dairy products (Hesseltine, 1991).

2.2.2. Penicillium and related genera

Fungi belonging to the *Penicillium* genus are among the most common microorganisms. It is hardly to find an area that does not contain penicillium spores. Interestingly, *Penicillium* species showed that these are substrate-specific. Some *Penicillium* species do not cause spoilage because their growth is limited. However, *Penicillium* species are a major cause of food spoilage. It can cause food spoilage in fruits, vegetables and grains (Blackburn, 2006).

Penicillium spp. also causes deterioration in foods such as butter, margarine, cheese (Garnier *et al.*, 2017).

2.2.3. *Aspergillus* and related teleomorphs

The genus *Aspergillus*, which includes approximately 350 species, is very important for public health (Bennett, 2010). *Aspergillus* spores can also survive in extremely harsh environmental conditions where usual mold growth would not occur (Pagano *et al.*, 2010). The genus *Aspergillus* is an important genus. The reason for this is that while it causes spoilage in foods, it also produces mycotoxins. This genus is quite common in products such as cereals, nuts, and spices. *Aspergilli* can generally thrive even at higher temperatures or lower water activity than *Penicillia*. *Aspergillus* species are more prominent in the tropics, while *Penicillium* species are more common in temperate regions (Hocking, 2006).

2.3. Bacteria

2.3.1. *Pseudomonas* and related genera

Pseudomonas, *Shewanella*, and *Xanthomonas* are among the bacteria that have the widest effect on food spoilage (Tarlak and Pérez-Rodríguez, 2021). These can be found in many environments such as soil and water. *Pseudomonads* have a very important place in aerobic degradation and biological degradation. Therefore, its effects on the environment are undeniable. *Pseudomonas fluorescens*, *Pseudomonas lundensis*, *Pseudomonas viridiflava* and *Pseudomonas fragi* are species that are particularly associated with food spoilage. When foods are spoiled, these cause a visibly watery and sticky structure and an unfavorable odor (Andreani ve Fasolato, 2017).

2.3.2. Lactic acid bacteria

Lactic acid bacteria are closely related to food fermentation and food spoilage. These bacteria are especially encountered in environments with vacuuming or modified atmosphere, low pH and low temperature, low oxygen content. It is the main microbial group that emerges under vacuum or modified atmosphere conditions (Kalschne *et al.*, 2015). Some lactic acid bacteria have a strong tolerance to salt and sugar. In a study, the most resistant species to salt was *Lactobacillus delbrueckii* subsp. bulgaricus was identified (Kwun *et al.*, 2020). Lactic acid bacteria also include *Lactobacillus*, *Pediococcus*, *Leuconostoc* and *Oenococcus* species that are useful in the production of fermented foods such as yogurt and pickles. In undesirable formations due to lactic acid bacteria, problems such as greening in the color of meat, mold formation in cheese, swelling in pickles appear. Lactic acid bacteria can produce exopolysaccharides that cause degradation (Audenaert *et al.*, 2010).

2.3.3. Spore-forming bacteria

Many of the spore-forming bacteria are important causes of food spoilage. These bacteria, which have more than 200 species, have a role in the deterioration of heat-treated foods because these can survive at high temperatures. Because spores can survive at high temperatures**.** These bacteria, which have resistance to environmental factors, wait in a dormant state when there is no suitable opportunity. When suitable conditions occur again, these continue their normal metabolism. These Gram-positive bacteria can be strict anaerobes or facultative (growth with or without oxygen) (Ande *et al.*, 2017). In foods kept at high temperatures, these bacteria produce species-specific hydrogen sulfide, hydrogen or carbon dioxide. In particular, these are a significant risk factor for the deterioration of milk and dairy products (Gopal *et al.*, 2015).

2.3.4. Enterobacteriaceae

Enterobacteriaceae are gram-negative, facultative anaerobic bacteria. Many organisms such as *Salmonella*, *E. coli*, *Shigella*, *Yersinia* are included in this group. These bacteria are common in soil, plant surfaces and the digestive systems of animals**.** *Enterobacteriaceae* is associated with pneumonia, especially in elderly individuals. In addition to their negative health effects, some members of this family are responsible for significant economic losses in some sectors of the food industry (Jenkins *et al.*, 2017).

Some microorganisms are common in many types of spoiled food, while others are less common. More than one species can often be identified in a single spoiled foodstuff. However, it may be a dominant species that is primarily responsible for the production of compounds that cause a difference in odor or taste. At this point, the basic indicator is the substance that becomes usable or depleted in the spoiled food. Thus, the microorganism population inside can increase or decrease (Gram *et al.*, 2002). In this review, food spoilage in many foods and food groups (meat products, poultry products, dairy products, seafood products, egg products, cereal products, fruits and vegetables) will be evaluated under headings

3. Spoilage Organisms in Meat Products

Degradation in meat products is one of the significant issues. Searching for the words (spoilage) and (meat) on PUBMED revealed that 1682 different articles have been published since 1947. While only certain microorganisms were identified in the beginning, hundreds of different species have been recognized today (Zhao *et al.*, 2015). The deterioration of meat products causes significant economic losses every year (Teixeira *et al.*, 2020).

Normally the muscle tissue of healthy animals is sterile, but a large number of microorganisms are seen after slaughter. Moreover, processes such as transportation and storage are also associated with the growth of microorganisms that cause degradation. The determination of these microorganisms and their growth conditions is important for the solution of the problem. Deterioration gene markers in microorganisms that cause spoilage are also being investigated (Mohareb *et al.*, 2015). Meat spoilage includes changes in the composition and sensory quality of meat. These changes are divided as enzymatic and non-enzymatic. Microorganisms are responsible for the deterioration of meat using macronutrients and other nutrients in meat. As a result, different metabolites are produced (Wang *et al.*, 2017).

Microorganisms in the degradation of red meat are molds, yeasts and bacteria. Bacteria are especially involved in the deterioration of raw meat. Molds and yeasts are more prominent in baked foods which have low moisture. However, degradation by molds and yeasts appears to be rare (Zhao *et al.*, 2015). The spoilage bacteria in red meat include Gram-negative Pseudomonas, *Acinetobacter*, *Psychrobacter*, *Aeromonas*, *Shewanella putrefaciens*, *Enterobacteriaceae*; Gram-positive lactic acid bacteria and *Brochothrix thermosphacta* (Ercolini *et al.*, 2011). There are also other bacteria responsible for spoilage. *Achromobacter* is a gram-negative bacteria. *Achromobacter* species can grow even at low temperatures, especially in pork sausage. Moraxella is particularly found in animal mucus. Although it has a low percentage of meat spoilage, it can be seen in vacuum-packed pork products (Li, 2006). As a gram-negative bacterium, *Psychrobacter* can grow at low temperatures. Clostridium can be seen especially in vacuum-packed products (Huang *et al.*, 2018).

Packaging conditions also have a direct effect on the deterioration of red meat. It has the positive outcome of removing dioxygen in packaging to delay the occurrence of spoilage. In the presence of dioxygen, the carbon dioxide ratio in gas mixtures directly affects the deterioration (Luong *et al.*, 2020). Temperature is another basic factor that is associated with degradation. Microorganisms need the optimal temperature to grow. For bacteria, this temperature range is 4–60 °C. As a result, meat products should be kept below 4 °C to prevent spoilage (Ercolini *et al.*, 2011). In PCR-denaturing gradient gel electrophoresis analysis to assess bacterial contamination sources, the bacterial diversity of cattle and sheep slaughter lines was significantly different. The reason for this is thought to be due to the hand slaughter of sheep. Salmonella enterica was observed most frequently in sheep with 30% and beef with 28%. It has been observed that the risk of salmonella contamination is significantly reduced by washing carcasses (Fletcher *et al.*, 2018).

3.1. Control and Prevention of Spoilage Microorganism in Meat Products

Physical (low temperature, high temperature and high pressure), chemical and microbiological methods can be used for the preservation of meat products. First, when looking at the physical methods; chilling is the reduction of the carcass temperature to the appropriate temperature for storage without the formation of ice crystals. Rapid carcass cooling has a reducing effect on microbial growth. Freezing is one of the most effective methods. Since both temperature and water activity decrease, it is effective in preserving meat without spoiling. Many microorganisms are destroyed by exposure to high temperatures (Tarlak, 2021). Another method used to preserve meat is drying. In drying, which is one of the old traditional methods, water is removed. In this way, microbial growth is prevented. Exposing meat to radiation is one of the most effective protection methods. The applied radiation can break down and destroy the DNA of microorganisms. In this way, it allows dealing with microorganisms. Packaging meat products is another effective method of protecting against spoilage effects (Triki *et al.*, 2018).

Looking at chemical methods; in ancient times, when refrigerators were not available, the way of curing meat was often used. Today, curing is done by adding substances such as sodium, potassium chloride, sodium nitrite to raw meat (Teixeiria *et al.*, 2019). Health concerns, especially with the addition of nitrites and nitrates, are still a major concern (Sebranek ve Bacus, 2007). At this point, the search for natural products appeared. Recently, essential oils as a natural product have attracted attention with their antimicrobial potential. Moreover, these essential oils have benefits for human health. Essential oils have antioxidant effects. It is thought that more data are needed to use essential oils as preservatives in meats (Chivandi *et al.*, 2016).

Finally, looking at the microbiological methods; The fermentation of meat, as a traditional method, has a protective effect against microorganisms. However, it gives a different flavor, color and texture to the product. Lactic acid is responsible for the antimicrobial properties of fermented meats. This formation occurs from the conversion of glycogen reserves in the carcass tissues and the sugar added during fermentation (Di Gioia *et al.*, 2016).

4. Spoilage Organisms in Poultry Products

Microorganisms have an essential place as the main factor causing deterioration (Tarlak and Khosravi-Darani, 2021). Microorganisms are seen in the feathers, skin, feet, and feeding ways of poultry. Various processes performed on these creatures generally reduce microbial contamination. But cross-contamination from the environment can be seen. In addition, processes such as transportation and storage may result in the formation and degradation of microorganisms (Wang *et al.*, 2017).

Campylobacter spp. and *Salmonella* spp. has a high risk in poultry products. Other main microorganisms responsible for degradation in poultry are pseudomonads and other Gram-negative bacteria. Apart from these, Acinetobacter is another organism responsible for spoilage in poultry carcasses (Barnea and Thornley, 1966). Yeast formation in poultry carcasses has also been described. *Candida, Cryptococcus, Debaryomyces* and *Yarrowiawere* species were identified in carcasses (Zhang *et al.*, 2012). Chicken liver is one of the perishable products. *Pseudomonas* spp. found to have an effect mainly. *Salmonella* managed to survive at 0 °C in chicken liver (Dourou *et al.*, 2021).

4.1. Control and Prevention of Spoilage Microorganism in Poultry Products

High-temperature exposure is one of the most effective methods for the control of microorganisms in poultry. In addition, hot water, chlorine, organic acid, or different chemicals have positive effects on the control and prevention of microorganisms (Wang *et al.*, 2017). Trisodium phosphate has been shown to reduce spoilage-causing bacteria. Moreover, it takes place without affecting the sensory quality of the products (Hinton and Ingram, 2005).

5. Spoilage Microorganisms in Seafood Products

Seafood is one of the foods that have the risk of perishable quickly. The spoilage of seafood is closely related to the composition of the microbiota. Factors such as the aquaculture environment and storage temperature affect this microbiota (Zhuang *et al.*, 2020). In addition to these, storage conditions, packaging atmosphere and preservatives also affect the microbiota in seafood (Sørensen *et al.*, 2020).

During the storage of seafood, carbon and nitrogen-derived compounds are metabolized. This situation is closely related to the formation of microorganisms. Structural proteins are hydrolyzed to peptides and amino acids. At this point, microbial proteases are involved (Zhuang *et al.*, 2019). The peptides produced are transferred to bacterial cells. The resulting amino acids result in the production of amines such as ammonia in the cytostome. Among the amino acids found in seafood, those containing sulfur, branched chains and aromatic amino acids are effective in microbial deterioration and malodor formation (Biji *et al.*, 2016).

Bacteria such as *Photobacterium*, Psychrobacter *Pseudomonas* are abundant in the intestines of fish (Shehata *et al.*, 2020). Gram-negative bacteria are more common in seafood grown in temperate waters. Gram-positive bacteria predominate in seafood grown in tropical environments (Françoise, 2010). *Vibrio* and *Pseudoalteromonas* are important microorganisms responsible for degradation in shellfish (Madigan *et al.*, 2014). In the following stages, the dominant microorganism changes. The main reason is that shellfish have a high carbohydrate content (Fernandez-Piquer *et al.*, 2012). In dried seafood, *Aspergillus niger*, *Cladosporium cladosporioides* and *Penicillium citrinum* are responsible for degradation (Park *et al.*, 2014).

5.1. Control and Prevention of Spoilage Microorganism in Seafood

Products Packaging method in seafood is one of the essential factor in preventing microorganisms. At this point, modified atmosphere packaging was found to be more successful than vacuum packaging in seafood (Aberoumand and Baesi, 2020). It has been observed that the CO_2 content in packaging has positive effects on preventing bacterial growth. Traditional preservatives such as salt and chemical additives can be used to store seafood (Olatunde *et al.*, 2020). Recently, due to health concerns, phytochemicals have been used as preservatives instead of chemicals ***(***Ribeiro-Santos *et al.*, 2017). As in meat products, essential oils come to the forefront as a protector against microbial degradation in seafood. Freezing, smoking, high pressure, dehydrating, ozone and ionizing radiation are also helpful preservatives which are used in seafood products (Wang *et al.*, 2017).

6. Spoilage Microorganisms in Dairy Products

Milk and dairy products are nutritious foods with the proteins, essential amino acids, oils, minerals and vitamins these contain. However, this content is also suitable for the growth of different heterogeneous microorganisms (Fusco *et al.*, 2020). Psychrotrophic microorganisms, *pseudomonads*, gram-negative and rod-shaped bacteria are the predominant microorganisms seen in raw milk. Pasteurization has an extensive effect on food safety. However, *Pseudomonas* and Acinetobacter spp. microorganisms such as can produce proteases and lipases even after pasteurization. Global warming is also one of the important risk factors at this point. Because of that, the risk of mycotoxin increases in milk and dairy products (Fusco *et al.*, 2020).

It is known that fungi also alter the deterioration of dairy products. In particular, these microorganisms are responsible for the formation of undesirable odor, color and taste. Coliforms, heterofermentative lactic acid bacteria, yeasts and spore-forming bacteria can cause gas formation in cheese. Methods such as the type of microorganisms that deteriorate, production, processing, packaging, storage, transportation have an impact. When the microorganisms in different milk and dairy products are examined; There are especially *Psychrotrophs*, spore formers in pasteurized milk. Spore-forming bacteria and osmophilic fungi are dominant in concentrated dairy products. Butter *Psychrotrophs,* cottage cheese *Psychrotroph*s, coliforms, yeasts, molds are dominant. Yeasts predominate in yogurt, fungi and coliforms in other fermented milk products. While fungi and spore-forming bacteria are common in cream cheese and processed cheese, Psychrotrophs, coliforms, fungi, and lactic acid bacteria are dominant in fresh cheese (Ledenbach and Marshall, 2009).

6.1. Control and Prevention of Spoilage Microorganism in Dairy Products

Heating milk to high temperatures kills most pathogenic bacteria and spoilage bacteria. The filling equipment of milk and dairy products must be sterile (Ledenbach and Marshall, 2009). Exposing the milk to high hydrostatic pressure, in particular, ensures the destruction of many bacteria. Spores are more resistant at this point (McClements *et al.*, 2001). Pasteurization eliminates the risk of most psychrotrophic microbes, coliforms, *leukonostoks* and many *lactobacilli*. Pasteurized milk has a limited shelf life due to the formation of psychrotrophic contaminants. Lactic acid bacteria are effective here and cause the formation of a sour taste (Erkmen and Bozoglu, 2016).

Freezing inhibits microbial growth and enzyme activity. Therefore, the microbial degradation in frozen desserts is thought to be due to previous contamination. Pasteurization of milk destroys most of the acid-forming bacteria. Heat-resistant bacteria can survive. During the ultra high temperature processing (UHT) procedure, contamination of spore-forming bacteria can be seen (Ledenbach and Marshall, 2009).

7. Spoilage Organisms in Egg Products

Eggs are a powerful food both economically and nutritionally. Eggs contain essential oils, protein, vitamins and minerals. Egg; It is the lowest cost animal food for protein, vitamin B12, vitamin A, iron, choline, riboflavin. It is the second-lowest cost animal food for zinc and calcium. The egg has an average of 76.1% water. Looking at the macronutrients; It contains 12.6% protein, 9.5% fat and 0.7% carbohydrates (Réhault-Godbert *et al.*, 2019). When looking at the microorganisms in the egg, Gram-positive bacteria such as *Staphylococcus*, *Streptococcus*, *Aerococcus* and Micrococcus are seen in the egg shell. Apart from this, bacteria such as Salmonella and Escherichia draw attention. Gram-positive bacteria predominate on the eggshell surface. Gram-negative bacteria are responsible for degradation in egg content. When eggs and egg-containing foods are spoiled, a black or green color change is usually observed with the formation of a foul odor (De Reu *et al.*, 2006).

Salmonella is responsible for more than half of all microbial outbreaks. It is also the pathogen associated with an increased risk of death and the most frequently reported pathogen responsible for 81% of deaths. Potential risk in a *Salmonella* outbreak was found to be egg-containing foods and equipment contaminated with eggs (Gurtler *et al.*, 2015).

Bacillus cereus has been found in raw and pasteurized eggs and bakery products made from them. This microorganism draws attention with its ability to form spores and survive at low-temperature treatments (Reis *et al.*, 2014). *Campylobacter*, as another microorganism, is transmitted mainly through poultry. It is seen in unpasteurized eggs and their products (Sato and Sashihara, 2010). 17.4% of raw egg products were found to contain Listeria (Rivoal *et al.*, 2010). As a result of the analysis of 1125 eggs, Staphylococci were found in 45.6% of them (Stepień-Pyśniak *et al.*, 2009).

7.1. Control and Prevention of Spoilage Microorganism in Egg Products

Heat treatment has an important position in the destruction of microorganisms in egg products. It is adequate to be exposed to heat between 65-68 °C for 5-6 minutes. In egg white, shorter time and lower temperature are sufficient. Methods such as adding sugar or salt and drying are also effective in preventing deterioration. Again, the realization of the right storage conditions has positive effects in preventing and controlling the deterioration of eggs and egg-containing products (Techer *et al.*, 2014).

8. Spoilage Organisms in Cereal Products

Grains are often contaminated with microorganisms during collection, transportation and storage**.** Microorganisms can be encountered in many situations and conditions. Moreover, many microorganisms can adversely affect health. When looking at cereal products, food poisoning is very rare. At this point, the underlying factor is thought to be the high temperature applied during cooking and the low amount of water associated with it (Cook and Johnson, 2009). Although food poisoning seems rare, the taste of cereal products changes after degradation by microorganisms and may become unusable. Molds can cause defective odor in grain products. In addition, mycotoxins may form. This may cause adverse health effects (Gupta and Srivastava, 2014). Humidity, temperature and oxygen are the most effective factors in the degradation of grains and the growth of microorganisms. The dominant bacteria occurring in cereals belong to the families of *Pseudomonadaceae*, *Lactobacillaceae*, *Micrococcaceae* and *Bacillacea*e. Molds are predominantly *Alternaria*, *Helminthosporium*, *Fusarium*, and *Cladosporium*.

8.1. Control and Prevention of Spoilage Microorganism in Cereal Products

Different methods such as ozone, radiation, antimicrobial agents are used to reduce microorganisms in cereals. Recently, the hazard analysis system of critical control points has been implemented to ensure food safety (Hulebak and Schlosser, 2002***)*.** Grinding in cereal products can reduce microbial formation. However, molds and some microorganisms may remain inside. Especially whole wheat flour and foods made from this flour are at higher risk in terms of microorganisms, since their bran is not separated. As a newer method, superheated steam pasteurization is one of the prominent microorganism control methods in grain products (Wang *et al.*, 2017).

Yeast is more resistant to disinfectants and preservatives. For this reason, quaternary ammonium can be preferred for surface cleaning. Packaging grain products quickly after cooking is one of the methods that can prevent mold contamination. This will prevent different microorganisms that may come from the environment. Packaging in a sterile atmosphere after cooking may be preferred (Saranraj, 2012).

Antimicrobial preservatives can be used, especially for bacteria, to ensure food safety. Examples of these are sorbic acid, calcium propionate and potassium sorbate. These are used especially in the bread production stage. Vinegar and malic acid can also be used to prevent acid degradation. Because these products will lower the pH. Spices with antimicrobial properties such as cinnamon and black pepper can also be added. In addition, starch can be added to the grain product to reduce the amount of water (Jay, 2012).

9. Spoilage Organisms in Fruits and Vegetables

Fruits and vegetables are basic sources of fiber, vitamins and minerals. Because of its high-water content, pathogens can easily develop in fruits and vegetables (Blackburn, 2006). Fruits and vegetables are very abundant in nutrients. In addition, vegetables have a pH value close to neutral. The natural acidic structure of fruits protects food from many microorganisms, especially bacteria. Fungi are responsible for the degradation of both fruits and vegetables. Fungi from microorganisms generate extracellular pectinases and hemicellulases for degradation (Miedes and Lorences, 2004).

Storage and transportation conditions are critical in the prevention of microorganisms. *Penicillium expansum* and *Botrytis cinerea* must be removed from the fruit before storage. If it is not removed, it may cause deterioration in other fruits. These appear, especially in pectin-rich fruits (van Kan, 2006). *Erwinia carotovora* subsp. *carotovora* is responsible for the degradation of fruits and vegetables (Lund, 1982).

Viruses, bacteria and fungi have different roles in degradation. Fungi, in particular, are responsible for mycotoxin growth (Marin *et al.*, 2013). Decay is mostly caused by fungi and bacteria. Rot and discoloration of citrus fruits are associated with *Penicillium digitatum* and *Penicillium italicum* molds (Caccioni *et al.*, 1998). *Colletotrichum musae* is a microorganism that is particularly effective in the blackening of bananas (Zakaria *et al.*, 2009). Food decay can often be seen in foods such as pears and apples. *Botryosphaeria obtusa* and *Physalospora cydoniae* are dominant in these fruits. In grapes, *Erysiphe necator* is responsible for degradation. Differences in color changes seen in fruits vary according to the type of microorganism (Wang *et al.*, 2017). In a study, it was seen that the most common fungi in fruits and vegetables were Penicillium and then Rhizopus (Saleh and Al-Thani, 2019).

9.1. Control and Prevention of Spoilage Microorganism in Fruit and Vegetables

It is tried to protect freshly cut fruits and vegetables by methods such as hot water, hot steam and hot sterilization. However, these heat treatments can cause deterioration of the quality of the product. Technologies that do not include heat treatment include physical and chemical processes. As physical processes, there are methods such as high pressure, ultraviolet radiation and ultrasound. As chemical processes, different liquid and gaseous forms (ozone and chlorine dioxide) are used to provide sanitation (Wang *et al.*, 2017). It has been observed that the application of ultrasound in fruits and vegetables reduces the microbial load and can prevent color change in the products (Roknul Azam *et al.*, 2020). Disinfectants are also used to destroy pathogens on the surfaces of fruits. Especially sodium hypochlorite, chlorine dioxide, ozone and chlorine dioxide are frequently preferred (Fukuzaki, 2006). As a natural alternative to chemicals, essential oils also have strong antimicrobial activity. Modified atmosphere packaging processes have emerged to prevent microbial growth by actively adding antimicrobial agents to packages (Gong *et al.*, 2016; Tarlak *et al.*, 2020).

Finally, ethylene has a significant effect on the deterioration of fruits and vegetables. Although studies on the subject are limited, it is thought that the use of ethylene scavengers in food packaging may be propitious (Wei *et al.*, 2021). Coating fruits and vegetables with aloe vera gel have a reducing effect on ethylene biosynthesis. Aloe vera coating can also prevent or delay processes such as softening, discoloration, rot (Hasan *et al.*, 2021).

10. Conclusions

In this review, the microorganisms responsible for deterioration of food products were comprehensively compared, and food preservation methods to minimize food spoilage were discussed in detail.

11. References

Aberoumand, A., & Baesi, F. (2020). Effects of vacuum packaging in freezer on oxidative spoilage indexes of fish *Lethrinus atkinsoni*. *Food science & nutrition*, *8*(8), 4145–4150.

Andreani, N.A., Fasolato, L. (2017). Pseudomonas and related genera. In: Bevilacqua A, Corbo MR, Sinigaglia M (ed), In Woodhead publishing series in food science, technology and nutrition, the microbiological quality of food. *Woodhead Publishing*, pp 25-59.

Audenaert, K., D'Haene, K., Messens, K., Ruyssen, T., Vandamme, P., & Huys, G. (2010). Diversity of lactic acid bacteria from modified atmosphere packaged sliced cooked meat products at sell-by date assessed by PCR-denaturing gradient gel electrophoresis. *Food microbiology*, *27*(1), 12–18.

Baker, L. B., & Jeukendrup, A. E. (2014). Optimal composition of fluid-replacement beverages.*Comprehensive Physiology*, *4*(2), 575–620.

Barnett, J.A., Payne, R.W., Yarrow, D. (2000). Yeasts: Characteristics and Identification. *Cambridge Univ Press:* Cambridge.

Bennett, J.W. (2010). An overview of the genus Aspergillus. In: Machida M, Gomi K (eds) Aspergillus Molecular Biology and Genomics, Caister. *Academic Press:* UK.

Biji, K. B., Ravishankar, C. N., Venkateswarlu, R., Mohan, C. O., & Gopal, T. K. (2016). Biogenic amines in seafood: a review. *Journal of food science and technology*, 53(5), 2210–2218.

Blackburn, C.W. (2006). Food spoilage microorganisms. *Woodhead Publishing:* UK

Burkepile, D. E., Parker, J. D., Woodson, C. B., Mills, H. J., Kubanek, J., Sobecky, P. A., & Hay, M. E. (2006). Chemically mediated competition between microbes and animals: microbes as consumers in food webs. *Ecology*, *87*(11), 2821–2831.

Caccioni, D. R., Guizzardi, M., Biondi, D. M., Renda, A., & Ruberto, G. (1998). Relationship between volatile components of citrus fruit essential oils and antimicrobial action on Penicillium digitatum and penicillium italicum. *International journal of food microbiology*, *43*(1-2), 73–79.

Carlile, M.J., Watkinson, S.C., Gooday, G.W. (2001). The fungi. *Academic Press:* London.

Chivandi, E., Dangarembizi, R., Nyakudya, T.T., Erlwanger, K.H. (2016). Use of essential oils as a preservative of meat, In: Preedy VR (ed) Essential oils in food preservation, flavor and safety. *Academic Press*, pp 85-91

Cook, F.K., Johnson, B.L. (2009). Microbiological spoilage of cereal products. In: Sperber WH, Doyle MP (eds), Compendium of the Microbiological Spoilage of Foods and Beverages, *Springer:* New York, pp. 223–244.

Couto, J. A., Neves, F., Campos, F., & Hogg, T. (2005). Thermal inactivation of the wine spoilage yeasts Dekkera / Brettanomyces. *International journal of food microbiology*, *104*(3), 337–344.

De Reu, K., Grijspeerdt, K., Heyndrickx, M., Uyttendaele, M., Debevere, J., & Herman, L. (2006). Bacterial shell contamination in the egg collection chains of different housing systems for laying hens. *British poultry science*, *47*(2), 163–172.

Di Gioia, D. (2016). Safety of fermented meat. *Regulating Safety of Traditional and Ethnic Foods*.

Dourou, D., Grounta, A., Argyri, A. A., Froutis, G., Tsakanikas, P., Nychas, G. E., Doulgeraki, A. I., Chorianopoulos, N. G., & Tassou, C. C. (2021). Rapid Microbial Quality Assessment of Chicken Liver Inoculated or Not With *Salmonella* Using FTIR Spectroscopy and Machine Learning. *Frontiers in microbiology*, *11*, 623788.

Ercolini, D., Ferrocino, I., Nasi, A., Ndagijimana, M., Vernocchi, P., La Storia, A., Laghi, L., Mauriello, G., Guerzoni, M. E., & Villani, F. (2011). Monitoring of microbial metabolites and bacterial diversity in beef stored under different packaging conditions. *Applied and environmental microbiology*, *77*(20), 7372–7381.

Erkmen, O., Bozoglu, T.F. (2016). Spoilage of Milk and Milk Products. Food Microbiology: Principles into Practice. *Wiley:* 307–336.

Fernandez-Piquer, J., Bowman, J. P., Ross, T., & Tamplin, M. L. (2012). Molecular analysis of the bacterial communities in the live Pacific oyster (Crassostrea gigas) and the influence of postharvest temperature on its structure. *Journal of applied microbiology*, *112*(6), 1134–1143.

Fletcher, B., Mullane, K., Platts, P. (2018) Advances in meat spoilage detection: A short focus on rapid methods and technologies. *CyTA - Journal of Food*, 16(1), 1037–1044.

Françoise, L. (2010). Occurrence and role of lactic acid bacteria in seafood products. *Food microbiology*, 27(6), 698–709.

Fukuzaki, S. (2006). Mechanisms of actions of sodium hypochlorite in cleaning and disinfection processes. *Biocontrol science*, 11(4), 147–157.

Fusco, V., Chieffi, D., Fanelli, F. (2020). Microbial quality and safety of milk and milk products in the 21st century. *Comprehensive Reviews in Food Science and Food Safety*, 19(2), 1-37.

Garnier, L., Valence, F., & Mounier, J. (2017). Diversity and Control of Spoilage Fungi in Dairy Products: An Update. *Microorganisms*, *5*(3), 42.

Gong, L., Li, T., Chen, F., Duan, X., Yuan, Y., Zhang, D., & Jiang, Y. (2016). An inclusion complex of eugenol into β-cyclodextrin: Preparation, and physicochemical and antifungal characterization. *Food chemistry*, 196, 324–330.

Gopal, N., Hill, C., Ross, P. R., Beresford, T. P., Fenelon, M. A., & Cotter, P. D. (2015). The Prevalence and Control of Bacillus and Related Spore-Forming Bacteria in the Dairy Industry. *Frontiers in microbiology*, 6, 1418.

Gram, L., Ravn, L., Rasch, M., Bruhn, J. B., Christensen, A. B., & Givskov, M. (2002). Food spoilage--interactions between food spoilage bacteria. *International journal of food microbiology*, *78*(1-2), 79–97.

Grinbaum, A., Ashkenazi, I., Treister, G., Goldschmied-Requven, A., & Block, C. S. (1994). Exploding bottles: eye injury due to yeast fermentation of an uncarbonated soft drink. *The British journal of ophthalmology*, 78(11), 883.

Gupta, R., & Srivastava, S. (2014). Antifungal effect of antimicrobial peptides (AMPs LR14) derived from Lactobacillus plantarum strain LR/14 and their applications in prevention of grain spoilage. *Food microbiology*, 42, 1–7.

Gurtler, J. B., Hinton, A., Jr, Bailey, R. B., Cray, W. C., Jr, Meinersmann, R. J., Ball, T. A., & Jin, T. Z. (2015). Salmonella isolated from ready-to-eat pasteurized liquid egg products: Thermal resistance, biochemical profile, and fatty acid analysis. *International journal of food microbiology*, 206, 109–117.

Hammond, S.T., Brown J.H., Burger J.R., Flanagan, T.P., Fristoe, T.S., Mercado-Silva, N., Nekola, J.C., Okie, J. (2015). Food spoilage, storage, and transport: implications for a sustainable future. *BioScience*, 65(8), 758-768 .

Hasan, M.U., Riaz, R., Malik, A.U. (2021). Potential of Aloe vera gel coating for storage life extension and quality conservation of fruits and vegetables: An overview. *The Journal of Food Biochemistry*, 45(4), 13640.

Hesseltine, C.W. (1991). Zygomycetes in food fermentations. *Mycologist*, 5(4), 162-169.

Hinton, A., Jr, & Ingram, K. D. (2005). Microbicidal activity of tripotassium phosphate and fatty acids toward spoilage and pathogenic bacteria associated with poultry. *Journal of food protection*, 68(7), 1462–1466.

Hocking, A.D. (2006). Aspergillus and related teleomorphs. In: Blackburn CdW (ed). Food Spoilage Microorganism. *Woodhead Publishing*: UK

Huang, L., Li, C., & Hwang, C. A. (2018). Growth/no growth boundary of Clostridium perfringens from spores in cooked meat: A logistic analysis. *International journal of food microbiology*, 266, 257–266.

Hulebak, K. L., & Schlosser, W. (2002). Hazard analysis and critical control point (HACCP) history and conceptual overview. *Risk analysis : an official publication of the Society for Risk Analysis*, 22(3), 547–552.

Jay, J.M. (2012). Modern Food Microbiology. *Springer Science & Business Media*: Berlin, Germany.

Jenkins, C., Rentenaar, R.J., Landraud, L., Brisse, S. (2017). Enterobacteriaceae. In: William WG, Opal SM (eds) Infectious Diseases, 4th edn. *Elsevier*.

Kalschne, D. L., Womer, R., Mattana, A., Sarmento, C. M., Colla, L. M., & Colla, E. (2015). Characterization of the spoilage lactic acid bacteria in "sliced vacuum-packed cooked ham". *Brazilian Journal of Microbiology*, 46(1), 173–181.

Kayacan Çakmakoğlu, S., Karasu, S., Akman, PK., Goktas, H., Doymaz, İ., Sağdıç, O. (2020). Effect of different drying methods on total bioactive compounds, peholic profile, in vitro bioaccessibility of phenolic and HMF formation of persimmon. *LWT-Food Science and Technology*, 118.

Kuchen, B., Vazquez, F., Maturano, Y. P., Scaglia, G. J. E., Pera, L. M., & Vallejo, M. D. (2021). Toward application of biocontrol to inhibit wine spoilage yeasts: The use of statistical designs for screening and optimisation. *OENO One*, 55(2), 75–96.

Kwun, S. Y., Bae, Y. W., Yoon, J. A., Park, E. H., & Kim, M. D. (2020). Isolation of acid tolerant lactic acid bacteria and evaluation of α-glucosidase inhibitory activity. *Food science and biotechnology*, 29(8), 1125–1130.

Ledenbach, L.H., Marshall, R.T. (2009). Microbiological Spoilage of Dairy Products. In: Sperber W., Doyle M. (eds) Compendium of the Microbiological Spoilage of Foods and Beverages. Food Microbiology and Food Safety. *Springer:* New York, NY.

Li, M. (2006). Study on the analysis of microbial ecology in chilled pork and shelf life predictive model. *Nanjing Agricultural University Press:* Nanjing, China.

Lund, B.M. (1982). The effect of bacteria on post-harvest quality of vegetables and fruits, with particular reference to spoilage. In:Rhodes-Roberts ME, Skinner FA (eds), Bacteria and plants Society for Applied Bacteriology, *Academic Press:* Sydney, pp. 133–153.

Luong, N. M., Coroller, L., Zagorec, M., Membré, J. M., & Guillou, S. (2020). Spoilage of Chilled Fresh Meat Products during Storage: A Quantitative Analysis of Literature Data. *Microorganisms*, 8(8), 1198.

Madigan, T. L., Bott, N. J., Torok, V. A., Percy, N. J., Carragher, J. F., de Barros Lopes, M. A., & Kiermeier, A. (2014). A microbial spoilage profile of half shell Pacific oysters (Crassostrea gigas) and Sydney rock oysters (Saccostrea glomerata). *Food microbiology*, 38, 219–227.

Marin, S., Ramos, A. J., Cano-Sancho, G., & Sanchis, V. (2013). Mycotoxins: occurrence, toxicology, and exposure assessment. *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association*, 60, 218–237.

Martin, G. D., Reynolds, W. F., & Reese, P. B. (2004). Investigation of the importance of the C-2 and C-13 oxygen functions in the transformation of stemodin analogues by Rhizopus oryzae ATCC 11145. *Phytochemistry*, 65(15), 2211–2217.

McClements, J. M., Patterson, M. F., & Linton, M. (2001). The effect of growth stage and growth temperature on high hydrostatic pressure inactivation of some psychrotrophic bacteria in milk. *Journal of food protection*, 64(4), 514–522.

Mekonnen, & Gerbens-Leenes, W. (2020). The Water Footprint of Global Food Production. *Water*, 12(10), 2696.

Miedes, E., & Lorences, E. P. (2004). Apple (Malus domestica) and tomato (Lycopersicum esculentum) fruits cell-wall hemicelluloses and xyloglucan degradation during Penicillium expansum infection. *Journal of agricultural and food chemistry*, 52(26), 7957–7963.

Modi, H.A. (2009). Microbial spoilage of foods. *Pointer Publishers: Jaipur, Rajasthan.*

Mohareb, F., Iriondo, M., Doulgeraki, A.I. (2015) Identification of meat spoilage gene biomarkers in Pseudomonas putida using gene profiling. *Food Control*, 57, 152–160.

Oda, Y., Ouchi, K. (2000). Saccharomyces, in: encyclopedia of food microbiology. *Academic Press:* London, pp. 1907–1913.

Olatunde, O. O., Benjakul, S., & Vongkamjan, K. (2020). Shelf-life of refrigerated Asian sea bass slices treated with cold plasma as affected by gas composition in packaging. *International journal of food microbiology*, 324, 108612.

Pagano, L., Caira, M., Valentini, C. G., Posteraro, B., & Fianchi, L. (2010). Current therapeutic approaches to fungal infections in immunocompromised hematological patients. *Blood reviews*, 24(2), 51–61.

Parapouli, M., Vasileiadis, A., Afendra, A. S., & Hatziloukas, E. (2020). *Saccharomyces cerevisiae* and its industrial applications. *AIMS microbiology*, 6(1), 1–31.

Park, S.Y., Lee, N.Y., Kim, S.H. (2014) Effect of ultraviolet radiation on the reduction of major food spoilage molds and sensory quality of the surface of dried filefish (Stephanolepis cirrhifer) fillets. *Food Research International*, 62,1108–1112.

Ratzke, C., & Gore, J. (2018). Modifying and reacting to the environmental pH can drive bacterial interactions. *PLoS biology*, 16(3), e2004248.

Rawat, S. (2015). Food Spoilage: Microorganisms and their prevention. *Asian Journal* of *Plant* Sciences, 5(4), 47-56.

Réhault-Godbert, S., Guyot, N., & Nys, Y. (2019). The Golden Egg: Nutritional Value, Bioactivities, and Emerging Benefits for Human Health. *Nutrients*, 11(3), 684.

Reis, A. L., Montanhini, M. T., Bittencourt, J. V., Destro, M. T., & Bersot, L. S. (2014). Gene detection and toxin production evaluation of hemolysin BL of Bacillus cereus isolated from milk and dairy products marketed in Brazil. *Brazilian journal of microbiology : [publication of the Brazilian Society for Microbiology]*, 44(4), 1195–1198.

Ribeiro-Santos, R., Andrade, M., de Melo, N.R. (2017). Use of essential oils in active food packaging: Recent advances and future trends. *Trends in Food Science & Technology*, 61,132–140.

Rivoal, K., Quéguiner, S., Boscher, E., Bougeard, S., Ermel, G., Salvat, G., Federighi, M., Jugiau, F., & Protais, J. (2010). Detection of Listeria monocytogenes in raw and pasteurized liquid whole eggs and characterization by PFGE. *International journal of food microbiology*, 138(1-2), 56–62.

Roknul Azam, S.M., Haile Ma et al. (2020). Efficacy of ultrasound treatment in the removal of pesticide residues from fresh vegetables: A review. *Trends in food science & technology*, 97, 417-432.

Rose, A.H., Harrison, J.S. (1993). The yeasts, second edition. Yeast Technology, *Academic Press:* London

Saleh, I., & Al-Thani, R. (2019). Fungal food spoilage of supermarkets' displayed fruits. *Veterinary world*, 12(11), 1877–1883.

Saranraj, P. (2012). Microbial spoilage of bakery products and its control by preservatives. *International Journal of Pharmaceutics*, 3(1), 38-48.

Sato, M., & Sashihara, N. (2010). Occurrence of Campylobacter in commercially broken liquid egg in Japan. *Journal of food protection*, 73(3), 412–417.

Sebranek, J. G., & Bacus, J. N. (2007). Cured meat products without direct addition of nitrate or nitrite: what are the issues?. *Meat science*, 77(1), 136–147.

Shehata, H. R., Mitterboeck, T. F., & Hanner, R. (2020). Characterization of the microbiota of commercially traded finfish fillets. *Food research international (Ottawa, Ont.)*, 137, 109373.

Sørensen, J. S., Bøknæs, N., Mejlholm, O., & Dalgaard, P. (2020). Superchilling in combination with modified atmosphere packaging resulted in long shelf-life and limited microbial growth in Atlantic cod (Gadus morhua L.) from capture-based-aquaculture in Greenland. *Food microbiology*, 88, 103405.

Stepień-Pyśniak, D., Marek, A., & Rzedzicki, J. (2009). Occurrence of bacteria of the genus Staphylococcus in table eggs descended from different sources. *Polish journal of veterinary sciences*, 12(4), 481–484.

Tarlak, F., Ozdemir, M., & Melikoglu, M. (2020). The combined effect of exposure time to sodium chlorite (NaClO2) solution and packaging on postharvest quality of white button mushroom (*Agaricus bisporus*) stored at 4° C. *Food Science and Technology*, 40, 864-870.

Tarlak, F. (2021). Development of a Novel Growth Model Based on the Central Limit Theorem for the Determination of Beef Spoilage. *Applied Food Biotechnology*, 8(2), 143-150.

Tarlak, F., & Pérez-Rodríguez, F. (2021). Development and validation of a one-step modelling approach for the determination of chicken meat shelf-life based on the growth kinetics of *Pseudomonas* spp. *Food Science and Technology International*, 10820132211049616.

Tarlak, F., & Khosravi-Darani, K. (2021). Development and validation of growth models using one-step modelling approach for determination of chicken meat shelf-life under isothermal and non-isothermal storage conditions. *Journal of Food & Nutrition Research*, 60(1), 76-86.

Teixeira, A., Rodrigues, S. (2019). Meat quality, brands and consumer trends. In: Lorenzo J, Munekata P, Barba F, Toldrá F (eds), *Springer:* Cham, Switzerland, pp. 21–29.

Teixeira, A., Silva, S., Guedes, C., & Rodrigues, S. (2020). Sheep and Goat Meat Processed Products Quality: A Review. *Foods (Basel, Switzerland*), 9(7), 960.

Tomičić, R., Tomičić, Z., & Raspor, P. (2017). Adhesion of *Candida* spp. and *Pichia* spp. to Wooden Surfaces. *Food technology and biotechnology*, 55(1), 138–142.

Triki, M., Herrero, A. M., Jiménez-Colmenero, F., & Ruiz-Capillas, C. (2018). Quality Assessment of Fresh Meat from Several Species Based on Free Amino Acid and Biogenic Amine Contents during Chilled Storage. *Foods (Basel, Switzerland)*, 7(9), 132.

van Kan, J. A. (2006). Licensed to kill: the lifestyle of a necrotrophic plant pathogen. *Trends in plant science*, 11(5), 247–253.

Wang, Y., Zhang, W., Linglin, F. (2017). Food spoilage microorganisms: ecology and control. *CRC Press*: Cambridge, UK.

Wei, H., Seidi, F., Zhang, T., Jin, Y., & Xiao, H. (2021). Ethylene scavengers for the preservation of fruits and vegetables: A review. *Food chemistry,* 337, 127750

WWF-UK, (2021). Driven To Waste: The Global Impact Of Food Loss And Waste On Farms. https://wwfeu.awsassets.panda.org/downloads/driven_to_waste___the_global_impact_of_food_loss_and_waste_on_farms.pdf Accessed on 15 Agu., 2021.

Zakaria, L., Sahak, S., Zakaria, M., & Salleh, B. (2009). Characterisation of colletotrichum species associated with anthracnose of banana. *Tropical life sciences research*, 20(2), 119–125.

Zhang, Q. Q., Han, Y. Q., Cao, J. X., Xu, X. L., Zhou, G. H., & Zhang, W. Y. (2012). The spoilage of air-packaged broiler meat during storage at normal and fluctuating storage temperatures. *Poultry science*, 91(1), 208–214.

Zhao, F., Zhou, G., Ye, K., Wang, S., Xu, X., & Li, C. (2015). Microbial changes in vacuum-packed chilled pork during storage. *Meat science*, 100, 145–149.

Zhuang, S., Hong, H., Zhang, L. (2020). Spoilage-related microbiota in fish and crustaceans during storage: research progress and future trends. *Comprehensive Reviews In Food Science And Food Safety*, 20(1), 1–37.

Zhuang, S., Li, Y., Jia, S., Hong, H., Liu, Y., & Luo, Y. (2019). Effects of pomegranate peel extract on quality and microbiota composition of bighead carp (Aristichthys nobilis) fillets during chilled storage. *Food microbiology*, 82, 445–454.