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İÇİNDEKİLER

CHAPTER 1

EFFECTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION

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1. INTRODUCTION

Climate and its change, which are of vital importance in the global public sphere, are emerging as a reality that is increasing and deepening in importance now and in the future. In general, the greenhouse effect caused by harmful gases released into the atmosphere due to human activities causes global warming, which causes an increase in the surface temperature of the earth. Global climate change is the name given to the changes resulting from global warming. (Dellal et al., 2011). According to the estimates made by the researchers, the global warming process will continue and this increase may be between 0.9-3.5°C by the end of 2100 (Chakraborty et al., 2000).

When the effects of climate change on the earth are examined recently, it is predicted that some natural disasters (such as floods, heat waves, storms, extreme weather events, forest fires) will increase due to climate change. (Davarcıoğlu and Lelik, 2018). According to researchers, it is stated that the increase in temperature and decrease in precipitation expected in the near future will affect the decreasing water resources even more negatively and will cause serious problems in many countries.

Forestry, agriculture and fishing activities are negatively affected by the natural events caused by climate change and the changes in the natural conditions of living things. Agricultural production, which changes in terms of quantity and quality as a result of climate change, directly affects food production and therefore human life. Studies of the effects of climate change on food areas show that climate change will generally cause a significant loss of productivity in agricultural production in the future (Cline, 2007; Bruinsma, 2017).

Climate events have vital effects on all living things. The problem of food security is one of these effects caused by climate change. As a result of dangerous natural events such as drought, flood and decrease in water resources caused by climate change and global warming; food resources, one of the most important needs in terms of life, have been endangered. Accordingly, access to food, availability of food and food security have started to decrease.

With the increasing effects of global warming and climate change, food security issues affecting quality, prices and supply chains in food production are attracting more attention. (Yahya and Lee, 2023; De Amorim et al., 2018). It is predicted that food security in the future will depend on socioeconomic and environmental changes. One of the biggest challenges to food security is the negative effects of climate change and especially increasing global warming on the livelihoods of societies in underdeveloped countries and those with agricultural economies that are highly sensitive to climate and have low adaptation to climate change (Schmidhuber and Tubiello, 2007).

1. CLİMATE CHANGE

Climate change is associated with temperature changes, rapid air flow, heavy rainfall and environmental changes. While changing ecosystems, plants and animals are under the threat of extinction. When population growth and the decrease in the agricultural population come together, signs of inadequate access to food have begun to be seen. In addition, human activities in many sectors cause carbon dioxide and other gases to be emitted into the atmosphere. Climate change phenomena include increasing temperature trends defined by global warming, rising sea levels, loss of ice mass in Greenland and Antarctica, changes in plant flowering and extreme weather events.

It is necessary to define climate change separately from global warming, because global warming only describes the increase in temperature on the Earth's surface (Adedeji et al., 2014). Climate conditions on Earth are determined by a continuous flow of thermal energy coming from the sun and penetrating the atmosphere. The atmosphere contributes to the protection of people and the environment by capturing the heat emitted from the sun's rays and warming its surface, ensuring the temperature balance between day and night. As the temperature increases, the Earth sends thermal energy to the atmosphere in the form of infrared radiation. Some of the thermal radiation is absorbed by "greenhouse gases" such as carbon dioxide (CO_2), methane (CH_4), nitrogen oxide (N_2O) and water vapor, thus trapping energy and keeping the average temperature of the Earth around 15°C. Considering that these are the temperature levels necessary for the survival of humans, plants and animals, the lack of these gases can lead to serious problems such as the Earth's temperature dropping to -18°C and the freezing of most living species. Of the above gases, carbon dioxide is the most important for maintaining the desired temperature levels of the earth (Demertzi et al., 2021).

It is known that the ecosystem plays an important role in the healthy functioning of the carbon cycle and the elimination of negative effects. At the same time, actions such as forest destruction as a result of human activities cause an increase in the levels of carbon dioxide drawn into the atmosphere (Kostopoulos, 2014). CO_2 is one of the most important gases that maintain the desired temperature levels on earth. Carbon dioxide emissions increase as a result of human activities, thus disrupting the natural balance between the amount emitted and the amount absorbed. This situation causes negative effects on the natural environment and increases climate change (Demertzi et al., 2021).

1.2 Factors Increasing Climate Change

Climate change is under the influence of various climate conditions and factors that have existed for many years. In addition to natural processes, many anthropogenic factors are responsible for climate change. When looking at the natural causes of climate change, research shows that the Earth's orbit around the Sun will change in the coming thousands of years, which will cause more radiation exposure (Solomon et al., 2007). Another factor is the explosions caused by volcanoes. They cause the release of sulfur dioxide and other gases that will burden the atmosphere for many years. Volcanic activities between 1890-2010 increased the general warming by 0.1 °C. Volcanoes emit carbon dioxide and carry particles to the upper atmosphere (Wilson et al., 2002). However, human activities cause 100 times more carbon dioxide emissions than volcanic activities every year. The great increase in carbon dioxide and fossil fuel emissions as a result of industry, agriculture and rapid deforestation creates the greenhouse effect. In other words, it causes the sun's rays to be retained on the earth's surface, increasing the temperature (European Commission, Causes of climate change).

Greenhouse gas concentrations have increased since the industrial revolution. Carbon dioxide, methane, and nitrous oxide accumulate in the atmosphere. Fossil fuel consumption also has negative effects on the climate. More specifically, human activities cause more than 30 billion tons of carbon dioxide to be released into the atmosphere every year. In the 20th century, the amount of methane gas has doubled compared to the pre-industrial period. It is stated that nitrous oxide increased by approximately 20% towards the end of the 20th century. The proportion of sunlight trapped by the planet reaches 70%, which causes the melting of sea ice and climate change (U.S. Environmental Protection Agency, 2021). Therefore, it has been concluded that air pollution is perhaps the most important factor that increases climate change and, when combined with global warming, can also lead to adverse effects on human health. Although the atmosphere has physicochemical mechanisms to remove atmospheric pollutants, pollution events are mainly caused by "adverse" meteorological conditions that significantly limit the ability of the atmosphere to dilute pollutants; Some of these conditions also serve as accelerators in the formation of atmospheric pollution (Demertzi et al., 2021).

1.3. Consequences of Climate Change

Climate change affects both the environment and people on a global scale. The decade between 2011-2020 is reported to be the hottest decade on record on a global scale. It has negative consequences for both the environment and human health. The human factor plays an important role in affecting the Earth's climate and temperature. As mentioned, the greenhouse effect is the main cause of this and is the factor that has the most serious consequences. Gases that act as glass in the atmosphere and prevent the return of solar heat to space are formed. Global warming also occurs in this way. In 2020, the concentration of gases in the atmosphere increased by 48% compared to 1750. Global warming also causes the melting of polar ice caps, in other words, its effects actually affect the entire planet. (IPCC, 2021).

Southern and Central Europe are experiencing more frequent heat waves, forest fires and droughts. In Northern Europe, due to high rainfall, urban areas are exposed to heat waves and floods because they are not prepared to protect themselves and adapt to climate change. They are the countries most affected by climate change. Underdeveloped countries are largely dependent on the natural environment for their survival and have difficulty coping with the changing climate. Severe droughts and forest fires are seen in the Mediterranean. Extreme weather events are predicted to increase in the coming years. The consequences are evident in social and economic structures, and urgent economic measures are needed to repair the damage to property and infrastructure. A typical example is the flood disaster that occurred between 1980 and 2011, which caused an economic loss of approximately 90 million euros and affected 5.5 million people. At the same time, tourism, agriculture and forestry are deeply affected (European Commission, 2009).

One of the most important effects of climate change is that it affects the soil. The continuous decrease in soil moisture can increase the need for irrigation in agriculture, thus causing a decrease in yield and soil degradation. It is predicted that changes in seasonal temperatures can change the annual cycles of plants and animals, which can lead to fewer harvests (European Environment Agency, 2020). According to research, it is predicted that rice and wheat grains can shrink to a certain extent if the temperature increases (Rezaei et al., 2018 ; Asseng et al., 2019). In addition, heavy rains can cause serious soil erosion, and water resources are expected to decrease due to increasing temperatures. It is also predicted that water reserves may be depleted in some regions and may affect food supply. On the other hand, rising water levels endanger food security as seawater affects freshwater resources and promotes water scarcity conditions. As a result of both climate change and human activities, animal and plant species are disappearing 100 times faster. In addition, the risk of disease is high as parasites, like weeds, can spread rapidly through the population creating interrelated diseases (Bakkenes et al., 2002).

2.AGRICULTURE

2.1 The Concept of Agriculture

Recently, the concept of agriculture has been redefined. While the concept of agriculture initially referred to the crops, animals and general vegetation and animals of an ecosystem, other factors that fell within the scope of the concept later emerged. It is stated that biodiversity and natural renewable resources are part of agriculture and are not independent sectors.

For the conceptual approach to agriculture, a term has been developed based on the assumption that agriculture involves the accumulated and evolving knowledge and practices of processing plants and animals, flora and fauna, and that these, together with additional post-harvest processing services, become food products for humans and animals, as well as public environmental goods with increasing demand for society as a whole. It is therefore concluded that agriculture is a complex production activity and has some fundamental characteristics. It is based on the biological phenomenon of the photosynthetic function of plants on soil, water, the agricultural technology available at a given time and the work of not only the active "agricultural population" but also of all those involved in the agro-food chain, which it defines (Fischer et al., 2005).

It promotes the sustainability of renewable natural resources and supports tourism with seasonal human resources, food and an attractive natural environment. It involves a high level of risk and uncertainty due to the fact that the rural area is affected by uncontrollable weather conditions as well as its production capacity. In this direction, measures to protect the land must be taken continuously. Considering the nutritional value that agriculture provides to humans, its protection is an obligation for state bodies. It is an indicator of socio-economic and ecological development. A developed countryside requires the existence of developed agriculture and vice versa (Tauger, 2010).

2.2 Agricultural Population and Current Status of Agriculture

The agricultural population consists of individuals whose employment and income are derived from agricultural activities (Tauger, 2010). The fact that the vast majority of Greek agriculture consists of self-employed individuals reveals the importance of implementing strategies for the development of the agricultural sector. The development of agriculture provides significant benefits to societies. The development of policies in the agricultural sector, beyond meeting the biological needs of people and the economic development of countries, also has a positive impact on the environment and climate. The implementation of new agricultural policy standards contributes, among other things, to the protection of biodiversity, the sustainability of agricultural enterprises, the preservation of soil quality, the reduction of greenhouse gas emissions, etc. (European Union, 2020). However, despite the important role agriculture plays in the development of a society, according to data published by the Turkish Statistical Institute in 2021, while the agricultural population is decreasing, more and more young people are employed as secondary workers in agricultural products (TÜİK, 2021). Since agriculture contributes to the elimination of the environmental effects of climate change with its good practices, it is important not to reduce the number of employees but also to implement innovative actions and environmentally friendly technologies (Tauger, 2010).

2.3 Agricultural Development Strategies

Strategies for developing agriculture are based on current developments and therefore both the use of technology and the implementation of innovative actions to solve the problem play an important role. The new European policy for green agriculture with lower carbon dioxide emissions aims to create a "smart" agriculture. On the other hand, climate change negatively affects the income of the agricultural population and leads to increasingly serious disasters in production and infrastructure. At the same time, climate change requires a change in the way agricultural activities are carried out. Chemical pesticides and fertilisers are factors that contribute to environmental degradation and pose a risk to biodiversity. Climate change is one of the main pillars of the agricultural strategic plans for the next decade. Agricultural production is a sector of activity that will be significantly affected by climate change, as the type, quantity and quality of agricultural products are largely dependent on climate. The main climatic variables affecting plant productivity are air temperature, the intensity and duration of exposure to sunlight, the CO_2 concentration in the atmosphere and the duration and intensity of extreme events. In addition, the degradation of agricultural lands due to the continuation or increase of the desertification phenomenon is expected to play an important role.

2.4. Extreme Weather Events

According to research, one of the most important effects of climate change in Turkey is the change in the intensity and frequency of extreme weather events. This will have negative effects on both societies and ecosystems as they will be exposed to environmental risks. It is estimated that heat waves in particular will be more frequent and their duration and intensity will increase. On the other hand, severe cold weather events are expected to be less frequent, but it is still estimated that severe cold waves may occur from time to time. Summer droughts are expected to increase further. This will lead to longer drought periods and pressure on water reserves in regions that are already increasingly vulnerable. It is also estimated that heavy rains will be more frequent in the coming years, and as a result, sudden floods in urban areas due to intense local rainfall will be increasingly frequent. Changes in these extreme events are expected to particularly affect sectors such as agriculture, fisheries, human health, biodiversity, ecosystems and energy. Therefore, adaptation to climate change regarding extreme events is an important part of the national strategy (Turkish Ministry of Environment, Urbanization and Climate Change, 2024; Türkeş, 2001).

2.5 Impacts on Production and Economy

Climate change has negatively affected the agricultural sector at both European and national levels. It is stated that changes in temperature and precipitation, as well as extreme weather and climate events, have a direct impact on yield and productivity in crop production (including the livestock sector). This is expected to lead to a decrease in agricultural yields due to insufficient exposure of plants to water, increased plant water demand, changes in irrigation practices and changes in storage and transportation conditions, water scarcity, heat waves, heavy rainfall and other extreme weather and climate events. The cascading effects of climate change can also affect the price, quantity and quality of products and hence trade flows, which is expected to affect agricultural income only at the national level (Turkish Ministry of Environment, Urbanization and Climate Change, 2024). One of the most widely used methods to assess the impacts of climate change on the agricultural sector is to map agricultural product outputs against a base year. For example, if the amount produced in a product (e.g. cotton) decreases by 20% due to the effects of climate change, there will be a corresponding decrease in the producer's income. This decrease reflects the cost of not taking precautions against climate change and is a cost reflected to the producer. Fertilizer use will also increase in order to increase crop yields to pre-climate change levels. In this case, the cost of production is higher and this is called the cost of adaptation to climate change (Karamanos and Vouloudakis 2011). In general, climate change does not only have a negative impact on the environment and agriculture, but also has a significant impact on the income, employment and general welfare of agricultural and urban populations (Skourtos et al., 2011).

2.6 The İmpact of Climate Change on Agriculture and Livestock

It is estimated that climate change will have both positive and negative impacts on the agriculture and livestock sector. As previously mentioned, the increase in air temperature, the decrease in precipitation and the decrease in soil moisture will lead to extreme events that will affect crops (Georgakopoulos, 2021). In general, it is estimated that climate change will have negative changes on agricultural products, such as the increase in plant and animal diseases and the emergence of parasite epidemics due to increasing temperatures, and the increase in temperature affecting crop yields (Hawkins et al., 2008).

It is stated that the negative impacts of climate change on agriculture may vary from region to region. It is predicted that crops and animals in some regions will be affected more. It is predicted that the increase in temperature in the northernmost countries will contribute to an increase in yield due to the extension of the growing season, and it will be possible to grow species that could not be grown until now. On the other hand, the decrease in precipitation and the increase in heat wave days in the southern regions will limit crops and increase water demand. The effects of climate change in these areas can be evaluated as negative because they will be associated with reduced yields, soil erosion due to extreme weather events, and even desertification of areas due to reduced field productivity and insufficient natural resources (Gemtos, 2022). At the same time, the increase in extreme weather events will have serious effects on the socioeconomic level, as it will lead to an increase in commodity prices and affect interstate trade balances.

CONCLUSION

There is ample evidence to suggest that climate change, expected in the coming decades, poses a serious threat to the stability of the global food system due to the increased demand for food to feed a growing population and the short-term variability in food supply. Climate change has particularly negative effects on agriculture, with characteristic effects such as increased disease in plants and animals due to rising temperatures, reduced photosynthetic capacity of plants, increased susceptibility of crops to flooding, and reduced transpiration. Climate change has socioeconomic consequences beyond agriculture. The reduction in productive activity results in reduced incomes for a large segment of the population, which in turn reduces the quality of life. The reduction in production also contributes to a reduction in the workforce, which in turn creates a domino effect of developments in the employment sector. Although the potential impacts are less obvious at the regional scale, climate variability and change are likely to exacerbate food insecurity in regions at risk of hunger and malnutrition. Access to and use of food will be indirectly affected through adverse effects on individual and household incomes, loss of access to safe water, and damage to health. Adaptation actions are therefore of fundamental and strategic importance, especially for the lowest-income producers, who are the most vulnerable to climate change, because of their limited capacity to invest in innovative practices and technologies to address changing climate conditions and their weak institutional frameworks. In an environment of increasing competition for land, water and energy, it is necessary and possible to have synergies between actions for food security and adaptation and mitigation, that is, to reduce the impact of the food system on climate and, more generally, on the environment and biodiversity. This will require significant efforts at different levels, starting with a global, multidisciplinary strategy that aims not only to maximize productivity but also to carefully consider the distribution of costs and benefits of choices and the benefits that climate and biodiversity protection will provide for future generations.

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CHAPTER 2

HOW DOES CLIMATE CHANGE AFFECT FOOD SECURITY?

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1. INTRODUCTION

The consequences of the increasing warming that our planet is experiencing are already beginning to show themselves and will become increasingly intense in the coming decades. This climate change has an inertia factor that cannot be stopped even if greenhouse gas emissions are significantly reduced. According to a report published by the IPCC in 2007, the global temperature increase should not exceed 2°C. This is because further increases could have disastrous consequences, especially for developing countries, where millions of people could face food insecurity due to droughts, increased adverse weather conditions, rising sea levels and warming oceans(IPCC, 2007).

According to Crowley and North (1988), Oreskes (2004), Maldonado et al., (2015), and others, climate change is the alteration of the atmosphere of a region or the entire planet and the conditions that govern it. Depending on the cause of the change, whether natural or man-made, it happens or speeds up at a specific time and has implications for the economy, biology, and even politics. Although it is a worldwide occurrence, its impacts vary greatly at the local level, resulting in complete instability and imbalance in all aspects of the climate. Farmers can alter a number of environmental elements by modifying their management strategies. However, the primary element influencing agricultural output and determining the crop's ultimate yield is climate (Vázquez-Montenegro et al. 2014).

One of the issues facing developing nations and those living in poverty and social, economic, and environmental vulnerability—who are frequently subjected to stress and natural disasters—is climate change. Every continent and ocean is now experiencing the effects of climate change. Most recently, these have included extreme weather events like heat waves, droughts, floods, and wildfires, which have demonstrated how vulnerable many human systems, including food production, and certain ecosystems are to climate variability (IPCC 2014). Climate change is already having an impact on ecosystems and species, food and water security, livelihoods, and human health, and it will only get worse. Particular difficulties exist in the tropics, the Arctic, coastal regions, and low-lying places (IPCC, 2014).

Numerous aspects of food security are impacted by climate change, both directly and indirectly, particularly the agriculture and animal industries. 70% of rural poor people worldwide rely on agriculture as their primary source of work and income. However, the cattle industry generates 18% of greenhouse gas emissions and is one of the primary drivers of land and water resource degradation (World Bank, 2021).

Particularly in developing countries, agricultural and livestock production systems need to undergo the necessary reforms to meet the requirements that, if not met, could have serious consequences for population and development. The current question is how to put these reforms into practice in order to mitigate the effects of climate change, adapt to it, and simultaneously guarantee the sustainability of agricultural activities and the security of food and nutrition. Given that agriculture provides a living for millions of people worldwide, the fourth IPCC report states that one of the most severe effects of climate change will be the rise in the number of people who are undernourished. In actuality, farmers have always faced difficulties due to the weather.

Agriculture is therefore the sector most affected by the consequences of climate change, directly affecting the economic activities of countries and increasing the risk of hunger and malnutrition. This is a cycle that is very difficult to break, because the poorest are the ones most affected by the adverse weather effects caused by climate change. At the same time, they are the ones least able to cope with these phenomena, due to malnutrition, overcrowding, lack of drinking water, inadequate sanitation conditions that lead to the rapid spread of infectious diseases and the lack of social protection systems. On the other hand, agricultural development is presented as the most effective tool in combating hunger and poverty, being two to four times more effective than other sectors in raising incomes among the poorest (IPCC, 2007).

Determining the direct impacts of climate change on agricultural output in various geographical areas is crucial, as is figuring out how agricultural practices interact to raise greenhouse gas emissions. This has a significant impact on how mitigation policies are designed and funded. Achieving climate-resilient agricultural production systems and making optimal use of resources without endangering future food security can only be accomplished in this manner. Climate change is having extremely localized consequences. However, developing regions are anticipated to see more severe regional impacts. For example, in Africa, the decline in productivity of rain-fed crops is expected to reach as much as 50 percent in some countries, which could jeopardize food security. It is also estimated that the percentage of arid and semiarid areas will increase by 5 percent to 8 percent by 2080. The outlook is equally bleak in Asia. By 2050, freshwater resources in major river basins are projected to decrease, sea levels to rise and deltas to be flooded (Nelson et al.,2010).

2. FOOD SECURITY

In order for everyone to have access to and consume food in quantities and quality free from contaminants, every day and at the appropriate time, as well as to other services like sanitation, health, and education that ensure nutritional well-being and good bio-utilization of food to enable them to thrive without implying ecosystem degradation, food and nutrition security is defined as the availability and stability of a culturally acceptable food supply. Pedraza, 2003. Food security, according to Figueroa et al., (2003), is the ability of every individual to always have access to the food they require in order to have an active and healthy life. Eliminating food insecurity is a significant challenge for governments, policymakers, donors, partners, organizations, and institutions attempting to address this issue, according to Appendini et al. (2003). Since millions of people worldwide suffer from chronic malnutrition and go hungry every day, ending food insecurity is not a simple feat. Because the harsh conditions of extreme poverty become the primary cause of food insecurity, it is noteworthy that low-income countries in continents like Africa, the Americas, and several Asian countries have the highest rates of malnutrition. Simultaneously, the effects of extreme weather events on agriculture put many households' food security and production at risk.

All family members must have access to enough food in the home to meet their needs, but non-food elements like hygiene, social norms, and health all affect nutritional security. Therefore, while it is not the only requirement, family food security is one of the requirements for reaching an acceptable nutritional status. Families classified as "poor" are the ones most at risk from food insecurity. Families with low-income producers who produce only a small amount of food, households with women as the primary breadwinners, large households, households in environmentally disadvantaged areas, and households with incomes too low to provide access to sufficient food resources in terms of both quantity and quality are a few examples (Figueroa et al., (2003). When access to nutrient-dense foods, foods that one desires, and socially acceptable resources are restricted or unpredictable, we might conclude that there is food insecurity (; Dehollain, 1995).

Four aspects of food security Food security is defined as "the state in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" by the Food and Agriculture Organization of the United Nations (FAO, 1996). According to the IPCC (IPCC, 2014), climate change may have direct and indirect impacts on all four dimensions of food security identified by the FAO:

1. the availability of food in sufficient quantities and quality, whether from domestic production or imports;

3. the availability of sufficient resources, both in terms of purchasing power and traditional rights to use common resources, to obtain food suitable for a nutritious diet;

3. use of food to attain a state of nutritional well-being where all physiological needs are satisfied by proper nourishment, clean water, sanitation, and medical attention;

4. Stability, which refers to a society's, a family's, or an individual's capacity to weather crises that could result in a more or less temporary lack of access to a healthy diet.

A detailed review of scientific articles published in international scientific journals on the subjects of food security and climate change, published in the journal Science (Wheeler and Von Braun, 2013), showed that until the mid-1990s, agriculture and food security were far removed from discussions on the effects of climate change. Since then, interest has increased, particularly since 2008. Analysis of published articles shows that, of the four dimensions of food security, food availability has been the most discussed topic in recent years (70% of publications). Only 12% of total publications on food security include access to food, 14% food use and 4% dietary stability.

Agriculture is not only a source of food but also a significant source of income. In a world of easy trade, the critical question for food security is not whether food is "available" but whether the monetary and nonmonetary resources at the disposal of the population are sufficient to ensure that everyone has access to sufficient food. Food security at the individual level cannot be guaranteed by a country's food self-sufficiency alone. In contrast, India is self-sufficient, but a significant section of its population is food insecure (Schmidhuber and Tubiello, 2007). Small states like Hong Kong and Singapore, for instance, are not self-sufficient (no agriculture), but their populations are food secure.

2.1. Impacts on Food Availability

A large number of studies have estimated the impact of climate change on global food production. For example, one important study has assessed in detail the yield data of the top four food crops, which provide 75% of the calories consumed globally. The results show that world agricultural yields decreased by 3.6% for maize, 5.5% for wheat and less for soybeans during the period 1980–2008. In rice, yield increases in the subtropics are offset by yield decreases in the tropics (Lobell et al., 2011).

The review in the IPCC Fifth Assessment Report found that recent climate trends have negatively affected wheat, maize and rice production in many regions, with changes in soybeans being less significant. Although increasing CO_2 concentrations and temperatures theoretically support agricultural production at high latitudes, the IPCC estimates that negative impacts on crops have been more widespread than positive on a global scale (IPCC, 2014a). The prediction of future food production variations corresponding to different global warming scenarios is also a very present theme in the scientific literature. The first issue addressed is the impact of climate variations on the physiology of crop plants, and hence on their development and the resulting food production. These are studies based on simulations using climate models combined with scenarios of atmospheric CO_2 concentrations and models (often based on very simplified parameterizations) that can describe the physiological responses of plants to changes in CO_2, temperature and water availability. Increased photosynthesis in plants exposed to higher CO2 concentrations generally leads to the development of stronger plants and higher yields, especially in C_3 plants (the first organic compound of photosynthesis is a 3-carbon carbon chain), including most cereals, legumes, forage crops and fruit crops. On the other hand, C_4 plants (maize, sorghum, millet, sugar cane, etc.) have a more efficient photosynthetic process than C_3 plants and are less responsive to increases in atmospheric CO_2 concentration (Taub, 2012).

The effects of increased CO_2 concentration on growth and yield also depend on other factors, such as the species, growth stage, and cultivation practices that make fertilizer and water available. In this last respect, several factors play a role, which can lead to both a decrease (lower stomatal conductance) and an increase (higher evaporative demand) in water use by plants (Bindi et al., 2014). In 1994, Rosenzweig and Parry published a paper simulating crop yields of wheat, rice, maize, and soybean at 112 sites in 18 countries under conditions that were altered by doubling current climate conditions and atmospheric CO2 concentrations. This was the first worldwide assessment of the potential effects of climate change on crops. (Rosenzweig and Parry, 1994). The results showed that increasing atmospheric CO_2 concentrations can increase the productivity of most crops by accelerating photosynthesis and improving water use efficiency.

Subsequent studies based on field experiments aimed at gaining a deeper understanding of climate effects on plant physiology, using more complex models and parameterizations, more computing power and available data sets, scaled back the results of Rosenzweig and Parry's pioneering work and showed that the results are sensitive to the structure of the parameterizations and the parameter values used (Long et al., 2006; Asseng et al., 2013). Large-scale research, such that done by Parry et al. (2007), has consistently shown how climate change affects crop yield and productivity (Cline, 2007; Lobell et al., 2011; Knox et al., 2012). In general, it is expected that temperature increase will have positive effects on agricultural activities in high and mid-latitudes (from the tropics to the poles), expanding arable lands and extending the yield growth period. Negative effects will be seen with the increase in the frequency of extreme events such as heat waves, droughts or heavy rainfalls and floods. According to many studies, production is expected to increase in Northern Europe and decrease in Africa and South America. In tropical regions, crop productivity will be affected because some areas will become unsuitable for cultivation due to reduced soil moisture. Increases in temperature may also expand the range of many agricultural pests and increase their ability to survive the winter and attack spring crops (Schmidhuber and Tubiello, 2007).

A common finding emphasized in the IPCC reports is that the more pronounced the increase in temperatures, the more severe the effects of changes in the production of certain food products at the regional level will be. While the IPCC predicts that crop yields will increase in colder environments, stress factors that may lead to a decrease in crop yields in warmer environments include not only heat stress but also increased insect infestation, increased fire risk, soil erosion and, in some regions, increased salinity in irrigation water. Even modest temperature rises are expected to have an impact on agricultural and food supply in low latitude regions worldwide, particularly in impoverished developing nations, according to the synthesis produced by IPCC scientists. Consequently, a significant finding that is generally accepted in the scientific literature is that the nations that are currently experiencing the greatest levels of hunger also happen to be the regions of the world where agricultural productivity is predicted to decline as a result of climate change. In other words, research indicates that in areas where hunger and malnutrition are already pervasive, climate change will exacerbate food insecurity. Numerous studies have shown that the greatest loss of arable land due to climate change is expected in Africa, while the greatest expansion of arable land is expected in the Russian Federation and Central Asia (FAO, 2002). In a study on South Asia by Knox et al. (2012), using 52 original publications from a review of 1144 studies, estimated that average crop productivity in both regions could decrease by 8% by 2050 due to climate change.

Even though there is proof that agricultural yield is directly impacted by climate change, there are significant restrictions when evaluating the total consequences on world food availability. Only major cereals, groundnuts, and certain root and tuber species have models that accurately depict how climate change will affect agriculture. Instead of being specifically investigated, effects on other significant crops (vegetables, legumes, or regionally significant but globally secondary crops) are sometimes deduced from the traits of related plants.

By assessing climate models at regional scales or on 200–250 km mesh networks, their spatial resolution can be improved. This will allow them to offer valuable insights into the future movements of production areas, potentially guiding the development of plant varieties that are more resilient to change and identifying areas for global crop improvement programs (Wheeler and Von Braun, 2013).

Higher model resolution will be an important factor in improving the adaptive capacity of agricultural practices to climate change, which is largely driven by decisions made at the level of individual farms and agricultural holdings. Due to the limits of input data (such as crop kinds, soils, topographic data, and management information), it is currently impossible to comment with certainty at this scale regarding the accuracy of crop models and climatic simulations. The fact that many crop studies "photograph" the effects of typical climate changes but are less successful in identifying changes brought on by extreme weather events that might have more substantial effects on crop output is the last source of uncertainty. It should come as no surprise that numerical models at extremely fine scales struggle to capture the immense complexity and variability of food production systems on a global scale. Projections of the production of the same crops in more drastically altered future climates will be regarded as more accurate when small-scale models are able to replicate observed climate fluctuations with previously documented alterations.

2.2. Impacts on Access to Food

Access to food has significantly improved in many developing nations as a result of the drop in real food prices and the rise in wages over the past 30 years. A growing number of individuals are able to purchase more food, but also more nutrient-dense foods that contain more protein, minerals, and vitamins because to their increased purchasing power (Schmidhuber and Tubiello, 2007). FAO (2002) states that additional expansions in food access could occur in the ensuing decades.

Climate change is recognized to have an indirect impact on food access and consumption. Food access is closely related to household and individual income and rights. Therefore, climate change may have an impact on it since it may increase the frequency and severity of food crises linked to drought and heavy rains, which may cause households and local communities to become impoverished.

Two different methods have been used to study food availability issues. The first is a top-down strategy that links large-scale crises (macro shocks) to household-level and local responses through the use of macro models. This method simulates productivity under various climate scenarios by feeding the output of a climate model into a crop model. Economic forecasts of how climate change would affect prices, incomes, trade, and other factors are then based on the outcomes of the crop simulations. Macro models can be built as general equilibrium models that try to capture the effects on the entire economy or as partial equilibrium models, which look at the effects on just one sector, like agriculture. This method's shortcoming is that it barely accounts for climate change adaptation.

The second method, which is more capable than macro models at taking into consideration families' and communities' ability to adapt to climate change, is based on bottom-up research conducted at the community and home level through in-depth observations of households. According to Silvestri et al. (2012), Kato et al. (2011), and Traerup (2012), many research that examine the dynamics of families and communities affected by climate shocks are able to account for changes in employment, migration, or other social or collective support policies among adaptive responses. One drawback of these research is that it is challenging to accurately depict, at the local level, the hazards connected with climate change that are anticipated in extremely vast regions.

In general, it can be assumed that food prices are expected to increase moderately (until 2050) following moderate temperature increases. However, some studies predict a slight decrease in real prices until 2050. Second, prices are projected to increase more significantly after 2050 and as temperatures continue to rise. The expected price changes due to global warming effects are, on average, lower than the price changes caused by socioeconomic development (Schmidhuber and Tubiello, 2007). The change in the geography of production on a global scale will have negative effects on the production of all biobased products (food, feed, fuel or fiber) and will have negative effects on farmers' incomes and access to food (Hertel et al., 2010). The location and relative productivity of some ocean species, such sardines and anchovies in the Pacific Ocean, have also changed in similar ways (Chavez et al., 2003). Additional ramifications pertain to situations in which customary land and water rights, or property rights, are not safeguarded, which is common in many developing nations. Along with instances of "land grabbing" by foreign and external interest groups, issues with food security have started to surface (Arezeki et al., 2011).

2.3 Effects on Food Use

Climate change will have an impact on the use of food that is essential for nutritional well-being and is dependent on water and sanitation. This is because the frequency of extreme weather events will have an impact on the structure of water resources (IPCC, 2013); this is particularly true in areas where there is already a lack of or no access to adequate sanitation, which can lead to droughts or floods (Shimi et al., 2010). It should be mentioned that the proliferation of gastrointestinal disorders, which are closely linked to temperature and the availability of drinking water, has a detrimental impact on the body's ability to absorb nutrients (Schmidhuber and Tubiello, 2007). In its assessment reports, the IPCC Working Group II offers comprehensive information on the health impacts of climate change, showing that the likelihood of certain disease kinds spreading either rises or falls. A vicious cycle in which infectious diseases can induce or encourage hunger, which in turn may render afflicted populations more vulnerable to infectious diseases, is feared to be triggered by changing climate conditions. It can therefore result in a sharp drop in agricultural output as well as a rise in poverty and death rates. By raising the expenses of preventing food from becoming contaminated by parasites or other disease vectors impacted by ecological changes, climate change can also have a detrimental impact on the quality of diets (Tefera, 2012). The uncertainty surrounding food security's susceptibility to climatic shocks stems from the challenge of evaluating the potential for enhancing climate change adaptation, which heavily relies on political decisions and actions. Many of the risks caused by climate change can be addressed, for instance, by properly structuring programs to support the poor financially, boost employment, or encourage nutrition in young children (Niño-Zarazúa et al., 2011). The last theme pertaining to issues with food access and nutrition is the recent "nutritional transition," which is the process by which lifestyle changes, urbanization, and globalization have caused many societies to consume excessive amounts of calories, eat poor-quality diets, and engage in little physical activity. Even in poor and emerging nations, the combined impact of these variables has caused the prevalence of obesity and chronic diseases to rise quickly (Popkin et al., 2012).

2.4. Food System Stability

Since climate is a major factor in determining food price trends and short-term price volatility, the stability of the entire food system is likely to be at risk under the impact of climate change (Nelson et al., 2010). Increased variability in global and regional weather conditions, and the frequency and severity of extreme events such as cyclones, floods, hailstorms and droughts, are causing fluctuations in crop yields and local food products, which in turn negatively impact the stability of food supplies and therefore food security. Weather variability and climate change are not new challenges for agriculture; agriculture has been shown in the past to develop adaptation strategies. Climate variability has historically been higher in some important agricultural regions of the world than in others, such Central Africa or Europe. These locations include the Midwest of the United States, northeastern Argentina, southern Africa, and southeastern Australia. According to recent reports, regions with high levels of climatic variability are not only destined to grow, but many regions will see unprecedented rates and degrees of warming in the upcoming decades, at levels that are not similar to those seen in previous centuries (IPCC, 2013).

Droughts and floods, which are the main causes of short-term changes in food production in semiarid and subhumid regions, are predicted to grow more severe and frequent as climate fluctuations become more noticeable and widespread. In semiarid areas, primarily in South Asia and sub-Saharan Africa, droughts can drastically lower animal and grain yields. This implies that the areas with the highest rates of chronic malnutrition will also experience the most food production instability (FAO, 2003). The ability to offset such changes through improvements in storage facilities, irrigation, or increased imports of food will determine how much of an influence they have.

Some studies have shown a link between climate change, agricultural yields, and migration flows. For example, using available data from Mexico, Feng et al. (2010) found a significant link between agricultural yields and migration rates to the United States. A 10% decrease in agricultural yields led to a 2% increase in the number of migrants attempting to cross the border into the United States. Based on different scenarios of global warming and adaptive capacity, it is estimated that by 2080, climate change could cause between 1.4 and 6.7 million Mexicans (2% to 10% of the current population aged 15 to 65) to migrate due to reduced agricultural yields.

It has become clear in recent years that the global food supply-demand balance is unstable. Therefore, even minor supply or demand-side shocks can have a big impact on pricing (von Braun, 2009). Because basic foods account for a significant amount of a poor family's income, prices of these goods have a particularly negative impact on the food security of the most impoverished. The production and availability of food will undoubtedly become more unstable due to climate change. Demand shocks can have an impact on the stability of food systems, as demonstrated by the significant subsidies provided to bioenergy and agri-food in the US and Europe during the last ten years. Food markets have become unstable as a result of such policies, which are partly motivated by worries about energy security and partly by the desire to reduce greenhouse gas emissions from fossil fuels. This has had detrimental effects on food security in many regions. According to Arndt et al. (2012), the 2008 food crisis was primarily caused by a confluence of factors, including general decreases in agricultural output, export limits imposed by numerous nations, a lack of market transparency, and insufficient regulation of financial obligations in food markets.

Food security risks are therefore a combination of factors. One of these is climate change. But also related factors are the destabilization of food systems, which can generate higher and more volatile prices that temporarily limit the food consumption of the poor; financial and economic shocks that lead to job losses and credit constraints; and food insecurity caused by wars and civil unrest (Berazneva and Lee, 2013). Therefore, significant investments in adaptation actions are needed throughout the food system to prevent progress in eliminating global hunger and malnutrition from slowing down due to the impacts of climate change. The development of agricultural resilience, or "climate-smart agriculture," requires advancements in social and nutritional policies, trade and stock management systems, and production technologies. Food security in its widest sense must be addressed by adaptation and resilience initiatives, which must also be incorporated into the global agriculture sector's growth.

3. CONCLUSIONS

Feeding the 9 billion people that will inhabit the earth by 2050 without raising greenhouse gas emissions is one of the biggest issues facing humanity. In poor nations, which are most vulnerable to the effects of climate change, both direct and indirect effects on food security are now evident and will only become more pronounced in the years to come. A vicious cycle is also created because a community that is malnourished is less able to withstand the negative consequences of climate change. The agriculture industry in poor nations must undergo a drastic transition in order to achieve food security in the face of climate change. This process should take into account the synergies between adaptation capacity and mitigation opportunities offered by the implementation of sustainable agriculture or "climate-smart agriculture" models that take into account traditional practices, the dependence on biodiversity and the fundamental role played by rural women in developing countries. This transformation of agricultural systems requires financing. In addition to contributions from development assistance programmes, access to funds created to combat climate change should be provided.

Climate change is undoubtedly the greatest challenge of our time. It affects all areas of human activity, especially food security in vulnerable areas. Given its interconnectedness, it requires addressing issues ranging from global political decisions to individual actions that can make a difference in the quality of life from one generation to the next.

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CHAPTER 3

EXPLORING MINIMAL PROCESSING TECHNIQUES FOR FRESH FRUITS AND VEGETABLES: TRENDS, BENEFITS, AND CHALLENGES

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1. Introduction

Minimal processing (MP) refers to various techniques, methods, or procedures used to transform plant or animal-based foods into ready-to-eat products while preserving their nutritional and sensory qualities. This process also meets consumer demands for convenience, a fresh appearance, no chemical additives, and enhanced nutritional value, making it a recent concept in food technology (Velderrain-Rodríguez et al., 2019). A more specific definition places minimal processing methods within the framework of traditional technologies, defining them as techniques that "maintain food preservation while more effectively preserving nutritional value and sensory qualities by minimizing the use of heat as the main preservation mechanism" (Ohlsson & Bengtsson, 2002).

Minimally processed foods (MPFs) are associated with "fresh-like" attributes. These foods are lightly processed, with temperatures kept below 100°C, and are subsequently packaged. After processing, they are either frozen or refrigerated (Rodgers, 2016). Minimal processing involves minimal alterations, such as washing, crushing, grinding, boiling, roasting, filtering, pasteurization, freezing, packaging, refrigeration, and fermentation, excluding those that involve alcohol use. These methods often involve foods directly obtained from nature without adding culinary ingredients (Wójcicki et al., 2019; Dávila-Aviña et al., 2015; Basile et al., 2024). Furthermore, MPFs are those in which chemical, biological, and physical hazards are kept within acceptable levels (Snyder et al., 2003).

According to Baysal and İçier (2012), MPFs;

- Have undergone mild preservation treatments or other treatments that reduce the initial microbial load of the food,
- Remain at temperatures between 0°C and 100°C during processing,
- Are stored or transported in cold conditions to prevent the growth of unwanted microorganisms or control their development,
- Have a shelf life of more than 5 days,
- Have a water activity above 0.85,
- Have a pH value greater than 4.5
- Do not require heating prior to consumption.

MPFs can be divided into four groups. The 1st group contains foods that require no cooking intervention. The supplier or grower ensures that pathogenic substances are at a safe level. The 2nd group includes foods that undergo mild disinfection, i.e., reducing pathogenic substances and chemicals by a factor of 10^{-2} to 10^{-5}. The 3rd group comprises pasteurized foods, where pathogens (typically *Salmonella*) are reduced by a factor of 10^{-5} to 10^{-7}, both inside the food and on its surface. Pasteurization can be achieved through various methods, including irradiation, ultraviolet light, pulsed light, heat, or high pressure. The final group includes foods made safe through processes such as fermentation, salting, drying, or acidification. Fig. 1 displays the groups of MPFs along with examples for each group (Snyder et al., 2003).

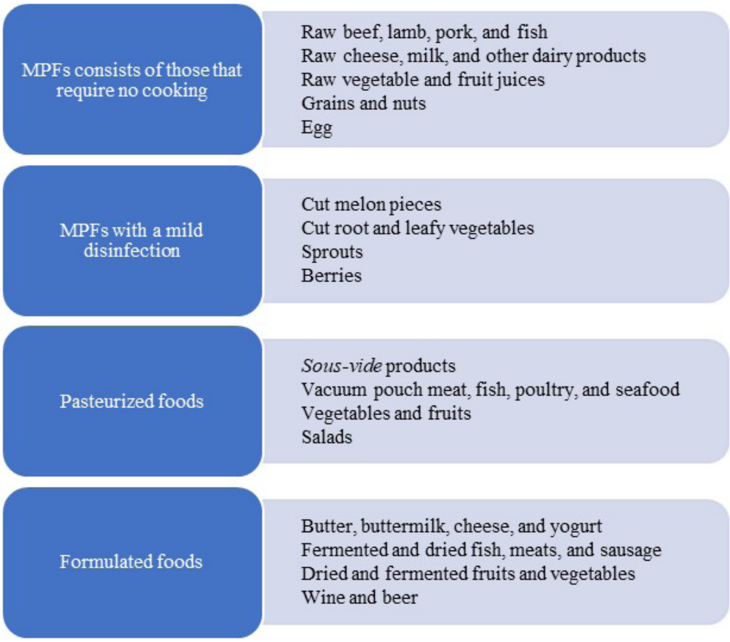

Fig. 1. *The groups of MPFs and food examples (Snyder et al., 2003)*

Contamination of fruits and vegetables can occur at multiple stages: in the pre-harvest phase, while the plants are growing in the field, during harvesting, and in the post-harvest phase, which includes processing, packaging, and transport. The various stages involved in processing fruits and vegetables comprise several steps, as shown in Fig. 2. Contamination of plants is influenced by environmental microbiota, including both non-pathogenic and pathogenic microorganisms, which can introduce health risks throughout the plant's life cycle. Pathogens from feces, such as *E. coli* O157:H7, can survive in soil for months, especially when animal waste is improperly composted. Crops near the ground, such as lettuce, are vulnerable to contamination. Irrigation water, particularly when contaminated or derived from wastewater, is another major source of pathogens, contributing to foodborne outbreaks. Insects, especially flies attracted to manure, can spread pathogens and damage plant tissues, thereby increasing the risk of contamination. Additionally, human factors, such as poor hygiene during harvesting, handling, and processing, as well as improper storage and cross-contamination, exacerbate contamination. The cutting stage of minimally processed vegetables, like lettuce, is particularly susceptible to contamination due to its increased surface area and tissue damage. To reduce contamination risks, careful management of soil, water, insects, and hygiene practices is essential throughout food production (Santos et al., 2023).

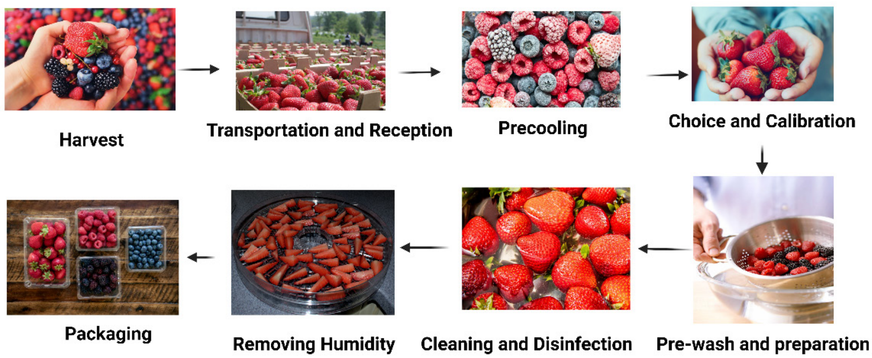

Fig. 2. *The stages of MP fruit and vegetable processing, from farm to packaging (Santos et al., 2023)*

MPFs are foods that undergo limited changes from their natural state. They are often considered healthier due to their higher nutritional content and fewer artificial additives. However, they are more susceptible to microbial growth of foodborne pathogens as they retain much of their natural moisture and structure and are therefore particularly vulnerable to contamination by foodborne pathogens, either directly or through cross-contamination during food preparation (Pinela & Ferreira, 2017; Capozzi et al., 2009). This makes proper preservation techniques crucial to ensuring their safety and longevity. Pathogens such as *Listeria* spp., *E. coli* O157:H7, and *Salmonella* spp., are frequently linked to outbreaks involving fruits and vegetables, posing a significant public health risk (Pinela & Ferreira, 2017). Without effective processing and preservation, microorganisms like bacteria, fungi, molds, and yeasts can rapidly spoil food, leading to potential health hazards (Rawat, 2015). To reduce these risks, various preservation methods are employed to extend the shelf life of MPFs while maintaining their flavor, nutritional value, and texture. Furthermore, proper handling, processing, packaging, transportation, and storage are essential for minimizing post-harvest losses of fruits and vegetables (Rawat, 2015).

MP fruits and vegetables must meet several key requirements for both quality and safety. These include using high-quality raw materials, adhering to strict hygiene and safety standards (such as HACCP and GMP), and maintaining low temperatures during processing. The produce should be carefully cleaned and washed with clean, high-quality water. Mild additives may be used to prevent browning or to disinfect. Gentle drying, cutting, and packaging methods are essential, as well as maintaining proper temperature and humidity during distribution and retail to ensure the produce remains fresh and safe for consumption (Laurila & Ahvenainen, 2002).

There is a growing demand for innovative techniques to maintain quality by preventing unwanted microbial growth throughout the production and distribution process. Recent advancements in minimal processing techniques include the use of chlorine dioxide, calcium-based solutions, ozone, ultraviolet light, heat, antimicrobials, antioxidants, electrolyzed water, irradiation, and ultrasound. Additionally, the use of advanced packaging systems and the implementation of combined technologies (hurdle technology) are being explored to enhance microbial control (De Corato, 2019).

In the following sections, we will explore some of the most widely used and effective methods for preserving MPFs, discuss the benefits and challenges associated with these products, and highlight recent advances and innovations in the field.

2. Types of Minimal Processing Techniques

Thermal techniques employed in food processing and storage can induce desired changes, including protein coagulation, starch gelatinization, texture modifications, and the creation of aroma compounds. Additionally, thermal processing offers several benefits, including the elimination of foodborne pathogens and toxins, extended shelf life, improved nutrient digestibility and bioavailability, enhanced texture, taste, and flavor, as well as improved functional properties, such as increased antioxidants and antimicrobial effectiveness (Van Boekel et al., 2010). However, these techniques can also result in undesirable effects, such as the loss of vitamins and minerals, the formation of certain compounds through the thermal reactions of biopolymers, and changes in taste, appearance, and texture that may negatively impact sensory appeal (Baysal & İçier, 2012). Furthermore, thermal processing can cause the formation of toxic compounds like furan, acrylamide, and acrolein (Van Boekel et al., 2010; Koszucka & Nowak, 2019).

Techniques for producing minimally processed fruits and vegetables vary based on the desired shelf life. Simple processing methods are sufficient for short shelf life (e.g., one or two days for catering). However, for longer shelf lives (e.g., several days to a week for retail marketing), more advanced and sensitive techniques, as well as higher investment, are required. Preservation is often achieved through the combination of multiple treatments (Wasana & Kariyawasam, 2020).

Physical preservation methods have gained importance recently due to their health benefits and eco-friendliness compared to chemical methods. These methods are categorized into thermal technologies, such as hot air and water, and non-thermal technologies, including irradiation, high pressure, ultraviolet radiation, and electrolyzed water. Additionally, storage strategies for minimally processed fruits and vegetables (MPFVs) have garnered attention, leading to advances in packaging (e.g., edible films, active, and intelligent packaging) and modified atmospheric conditions (e.g., controlled atmospheres and vacuums) (Gomes et al., 2023).

Preserving MPFVs involves a combination of preparatory operations, physical preservation methods, and advanced packaging techniques to guarantee food safety, quality, and extended shelf life. Preparatory steps, such as cleaning and cutting, remove contaminants and reduce microbial load. Physical methods, including both thermal (e.g., hot water or air treatment) and nonthermal (e.g., irradiation, high pressure, UV radiation), control microbial growth and preserve the produce's nutritional and sensory qualities. To further extend shelf life, packaging techniques such as edible films, active packaging, and modified atmospheres are used. These methods work together to create an optimal storage environment, thereby reducing post-harvest losses and ensuring the production of fresh, safe, and appealing products.

2.1. Preparatory Operations

Preparatory operations are crucial in enhancing the quality of fruits and vegetables during processing. Before implementing any MP techniques, essential tasks such as washing, cutting, peeling, and shredding must be completed. The choice of these processes depends on the features of the raw material and its intended purpose (Pasha et al., 2014).

Washing: Preliminary washing of raw materials is essential in food processing to remove impurities such as sand, mud, and other inert materials. While cleaning before peeling or cutting is important, a second wash is crucial to remove tissue fluids and microbes, which helps reduce microbial activity and enzymatic oxidation during processing and storage (Ali et al., 2018; Wasana & Kariyawasam, 2020). Commercial washing systems can vary greatly in effectiveness. Removing dirt and contaminants is inconsistent, pesticide removal is limited, and extending shelf life through washing is virtually impossible (Seymour et al., 2002). The microbiological quality, water temperature, and contact time are key elements that impact the product's quality and shelf life. Dipping produce in water is the simplest method, but using flowing or air-bubbling water is more effective. Washing helps remove damaging enzymes from wounded surfaces, a critical step for ready-to-eat products. After washing, gentle water removal is recommended (Wasana & Kariyawasam, 2020).

***Peeling & Cutting**:* Peeling is the process of removing the outer layer of fruits or vegetables when it is inedible or when the presentation demands it. This can be done manually, mechanically, or through enzymatic methods, with the option of using hot water or high-pressure steam. It is crucial to peel the fruit or vegetable gently to minimize abrasion, as excessive force can lead to the penetration of microorganisms into the internal tissues, a process known as internalization, and can also prevent the fruit or vegetable from darkening. Cutting is a process that reduces the size of fruits or vegetables through methods such as slicing, chopping, grating, or cutting into cubes or sections. This can be done either manually or mechanically. Using sharp cutting tools is essential to minimize cell damage, helping to preserve the food's quality and structure (Melo & Quintas, 2023).

Rinsing: Rinsing is the process of removing excess surface water and disinfectant residues from MPF. Leftover moisture on the surface and the exudation from freshly cut fruits can encourage the growth of fungi and bacteria. It is crucial to rinse gently to prevent any damage to the fruit tissues while effectively eliminating these residues (Melo & Quintas, 2023).

These preparatory steps help ensure that fruits and vegetables remain safe, fresh, and high-quality during minimal processing.

2.2. Physical Preservation Methods

Physical preservation methods are essential techniques used to extend the shelf life and maintain the quality of food, particularly fruits and vegetables, by controlling or preventing microbial growth, enzymatic activity, and physical deterioration. Unlike traditional chemical preservation methods, these methods rely on nonchemical approaches, such as heat, pressure, radiation, and other physical forces, to preserve food while keeping its nutritional, sensory, and functional properties intact. As consumer demand for healthier MPFs increases, physical preservation methods are gaining popularity in the food industry due to their ability to maintain the natural characteristics of the product and reduce the reliance on preservatives. Common physical preservation techniques include thermal treatments (such as hot water or air treatment), non-thermal treatments (like high-pressure, irradiation, and ultraviolet radiation), and innovative methods such as electrolyzed water. Each method offers distinct advantages and can be customized to meet the specific requirements of the product, ensuring food safety and extending shelf life without compromising quality.

Cold Storage and Refrigeration: Cold minimal processing techniques, such as freezing, chilling, blast freezing, cryogenic freezing, modified atmosphere packaging (MAP), cool storage with humidity control, and vacuum cooling, preserve food by slowing spoilage through low temperatures and, in some cases, adjusting the environment's gas concentration while maintaining its quality and nutrients. Cooling inhibits microbial growth at temperatures between −1°C and 4°C, while freezing requires temperatures of approximately −18°C to −30°C to prevent bacterial growth. However, both enzymatic and nonenzymatic changes still occur, albeit at a minimal rate. In the cooling method, both enzymatic and nonenzymatic activities persist, allowing microbial growth to continue. As a result, freezing is used to better control microbial growth and enzymatic activity (Ali et al., 2022). While cooling is beneficial, prolonged refrigeration can lead to chilling injury, especially in tropical and subtropical produce. However, MPFVs typically avoid this due to their short storage time. Since MPFs are more perishable, they should be kept at lower temperatures than intact produce (Gomes et al., 2023). Cold storage plays a vital role in enhancing the shelf life and preserving the quality of fruits and vegetables. Studies have shown that storing produce at lower temperatures helps maintain freshness, slows down respiration, and delays ripening. For example, a study on apricots found that keeping them at 1°C reduced weight loss and minimized symptoms of chilling injury when compared to storage at 5°C. Furthermore, apricots stored at 1°C retained higher levels of antioxidants throughout the storage period (Kafkaletou et al., 2023). Moreover, mangoes stored in a Coolbot™ cold room lasted 23 days longer than those kept at room temperature. The cold storage also slowed down the mangoes' respiration, helping to preserve their firmness and reduce changes in ripening, both in the peel and flesh (Ambuko et al., 2016).

Chlorination: Chlorine-based substances, including liquid chlorine, chlorine dioxide, and hypochlorite, are the primary sanitizers used to disinfect fresh produce (Cardador & Gallego, 2012). The most utilized sanitizer, chlorine, is often applied in wash, spray, or flume waters for fresh fruits and vegetables. Chlorine is an effective and cost-efficient disinfectant, widely available and usually used in food processing due to its ability to reduce microbial contamination (Wasana & Kariyawasam, 2020). Chlorine, however, has a limited effect on reducing microorganisms on the surfaces of fruits and vegetables (Garcia et al., 2003). Chlorination is effective to an extent, but its efficiency diminishes at high pH levels or against spore-forming microbes. However, it is stated that chlorine, while effective against bacteria, mold, yeast, and viruses, is ineffective against spores (Chinchkar et al., 2022). The effectiveness of chlorine in reducing pathogens depends on elements such as the type of produce, chlorine concentration, and exposure time. Research has shown that increasing exposure time to chlorine improves its antimicrobial effect. For instance, treating peaches with chlorine for 40 min led to a 1.6 log reduction in *Listeria innocua* (Shen et al., 2024). Moreover, it can produce harmful byproducts such as trihalomethanes and haloacetic acids, negatively impacting human health and the environment. For example, studies have found that about 23% of minimally processed vegetables, sanitized with a chlorine solution, contained at least two types of haloacetic acids, with concentrations ranging from less than 0.4 to 24 µg/kg (Cardador et al., 2012). Additionally, chlorine can cause off-flavors and alter the taste of the fruits and vegetables (Horvitz & Cantalejo, 2014; Mendoza et al., 2022). Due to challenges such as the creation of disinfection by-products and variable efficacy, chlorination, while effective in reducing microbial load and prolonging the shelf life of minimally processed fruits and vegetables, may not always be the ideal solution. Exploring alternative sanitization methods, like peracetic acid (PAA), ozonated water, and chlorine dioxide, could provide viable solutions to improve food safety while maintaining product quality (Fatica & Schneider, 2009).

Ozone treatment: Ozone is a triatomic form of natural oxygen, first identified in 1840. Its formation can be represented by the following reaction:

$$3O_2 \leftrightarrow 2O_3 + Heat + Light$$

Ozone is moderately soluble in water, with its solubility increasing as the temperature decreases, typical of most gases. It effectively destroys microorganisms by oxidizing their cell membranes, deodorizes organic matter, bleaches substances, prevents putrefaction, and helps in degrading mycotoxins (Pasha et al., 2014). Ozone is considered one of the most promising methods for decontaminating fresh produce, with numerous applications in the food industry. Ozone technology for prolonging the shelf life of food is regarded as a nonthermal preservation method that enhances food safety without compromising quality or harming the environment. Meanwhile, ozone does not present any safety concerns regarding the presence of chemical residues in treated food products. Ozone's precursors are readily available and cost-effective, and it can be applied either in its gaseous or aqueous form, depending on the type of commodity (Horvitz & Cantalejo, 2014; Sarron et al., 2021). As ozone is a very unstable molecule that spontaneously decomposes into oxygen atoms at room temperature, it cannot be collected, stored, or transported. Consequently, it must be generated continuously on-site (Pasha et al., 2014). Ozone's sanitizing properties are favored in the food sector because it decomposes into harmless oxygen, leaving no residues. While it can react with organic compounds, the by-products are safe for human health. In contrast, chemicals like chlorine can produce harmful by-products linked to cell damage and degenerative diseases (Pascual et al., 2007). Moreover, using ozone in minimal processing can increase the antioxidant levels in products and help slow down the ripening of fruits and vegetables when stored at low temperatures. Ozone has an oxidation potential 1.5 times higher than chlorine, making it more effective against a broader range of microbes than chlorine and other sanitizers (Mendoza et al., 2022; Wasana & Kariyawasam, 2020). Ozone is effective in eliminating both Gram-positive (e.g., *L. monocytogenes*, *S. aureus*) and Gram-negative bacteria (e.g., *P. aeruginosa*, *Y. enterocolitica*), together with spores and vegetative cells. It also efficiently inactivates yeasts (e.g., *C. albicans*), fungal spores, and a variety of viruses, including hepatitis A and influenza A (Horvitz & Cantalejo, 2014). A study by Abd El-Moniem et al. (2022) found that gaseous ozone treatment enhanced the quality attributes of fresh-cut avocados, including soluble solids content, ascorbic acid levels, and concentrations of chlorophyll and carotenoids. Specifically, exposure to 40 ppm ozone for 45 min extended the storage life of avocado slices when stored under cold conditions. Additionally, ozone treatment effectively reduced pesticide residues and helped maintain the green color of fresh-cut peppers during storage. The ozone-treated samples showed minimal changes in color, preserving their visual appeal throughout the storage (Özen et al., 2021). Moreover, a study conducted by Li et al. (2022) found that ozone exposure increased the total phenol content and antioxidant capacity in fresh-cut dragon fruit. The 4 mg L^{-1} ozone treatment helped maintain higher levels of ascorbic acid and phenolic compounds during storage, contributing to improved nutritional quality.

Electrolyzed water (EW): EW is produced by passing a salt solution, approximately 1% NaCl, through an electrochemical cell that comprises inert platinum electrodes with positive and negative charges. This process generates water with enhanced properties for various applications. During the process, the anode and cathode are separated by a membrane, resulting in the production of acidic and alkaline EW. The acidic EW has a high reduction-oxidation (redox) potential (greater than 1000 mV) and a low pH, ranging from 2.3 to 2.7. In contrast, alkaline EW possess a lower redox potential (between 800 and 900 mV) and a higher pH (varying from 10.0 to 11.5) (Mendoza et al., 2022). EW, containing HOCl as a sanitizer and NaOH as a cleaner, has gained popularity in recent years. It is made from regular water and only requires NaCl, without the need for harmful chemicals. The ease of production and application has contributed to its popularity. EW is now widely accepted as a sanitizer, with diverse uses in agriculture, food sanitation, and other fields that rely on antimicrobial methods. EW demonstrates antimicrobial activity against a broad range of microorganisms, effectively eliminating most common bacteria, viruses, fungi, and spores in a short time (typically within 5 to 20 s). According to Tango et al. (2017), combining slightly acidic electrolyzed water with agents like calcium oxide and fumaric acid, followed by ultrasonication, significantly reduced bacterial contamination on apples and tomatoes. This combination also improved microbial safety while maintaining the quality of the fruits during storage. It is effective on food products, processing surfaces, and non-food surfaces (Rahman et al., 2016). EW offers several benefits over toxic alternatives in fields like food, agriculture, and medicine. It is produced from table salt (NaCl) and distilled water, and after use, it returns to its original form, posing no threat to humans or the environment. One key advantage is its on-site production, which eliminates issues related to the transport, storage, and handling of chlorine. EW is effective against a wide range of bacteria, exhibiting nonselective antimicrobial properties, and it is believed not to contribute to bacterial resistance. Additionally, EW is cost-effective (Rahman et al., 2016). EW aids in food decontamination while maintaining the nutritional content and bioactive compounds, including polyphenols, flavonoids, and vitamin C. This improves food acceptability with minimal weight loss and firmness (Meghwar et al., 2024). Furthermore, alkaline and acidic electrolyzed water treatments effectively removed pesticide residues from fresh-cut broccoli, cabbage, and colored peppers. The study found that treatment duration and oscillation methods influenced the efficacy without compromising the texture quality of the vegetables. Despite its advantages, several disadvantages are associated with the use of EW. These include the high initial cost of purchasing the equipment, the potential formation of chlorine gas by some machines, which can cause discomfort for the operator, and the corrosive nature of EW, which can irritate hands and be phytotoxic due to its high oxidation-reduction potential or free chlorine content. Additionally, the antimicrobial activity of EW may be reduced by the presence of organic matter or improper storage (Hricova et al., 2008).

Irradiation: Irradiation uses ionizing radiation to increase microbial safety and prolong the shelf life of food. It is considered an effective, safe, and nutritionally sound method of food processing when used with the right technology (Wasana & Kariyawasam, 2020). The main advantage of irradiation is that ionizing radiation leaves no residual traces. It helps reduce chemical exposure in food, making it a safer alternative for food processing (Goel et al., 2025). In addition to microbial destruction, irradiation offers benefits such as fewer foodborne illnesses, longer shelf life, and improved product quality. However, its use is currently limited to a small range of foods due to consumer acceptance and legal restrictions (Arapcheska et al., 2020). The effect of irradiation on food depends on several factors, including the type of irradiation, its energy level, temperature, food composition, physical state, and the atmospheric conditions of the material being treated. The irradiation process generates energetic electrons and free radicals in the food, which damage the DNA of target microorganisms, leading to their death. When irradiating frozen foods, a higher dose and longer exposure time are needed to effectively kill the microorganisms (Ibrahim, 2020). According to a study conducted by Chaudry et al. (2004), irradiation doses of 1.0 kGy and above effectively reduced microbial load in minimally processed carrots during a two-week storage period at 5°C, with no negative impact on firmness or sensory attributes. A dose of 2.0 kGy completely eliminated fungal and bacterial counts.

Ultraviolet (UV) radiation: Ultraviolet (UV) radiation is an effective nonthermal technology for disinfecting and decontaminating fresh-cut fruits and vegetables. UV radiation spans a wavelength range of 100–400 nm, which is further divided into UV-C (100–280 nm), UV-B (280–315 nm), and UV-A (315–400 nm). This cost-effective technology is popular in the fresh-cut industry because it operates with low set-up and maintenance costs, while also preventing chemical residues that could affect the sensory qualities of the products (Ali et al., 2018). Especially, UV-C light is becoming increasingly recognized as an effective method for improving the safety and quality of minimally processed fruits and vegetables. Studies have shown that it reduces microbial contamination, boosts the production of bioactive compounds, and helps extend shelf life. For example, using UV-C irradiation in combination with modified atmosphere packaging effectively inactivated *Salmonella enterica serovar Typhimurium* on cherry tomatoes, which helped extend their shelf life during cold storage (Esua et al., 2020). Moreover, UV-C treatment has also been shown to increase the levels of beneficial phytochemicals, such as ascorbic acid, glucosinolates, carotenoids, and phenolic compounds. The extent of this increase varies based on factors like the type of produce, UV dose, its maturity stage, and exposure conditions (Darré et al., 2022). Factors such as UV-C dose, exposure time, and the specific characteristics of the produce, along with combining UV-C irradiation with other methods like modified atmosphere packaging, significantly influence the effectiveness of the treatment in enhancing produce safety and quality.

Gamma radiation: Gamma radiation consists of high-frequency rays emitted by high-energy protons that can penetrate cells and induce ionization. This process kills bacteria by damaging their DNA, which prevents cell division. It is a cost-effective and safe method commonly used to sterilize healthcare products, prolong shelf life, and reduce the microbial load in food (Goel et al., 2025). Gamma irradiation at a dose of 2.0 kGy effectively reduced microbial counts and inhibited polyphenol oxidase activity, helping to maintain the green color and overall quality of minimally processed kiwi fruit stored in the refrigerator for up to 16 days. This treatment also preserved the levels of ascorbic acid, total phenols, and chlorophyll (Hussain et al., 2021).

Cold Plasma: Cold plasma is a partially ionized gas created by applying high voltage, high frequency, or a combination of both. It has been researched as a potential method for decontaminating food at room temperature and atmospheric pressure (Jadhav et al., 2021; Mendoza et al., 2022). Cold plasma is a promising technology for the fresh-cut industry, as it can clean produce while keeping its taste, safety, and nutritional value intact. Unlike traditional preservatives, it doesn't harm food quality and works at room temperature. It kills bacteria by damaging their cell walls and disrupting their structure, particularly in gram-negative bacteria (Goel et al., 2025). Moreover, cold plasma is an emerging technology that has recently gained attention in the food processing industry due to its lack of residue formation, reduced processing times, absence of toxicity, and relatively simple and affordable experimental setup. In recent years, cold plasma has demonstrated unique advantages and applications in the food industry. These include eco-friendly sterilization of surfaces in contact with food, such as polyethylene and stainless steel, as well as food packaging materials. Cold plasma treatment can also produce antimicrobial packaging films by immobilizing substances like triclosan, silver, and silver ions into the films. Additionally, cold plasma is used in in-package food processing, microorganism and biofilm inactivation on food surfaces, removal of toxins, inactivation of enzymes, allergens, and anti-nutrients, and the degradation of pesticides and dyes, among other benefits (Mao et al., 2021). According to a study on the efficiency of cold plasma, increasing the water activity of dried figs from 0.70 to 0.93 improved the effectiveness of cold plasma in reducing populations of *Escherichia coli O157:H7* and *Listeria monocytogenes*. Additionally, lowering the figs' pH from 6 to 4 had a synergistic effect, further enhancing microbial inactivation (Lee et al., 2015). Cold plasma treatment has been shown to effectively inactivate pathogens in fresh-cut fruits and vegetables without impacting their quality. For instance, cold plasma treatment successfully reduced the microbial load on lettuce, enhancing safety while maintaining its quality (Song et al., 2015). Furthermore, combining indirect cold plasma with MAP has been shown to reduce microbial load and delay quality deterioration in fresh produce. This method extended the shelf life of cucumbers, cherry tomatoes, and lettuce by two additional days while preserving their quality (Liu et al., 2024).

Thermal Treatments: Thermal treatments use high temperatures to control pathogens, effectively targeting both those inside and on the surface of fruits and vegetables. This method is a chemical-free and efficient way to preserve MPFs. Heat treatments can reduce the physical and nutritional quality of fruits and vegetables, leading to a loss of heat-sensitive vitamins and potential damage. This highlights the need for careful application of the technique. Heat treatment, applied at temperatures of 40 to 60°C using water, steam, or air, is commonly used in minimal processing. It improves product quality and extends shelf life, making it a sustainable method for preserving MPFVs (Gomes et al., 2023). The conventional thermal processing of fruits and vegetables includes pasteurization and sterilization. The main difference between them is the temperature and processing time. Sterilization aims to eliminate all bacterial contaminants, including spores, providing a long shelf life without refrigeration. In contrast, pasteurization may not inactivate spores, resulting in a shorter shelf life for the product. Thermal sterilization and pasteurization ensure microbial safety but result in nutrient losses, such as Vitamin C and carotene, making the food less nutritious. To balance sterilization and nutrient retention, novel technologies are now being combined with thermal treatments to achieve effective sterilization in a shorter exposure time (Soni & Brightwell, 2022).

High Pressure: High-pressure processing (HPP), also known as high hydrostatic pressure (HHP) or ultra-high pressure (UHP), involves applying pressures of around 600 MPa to food products, often at temperatures below 40°C (Mieszczakowska-Frąc et al., 2021). HPP is a nonthermal pasteurization technique used for sealed food products in their final packaging. The sealed packages are placed in an HPP vessel and exposed to high isostatic pressure (above 400 MPa or 58,000 psi) at low temperatures or sometimes at ambient temperature. This process inactivates harmful microorganisms, including bacteria, mold, yeast, viruses, and parasites, while extending the shelf life and ensuring the safety of refrigerated foods. Since HPP does not involve heat, the food retains its nutritional value, flavor, and freshness (Ibrahim, 2020). This method enhances microbiological stability, reduces enzyme activity, and better retains bioactive compounds (like vitamin C) compared to traditional thermal processing. HPP is environmentally friendly, effectively destroys pathogens, and is especially popular in the cold-pressed juice market (Mieszczakowska-Frąc et al., 2021). HHP is used in the food industry to enhance nutritional quality, extend shelf life, prevent degradation, modify properties, alter microstructures, and support product development across a variety of food products, such as dairy, vegetables, fruits, fish, meat, and meat products (Ali et al., 2022).

Ultrasound: Ultrasound technology uses vibrational energy in the frequency range of 20–100 kHz, which is above the range of human hearing (Ali et al., 2018; Goel et al., 2025). Ultrasound processing generates mechanical and chemical effects by propagating acoustic waves, which alter the food structure at various levels. Ultrasound effects on food structure are challenging to predict or generalize due to the complexity of fruits and vegetables. These products vary in form (solid or liquid) and structure (tissue type, size, and composition). Additionally, processing conditions, such as the wave propagation medium, type of ultrasound equipment, and factors like power, frequency, time, and temperature, significantly impact the level of structural modification (Rojas et al., 2021). High power ultrasound, with intensity ranging from 10 to 1000 W cm^{-2} and frequencies between 16 and 100 kHz, is widely used in food processing, preservation, and safety (Ali et al., 2018). Ultrasound technology is an emerging nonthermal method that offers advantages over traditional thermal processes, including energy savings, shorter processing times, improved food quality, and extended shelf life. It also allows for high automation, reducing labor costs. The food industry has extensively studied ultrasound for applications like drying, cleaning, tenderization, sterilization, and curing (Chen et al., 2020). Ultrasound processing has been found to boost the bioaccessibility of phenolic compounds and improve antioxidant capacity in vegetables like lettuce and green pepper, without adversely affecting their physicochemical properties (Lafarga et al., 2019). In addition, ultrasound treatment has been found to preserve the firmness of strawberries and slow down softening during storage, helping to maintain their quality (Fan et al., 2019). Ultrasound is a powerful, minimally processed method that improves microbial safety, preserves nutritional value, and maintains the quality of fruits and vegetables, offering a promising alternative to conventional processing methods.

Pulsed Electric Fields (PEFs): The pulsed electric field (PEF) technique is a nonthermal technique that uses high-voltage electrical pulses, minimizing thermal effects and setting it apart from other thermal electrical techniques like ohmic heating. PEF is used to reduce microbial activity, extract valuable compounds, and enhance mass transfer by disrupting cells, all while minimizing damage. Its quick operation makes it more efficient than traditional methods, and it is increasingly applied for extracting high-value components and studying mass transfer (Ali et al., 2022).

Physical preservation techniques, such as cooling, freezing, and treatments like MAP, are essential for prolonging the shelf life of fruits and vegetables while preserving their quality and nutritional value. These methods work primarily by slowing down microbial growth, enzymatic reactions, and other spoilage processes. While cooling and freezing are effective, each method has its limitations, such as the risk of chilling injury in certain crops or reduced effectiveness against specific microorganisms. Despite these challenges, minimal processing and physical preservation remain crucial in the fresh produce industry, helping to provide safer and longer-lasting products. Future improvements in these techniques, along with their combination with other preservation methods, could enhance their efficiency, reduce food waste, and improve food safety for consumers. Pulsed electric field treatment has been found to boost the levels of bioactive compounds, including total polyphenols, lycopene, and vitamin C, in tomatoes. For instance, applying 30 pulses at 1.2 kV/cm resulted in a 44% increase in total polyphenol content. Additionally, when combined with natural preservatives like tea polyphenols, PEF helped maintain vitamin C levels in cantaloupe juice, demonstrating its potential to preserve nutritional quality (Vallverdu-Queralt et al., 2012; Li et al., 2021). Furthermore, PEF treatment improved the peeling efficiency of tomatoes and kiwi fruits, providing a viable alternative to conventional thermal peeling methods (Giancaterino & Jaeger, 2023).

2.3. Packaging Techniques

Packaging techniques play a crucial role in preserving the quality, safety, and shelf life of fruits and vegetables. As fresh produce is highly perishable, effective packaging not only protects against physical damage but also helps in controlling environmental factors such as temperature, moisture, and oxygen levels, which can accelerate spoilage. From simple plastic wraps to advanced methods like MAP and vacuum sealing, these techniques are designed to slow down the natural deterioration processes, reduce microbial contamination, and maintain the nutritional value and freshness of produce. With increasing consumer demand for fresh, high-quality products, packaging has become a vital tool in the food industry, helping to minimize food waste, ensure food safety, and meet the logistical challenges of distribution.

Modified Atmosphere Packaging (MAP): MAP creates a controlled environment with low oxygen and high carbon dioxide to slow down spoilage, ripening, and other deterioration processes. This is achieved by adjusting the packaging's permeability to CO_2. However, as plant materials continue to respire, CO_2 levels can increase too much, so gradual release is needed. Higher CO_2 levels help inhibit microorganism growth but are most effective under refrigerated conditions. Therefore, MAP products should be stored in a cold environment to optimize quality and shelf life (Wasana & Kariyawasam, 2020). MAP plays a significant role in preserving the quality and prolonging the shelf life of fresh-cut fruits and vegetables. MAP is a widely used for preserving fruits and vegetables during handling and distribution. It is particularly effective in extending the shelf life of fresh-cut produce by reducing respiration rates. MAP is commonly used for various fresh-cut fruits and vegetables, including salads, sliced fruits and packaged vegetables, helping producers and retailers maintain high-quality products throughout the distribution chain (Yousuf et al., 2018).

Controlled atmosphere storage: Controlled Atmosphere Storage (CAS) is a method where the levels of ambient gases are carefully regulated. It involves maintaining a sealed storage environment equipped with oxygen (O_2) and carbon dioxide (CO_2) analyzers, along with systems to remove or inject gases as needed to control the atmosphere. CAS is generally more expensive than MAP due to the continuous maintenance of gas levels in large storage chambers. Nonetheless, when combined with proper temperature control and post-harvest handling, CAS can significantly prolong the shelf life of perishable foods. It is mainly used for high-value products like apples and pears (Gomes et al., 2023). Research investigated the effects of controlled atmosphere (CA) storage, MAP, and gaseous ozone treatment on the survival of *Salmonella Enteritidis* on cherry tomatoes. These methods successfully reduced microbial presence, improving safety without compromising the quality of the tomatoes (Daş et al., 2006). Also, the study assessed the visual quality of minimally processed Romaine and Iceberg lettuces stored in air versus controlled atmosphere. The findings indicated that controlled atmosphere storage enhanced color retention, minimized decay, and prolonged shelf life while maintaining the quality of the lettuces (Lopez-Galvez et al., 1996).

Vacuum Packaging: Vacuum packaging, a type of MAP, offers benefits over traditional packaging, including reduced microbial growth, improved gas barrier properties, control of oxidation-reduction, and prevention of discoloration. While vacuum packaging offers several benefits for MPFVs, combining it with other technologies like active and intelligent packaging could further improve storage outcomes. These additional technologies could enhance preservation by actively monitoring and adjusting conditions, improving shelf life and quality (Gomes et al., 2023). Research shows that vacuum packaging significantly extends the shelf life of MP lettuce. Lettuce packed under vacuum remained acceptable for up to 10 days at 4°C. It displayed lower polyphenol oxidase activity, better color retention, and reduced loss of vitamin C and chlorophyll compared to MAP and non-packaged controls (Cha et al., 2007). Combining vacuum packaging with probiotic coatings has proven effective in improving the safety and quality of fresh-cut cantaloupe. This approach significantly reduced microbial loads during storage at various temperatures, including psychrotrophic bacteria, yeasts, molds, and Listeria monocytogenes (Hua & Li, 2025). Additionally, vacuum packaging has been shown to preserve the total antioxidant capacity and phenolic content of various berries during storage. Berries stored under vacuum at 4°C retained higher levels of these compounds than those stored without vacuum packaging, indicating that vacuum packaging helps slow enzymatic and oxidative reactions, thus maintaining nutritional quality (Nisari et al., 2025).

Antioxidant coatings and edible films/coatings: For centuries, edible films and coatings, such as wax on fruits, have been applied to prevent moisture loss and enhance the fruit's shiny appearance for aesthetic purposes. These thin layers, which can surround food or be placed between its components, are designed to be consumed along with the food (Pavlath & Orts, 2009). The purpose of using edible films and coatings is also to prevent gas, lipid, and aroma migration. Additionally, due to some of their functional properties, they also serve as active packaging materials by carrying antioxidants, antimicrobial agents, color, and flavor compounds (Bourtoom, 2008). Edible coatings and films are increasingly being used in the food industry, particularly for MPFVs, to improve shelf life, maintain quality, and provide a protective barrier (Baysal & İçier, 2012). These natural films and coatings are obtained from plants and animals in the form of polysaccharides, lipids, and proteins (Chhikara & Kumar, 2022). Edible coatings serve as a packaging solution to prolong the shelf life of fresh-cut fruits and vegetables. Made from natural materials, these coatings are eco-friendly and help improve the quality of the produce (Yousuf et al., 2018). Edible films are pre-formed structures that wrap or cover food after being created, while coatings are applied directly to food products to provide protection. Edible films include starch-based films (from corn, potato, or tapioca), gelatin, chitosan, alginate, cellulose, protein-based films (from whey or casein), pectin, lipid-based films, xanthan gum, and gellan gum, all used for coating or packaging foods to enhance shelf life, moisture retention, and texture (Díaz-Montes & Castro-Muñoz, 2021). Edible films are initially formed as thin solid layers or sheets and then used to wrap the food. In contrast, edible coatings are applied in liquid form, typically by immersing the food in a solution containing substances like carbohydrates, proteins, or lipids (Yousef et al., 2018). Edible coatings include wax (like carnauba or beeswax), chitosan, starch-based coatings (from corn, potato, or tapioca), gelatin, alginate, carrageenan, protein-based coatings (like whey or casein), cellulose, lipid-based coatings, and natural spice coatings (such as cinnamon or clove), all used to enhance shelf life, texture, appearance, or prevent spoilage of various foods (Liyanapathiranage et al., 2023).

Natural preservatives and antimicrobial packaging: Antimicrobial food packaging is designed to prevent the growth of spoilage or harmful microorganisms in food or packaging materials. It acts as a delivery system for antimicrobials, helping to control microbial growth throughout the food's journey from transportation to consumption. It is especially useful for fresh produce, meat, and dairy. While effective, its performance can be improved by combining it with other preservation methods. Challenges include recycling, cost, and production complexity. Future improvements focus on finding more stable natural antimicrobial compounds and selecting the best packaging based on the type of food, storage conditions, and regulatory requirements (Fadiji et al., 2023). For instance, combining UV-C radiation with garlic extract, rich in allicin, a powerful antimicrobial compound, has been found to decrease microbial load and preserve the quality of tomatoes during storage (Udayakumar et al., 2024). Similarly, using grapefruit seed extract in alginate coatings has effectively prolonged the shelf life of grapes, demonstrating the potential of natural preservatives in maintaining produce quality (Jung & Zhao, 2025; Siddiqui et al., 2011).

Active Packaging: Active packaging aims to enhance food safety, quality, and shelf life, as well as improve sensory characteristics. Common types include antimicrobial films, moisture regulators, packaging with oxygen or ethylene absorbers, and flavor/odor releasers or absorbers. These features help protect food from external factors while maintaining its freshness (Gomes et al., 2023). Active packaging can integrate antioxidant agents that neutralize free radicals, preventing oxidative degradation and browning in fresh-cut produce. This is particularly helpful for fruits like apples, which are highly susceptible to enzymatic browning (Rodriguez et al., 2024).

In brief, packaging techniques such as MAP, controlled atmosphere packaging, and vacuum packaging play a crucial role in enhancing the shelf life, quality, and safety of fruits and vegetables. By carefully controlling factors like oxygen, carbon dioxide, humidity, and temperature, these methods help slow down spoilage processes, reduce microbial growth, and preserve the nutritional value of fresh produce. Each packaging method offers unique advantages and can be adapted to specific types of fruits and vegetables, ensuring that they reach consumers in optimal condition. As demand for fresh and convenient food continues to rise, ongoing advancements in packaging technologies will not only improve the efficiency of preservation but also contribute to reducing food waste and enhancing sustainability within the food supply chain. Ultimately, these innovations in packaging are key to meeting consumer expectations for fresh, safe, and nutritious produce while supporting a more sustainable food system.

Hurdle technology: Hurdle technology uses a combination of preservation methods to enhance microbial kill while preserving food quality. Applying multiple barriers such as water activity, pH, temperature, and preservatives ensures food safety (Goel et al., 2025). Hurdle technology combines multiple non-thermal techniques to overcome the limitations of individual methods, effectively combating pathogens and extending shelf life. The right combination reduces the need for excessive treatment, shortens processing time, and maintains food quality, including pH, color, Brix, and viscosity. The choice of techniques depends on the food matrix, achieving similar pathogen reductions with lower doses and exposure times (Varalakshmi, 2021). Some studies demonstrate the effectiveness of hurdle technology in improving food safety and quality. For instance, in a study by Goyeneche et al. (2016), response surface methodology was used to optimize combinations of mild heat treatments, citric acid application, and MAP, which led to improved quality and a longer shelf life for minimally processed radishes. Another study explored the use of vacuum precooling and MAP together as hurdles to prevent enzymatic browning and microbial growth in fresh-cut leafy vegetables, leading to a notable extension of shelf life (Wanakamol et al., 2022). Incorporating hurdle technology in the processing of fruits and vegetables offers a promising approach to deliver safe, high-quality, and minimally processed food products that meet consumer demands for convenience and health benefits.

2.4. Benefits of Minimal Processing

MPFs are an excellent alternative for modern lifestyles, offering safe handling, a rich nutrient profile, and an appealing presentation. These products help preserve freshness and essential nutrients by minimizing production changes, ensuring that foods retain their natural characteristics, such as texture, flavor, and nutritional value. MPFs prevent nutrient loss and avoid undesirable changes in texture, color, flavor, and aroma that can result from microbial spoilage or ripening. Additionally, MPFs help reduce food waste by ensuring that only the edible portions are taken home (Melo & Quintas, 2023; Velderrain-Rodríguez et al., 2019). Techniques like freezing, refrigeration, and fermentation, which fall under minimal processing, extend shelf life without the need for synthetic additives or preservatives (Ohlsson & Bengtsson, 2002). MPFs are typically convenient, ready-to-eat options that can be easily incorporated into a daily diet while providing health benefits. Unlike heavily processed foods, MPFVs retain more vitamins and minerals, making them healthier choices. Furthermore, minimal processing of fruits or vegetables grown in specific regions or facing other commercialization challenges can help address these issues. Minimally processed fruits, such as apples, kiwis, mangoes, and melons, are commercially important. For these to be successful, their minimal processing must preserve quality over an extended shelf life. For example, fresh-cut melons typically last 2–3 days on store shelves, but with proper processing, their shelf life can be extended to 11–14 days. This extension allows ample time for production, transportation, and retail, increasing marketability and boosting demand for minimally processed fruits (Velderrain-Rodríguez et al., 2019). Lastly, minimal processing supports sustainability by reducing the need for excessive packaging, chemicals, and energy-intensive processing methods, offering an eco-friendly alternative in food production.

2.5. Challenges of Minimal Processing Techniques

Minimal processing techniques, often referred to as "minimal processing," aim to preserve the natural qualities of food while prolonging its shelf life and maintaining its nutritional value. However, there are several challenges associated with these methods. Fresh fruits and vegetables are highly perishable, contain a lot of water, and are susceptible to spoilage, making it critical to ensure their stability and safety throughout the supply chain. Unfortunately, this often leads to excessive packaging and the overuse of additives to maintain safety, contributing to waste and environmental pollution. Moreover, significant waste is produced during producing, processing, and storing fruits and vegetables. Due to their high moisture content and organic matter, this waste can result in serious environmental pollution (Liu et al., 2022). Given the seasonal nature of fruits and vegetables, traditional post-harvest techniques have focused on ensuring their availability year-round, offering a diverse diet. These methods also help improve factors like texture, stability during transport, and consumer convenience. Consumer preferences such as visual appeal (e.g., color, size, firmness), sensory experience (e.g., taste, texture), and credence attributes (e.g., organic, local, pesticide-free) significantly influence consumption patterns. Consequently, the future of processed fruits and vegetables must meet consumer demands for natural, nutritious, and personalized qualities (Knorr & Watzke, 2019). However, the processing and consuming of fresh-cut vegetables can increase the risk of foodborne disease outbreaks. Cross-contamination during washing is often overlooked in public health assessments. Additionally, the high moisture content of these vegetables promotes rapid microbial growth, further complicating efforts to maintain safety and quality. These challenges underscore the need for improved handling and processing practices to reduce contamination risks (Raffo & Paoletti, 2022). Fig. 3 shows the challenges in minimally processing techniques.

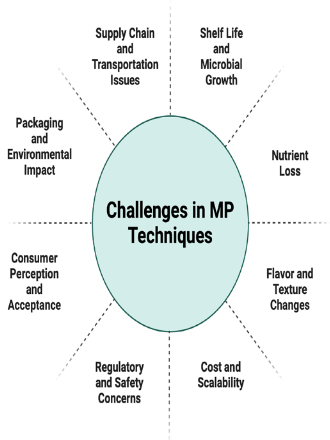

Fig. 3. *Challenges in Minimally Processing Techniques*

2.6. Recent Advances and Innovations

The future of minimally processed fruits is focused on enhancing freshness, extending shelf life, and preserving their nutritional value. Innovations like cold plasma technology, natural preservatives, and high-pressure processing (HPP) are emerging to maintain fruit quality without using heat or synthetic chemicals. Additionally, smart packaging with sensors to monitor freshness, MAP, and edible coatings are helping extend the shelf life of fruits. There is also a growing trend in using plant-based and fermentation-based processes for new flavors and health benefits, while upcycled fruit waste is being converted into valuable products. Packaging for minimally processed fruits is shifting toward sustainability and convenience. Biodegradable and compostable materials, such as seaweed and mushroom-based packaging, are replacing traditional plastics. Active and intelligent packaging, which responds to changes in the environment to extend freshness, is on the rise. Innovations like edible packaging, oxygen absorbers, and customizable portion packaging cater to consumer needs for sustainability and convenience. Moreover, automation and robotics are streamlining sorting and packaging processes, reducing waste, and improving efficiency. These advancements are collectively improving the environmental and consumer experience in the fresh fruit market.

3. Conclusion

In conclusion, minimally processed techniques are key to preserving the freshness, nutritional value, and convenience of fruits and vegetables. These methods help meet the growing demand for fresh, healthy, and easy-to-eat food options. While challenges like spoilage, waste, and contamination risks exist, ongoing innovations in processing technologies can address these issues. The future of minimally processing in the food industry looks promising, with potential advancements focused on improving safety, sustainability, and quality. As consumers increasingly seek fresh and minimally processed products, these techniques will play a vital role in shaping a healthier, more sustainable food system.

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CHAPTER 4

EFFECT OF THERMAL PROPERTIES OF DIFFERENT OVEN BAGS ON BISPHENOL-A MIGRATION LEVEL IN MEAT

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Introduction

Packaging has an important place in the food industry due to its functions such as protecting food from environmental effects, increasing shelf life, and providing information to consumers about food content. Metal, glass, paper, plastic, etc. packaging materials are widely used as food packaging materials. However, due to its ability to easily adapt to certain requirements, plastic-based packaging has a wide area of use in the food industry (Xia, 2012). Today, changing lifestyles and women's more active role in working life have increased the demand for cooking tools that shorten the preparation time of food, preserve its aroma and flavor, and allow easy cleaning after cooking (Collado et al., 2019; Di Giorgio et al., 2019; Paulsen et al., 2021). In this context, oven bags are also a plastic derivative that has been widely used in oven cooking in recent years (Savaş et al., 2021). Oven bags are generally used to preserve the natural aroma and authentic flavor as well as the vitamin and mineral content of various meat types such as chicken, fish and red meat (Di Giorgio et al., 2019). There are currently different brands of oven bags based on different synthetic polymers on the market. However, any material that will come into contact with food is expected to be inert enough to prevent the migration of substances from its structure into the food. Bisphenol-A (BPA) is a monomer widely used in the production of packaging materials, especially to improve the thermal stability of the material (Wu et al., 2019). Although it has a global area of use, BPAs have properties that can negatively affect the environment and human health. Therefore, BPA migration from BPA-containing plastic materials that come into contact with food into food is a significant concern. The most important risk of BPA is its carcinogenic activity, which can be associated with cancers such as breast cancer. It has been reported that BPA can affect breast tissue growth, which increases the risk of breast cancer, can increase the sensitivity of breast tissue to cancer-causing agents, and can significantly support the growth of cancer cells (Xia, 2012). Therefore, it is important to determine the levels of BPA migrating from food-contact packaging materials to food. The level of components such as BPA migrating from plastic-derived materials to food can have harmful effects on human health if it exceeds toxicological values or levels determined by legislation (Fasano et al., 2012). In this context, the US Environmental Protection Agency (EPA) has determined the oral reference dose (RfD) of BPA as 50 μg/kg body weight/day. It is stated that in order to protect human health, the estimated exposure dose should not exceed the RfD value according to the level of BPA migration into food (Xia and Rubino, 2015). On the other hand, since foods constitute a direct path for human exposure to BPA, it is also extremely important to understand how BPA migration from packaging to food occurs and how different conditions serve this migration in order to avoid possible food risks for the consumer. In this context, temperature is the most important environmental variable affecting the migration process, and studies have generally focused on this aspect (Galotto and Guarda, 2004). Thermal applications such as heating, sterilization, pasteurization and microwave facilitate migration. In addition, many factors such as the characteristics of the packaging material, its type, food composition and process type also affect the migration process (Di Giorgio et al., 2019). However, it was determined that the BPA migration level in chicken meat cooked in oven bags of different brands at the same temperature differed depending on the oven bag brand (Savaş et al., 2021). This suggests that differences in the thermal properties of oven bags may also affect the level of BPA transferred to food. In other words, it is thought that similar temperature application may cause different structural changes in different packages. Therefore, it is thought that determining the relationship between the packaging feature and the level of BPA transferred to food will contribute to the revision of packaging formulations and thus to minimizing the risk of BPA in foods.

Materials and Methods

Materials

M. *Longissimus thoracis et lumborum* muscle obtained from 3 different cattle carcasses was used as material. The muscles were brought to the laboratory under cold chain and since the contact surface area is of great importance in migration analysis, the muscles were trimmed. Then, 3 meat slices with a thickness of 1.5 cm were obtained from each muscle. 5 different brands of oven bags obtained from local markets were used as oven bags.

Cooking

The instructions of the manufacturers were followed in the preparation of the samples. In this context, after the samples were placed in oven bags, the mouth of the packages was clipped and holes were opened in several places to release excess steam (Savaş et al., 2021). A convection oven was used for cooking (Arçelik). The cooking process was carried out at 200 °C for 45 minutes, considering the recommendations of the manufacturers. In order to determine the effect of using only oven bags on BPA migration, no salt, spices, etc. were added to the samples.

Methods

Fat content, fatty acid composition and Bisphenol-A analysis were performed on meat samples; DSC, TGA and FTIR analyses were performed on oven bags.

Fat content

The amount of crude fat in the samples was determined using the ether extraction method (Gökalp et al. 2010).

Fatty acid composition

Fatty acid composition was determined according to the fatty acid methyl ester method (AOAC 996.01) (Satchithanandam et al. 2001). Fatty acid composition was analyzed using capillary column and flame ionization detector in gas chromatography. Helium was used as the carrier gas and the flow rate was determined as 0.64 mL/min. The injection split ratio was used as 1:80. FAME mix 37 standard (Supelco) was used as the standard.

Bisphenol-A migration

The BPA content of meat samples was determined according to the method reported by Savaş et al. (2021). In this context, 1 g of meat sample was mixed with 10 mL of acetonitrile and 2 g of anhydrous sodium sulfate on a magnetic stirrer for 1 hour. The mixture was then filtered. The filtered samples were washed with 6 mL of acetonitrile. Then, n-hexane solution saturated with acetonitrile was added and waited for 15 minutes. Then the acetonitrile layer was transferred to the centrifuge tube and 10 mL of acetonitrile was added to the n-hexane layer. The obtained acetonitrile layers were combined and evaporated under nitrogen gas at 40 °C. The residue obtained was extracted with acetone/n-heptane solution in a Florisil cartridge. After the extraction process, the solvent was removed with nitrogen gas and the residue was analyzed by HPLC-FLD. A 5 µm particle size (Pursuit RPC18, Varian) column was used to determine the BPA migration level in the samples and acetonitrile/deionized (40/60 v/v) water mixture was used for the separation process. The separation process was carried out at 40 °C at a flow rate of 1 mL/min. Method validation was carried out with LOD, LOQ, R^2 and recovery parameters in accordance with single laboratory verification. The retention time of the standard was used for the identification of the BPA compound, and the external calibration curve method was used for quantification.

Thermal properties of oven bags

Thermal analysis of oven bags was performed using DSC. The analysis was performed to the method reported by Hazrati et al. (2021). Briefly, 5-10 mg of sample was placed in tightly closed aluminum sample trays. A similar step was applied to an empty sample tray to be used as a reference. Samples were analyzed in air at a heating rate of 10°C/min between 25 and 600 °C. Alumina was used as a standard in the conditioning of the DSC.

Thermal degradation behavior of oven bags

A thermogravimetric analyzer was used to determine the thermal degradation behavior of oven bags. The analysis was carried out in a nitrogen environment, at temperatures ranging from 25 to 600 °C and at a heating rate of 10 °C/min. The sample weighing 5-15 mg was heated after being placed on the sample tray and thermogravimetric curves were obtained for each sample (Hazrati et al., 2021).

Statistical analysis

This current study, in which oven bags of different brands were taken as factors, was conducted according to a randomized complete block design with 3 replications. Analysis of variance was used to evaluate the significance of differences between treatment groups.

Results and Discussion

Fat content of meats

Data on fat content of meats cooked in oven bags of different brands are presented in Table 1. Accordingly, the use of oven bags of different brands had a very significant ($P<0.01$) effect on the fat content of the samples. The fat content varied between 6,11-11,05 % depending on the oven bag brand.

Table 1. *Duncan multiple comparison test results for fat content of meat cooked in oven bags of different brands (mean ± SD)*

Oven bag brand	Fat content (%)
1	$6,50 \pm 0,08^{cd}$
2	$8,27 \pm 0,65^{bc}$
3	$8,60 \pm 1,93^{b}$
4	$6,11 \pm 0,71^{d}$
5	$11,05 \pm 0,45^{a}$
Sign.	**

a-d: Means with different letters in the same column are significantly different ($P<0,05$)

The highest fat content was determined in meat samples cooked with oven bags belonging to brand number 5, while the lowest fat content was determined in samples cooked with oven bags belonging to brand number 4. On the other hand, the averages of the fat content of meat samples cooked with oven bags belonging to brand number 1 and the fat content of samples cooked with oven bags belonging to brands number 4 and 2 did not differ statistically from each other.

Fatty acid composition of meats

Data on fatty acid composition of meats cooked in oven bags of different brands are presented in Table 2. In all treatment groups, it was found that the majority of ∑SFA (total saturated fatty acid) content was composed of palmitic and stearic acids, the majority of ∑MUFA (total monounsaturated fatty acid) content was composed of oleic acid and the majority of ∑PUFA (total polyunsaturated fatty acid) content was composed of linoleic acid.

Table 2. *Duncan multiple comparison test results for fatty acid composition of meat cooked in oven bags of different brands (mean ± SD)*

Fatty acid	1	2	3	4	5	Sign.
Myristic acid	$2,94 \pm 0,22^{a}$	$2,96 \pm 0,17^{a}$	$2,98 \pm 0,05^{a}$	$3,04 \pm 0,20^{a}$	$2,96 \pm 0,10^{a}$	ns
Palmitic acid	$30,25 \pm 0,75^{a}$	$30,82 \pm 0,30^{a}$	$30,67 \pm 0,13^{a}$	$30,92 \pm 0,15^{a}$	$30,89 \pm 0,21^{a}$	ns
Stearic acid	$19,43 \pm 0,59^{b}$	$21,02 \pm 0,59^{a}$	$20,45 \pm 0,36^{a}$	$19,27 \pm 0,68^{b}$	$21,45 \pm 0,33^{a}$	**
Other saturated fatty acid	$1,45 \pm 0,06^{ab}$	$1,54 \pm 0,11^{a}$	$1,54 \pm 0,08^{a}$	$1,33 \pm 0,05^{b}$	$1,53 \pm 0,04^{a}$	*
Total saturated fatty acid	$54,06 \pm 1,07^{c}$	$56,33 \pm 0,93^{a}$	$55,64 \pm 0,58^{ab}$	$54,57 \pm 0,45^{bc}$	$56,83 \pm 0,31^{a}$	**

Palmitoleic acid	3,27±0,29[a]	3,04±0,09[a]	3,22±0,13[a]	3,40±0,37[a]	3,02±0,04[a]	ns
Oleic acid	38,06±0,66[ab]	37,06±0,99[bc]	37,61±0,59[abc]	38,40±0,14[a]	36,61±0,29[c]	*
Other monounsaturated fatty acid	1,37±0,07[a]	1,45±0,11[a]	1,45±0,07[a]	1,41±0,05[a]	1,47±0,01[a]	ns
Total monounsaturated fatty acid	42,69±1,0[ab]	41,54±0,87[bc]	42,28±0,57[abc]	43,22±0,40[a]	41,09±0,32[c]	*
Linoleic acid	3,05±1,70[a]	2,01±0,09[a]	1,98±0,06[a]	2,13±0,06[a]	1,98±0,05[a]	ns
Other polyunsaturated acid fatty acid	0,20±0,08[a]	0,11±0,02[a]	0,10±0,0[a]	0,08±0,07[a]	0,10±0,0[a]	ns
Total polyunsaturated fatty acid	3,25±1,77[a]	2,12±0,08[a]	2,08±0,06[a]	2,21±0,05[a]	2,08±0,05[a]	ns

a-c: Means with different letters in the same line are significantly different (P<0,05)

Cooking with oven bags of different brands had a very significant effect on stearic acid and total saturated fatty acid contents of meat samples ($P<0.01$) and a significant effect on other saturated fatty acids, oleic acid and total monounsaturated fatty acid contents ($P<0.05$). The highest stearic acid, other total saturated fatty acid and total saturated fatty acid contents and the lowest oleic acid and total monounsaturated fatty acid contents were determined in samples cooked with oven bags of brand 5. However, it was observed that these values were not statistically different ($P>0.05$) from the samples cooked with oven bags belonging to brands 2 and 3. On the other hand, it was determined that the lowest stearic acid and total saturated fatty acid content and the highest oleic acid and total monounsaturated fatty acid contents belonged to the samples cooked with oven bags belonging to brands 1 and 4.

Bisphenol-A migration level of meats

Data on Bisphenol-A migration levels in meat cooked in oven bags of different brands are presented in Table 3. Accordingly, the use of oven bags of different brands had a very significant (P<0.01) effect on the BPA level of the samples. The BPA level varied between 4.19-10.89 ng/g depending on the oven bag brand.

Table 3. *Duncan multiple comparison test results for BPA content of meat cooked in oven bags of different brands (mean ± SD)*

Oven bag brand	BPA content (ng/g)
1	4,42±0,34[c]
2	4,74±0,53[c]
3	4,19±1,06[c]
4	10,89±0,75[a]
5	8,71±0,43[b]
Sign.	**

a-c: Means with different letters in the same column are significantly different (P<0,05)

The highest BPA level was detected in samples cooked in oven bags of brand 4. While the second highest BPA level was observed in samples cooked in oven bags of brand 5, the difference between the BPA content of samples cooked in oven bags of brands 1, 2 and 3 was not found to be statistically significant (P>0.05).

Thermal properties of oven bags

Oven bags, which are widely used for cooking various types of meat, are made of polyethylene terephthalate (PET), a type of plastic that is generally considered safe for use in food and water. It is known that the glass transition temperature (Tg) of PET varies between 67-80 °C and its melting temperature (Tm) is approximately 267 °C.

In the present study, TG, DTG and DSC analyses were performed on oven bag samples belonging to five different brands using thermal gravimetric analysis methods, and the decomposition temperatures and decomposition amounts of the samples were examined. As can be seen from the thermal analysis graphs presented in Figure 1, all five samples examined exhibited a very stable thermal structure up to approximately 370°C.

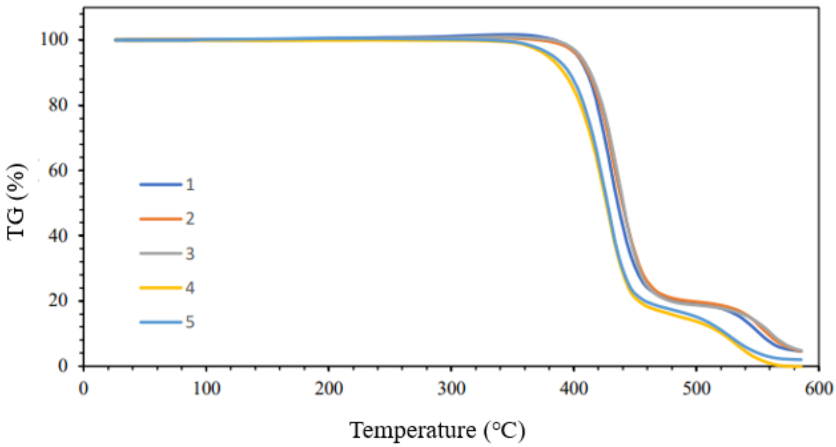

Figure 1. *TG diagram of oven bags*

In light of the DTG graphic data presented in Figure 2, which expresses the thermal decomposition rate, it was assessed that all samples decomposed in two steps. It was determined that the temperature values of the first decomposition step were similar in all samples, while the decomposition temperature of the second step varied depending on the brand. These decomposition temperatures were determined to be approximately 375 °C for oven bags belonging to the first three brands, and 345 °C for samples belonging to brands 4 and 5. The weight losses determined from the TG graph were calculated as 95.65, 96.24, 96.02, 99.89 and 98.03%, respectively.

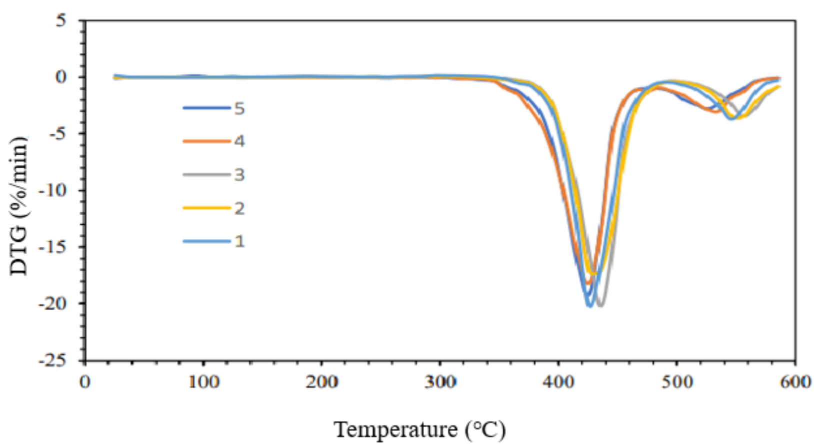

Figure 2. *DTG diagram of oven bags*

It was observed that the decomposition energies of the oven bag samples belonging to brands numbered 1, 2 and 3 gave endothermic peaks, while the decomposition energies of the oven bag samples belonging to brands numbered 4 and 5 gave exothermic peaks (Fig. 3).

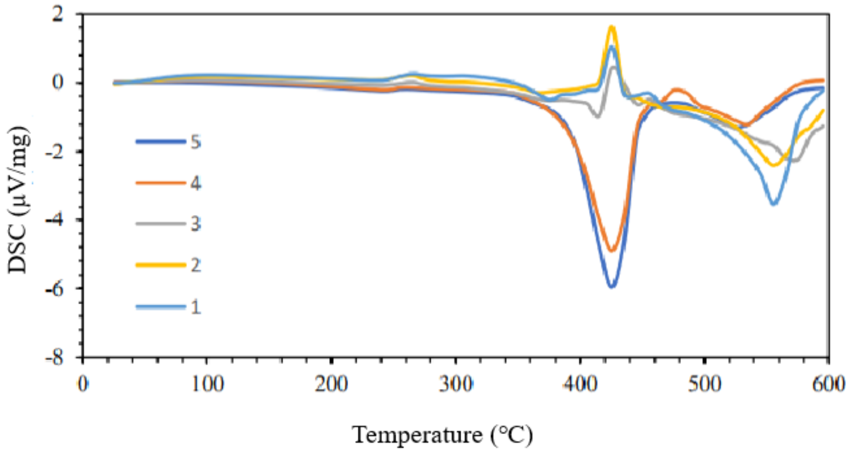

Figure 3. *DSC diagram of oven bags*

When the TG/DTG and DSC thermograms of the samples were examined, it was evaluated that the oven bag samples belonging to brands 1, 2 and 3 were quite similar in terms of both decomposition temperatures and weight losses. In addition, it was understood that the oven bag samples belonging to brands 4 and 5 were quite similar in terms of the relevant parameters, but different from the other three oven bags. It was determined that there was a difference of approximately 30 °C in terms of decomposition temperatures and a difference of approximately 3% in terms of weight loss between the two groups mentioned.

Conclusion

The results of this work have demonstrated that the use of oven bags of different brands in the cooking process affect the level of BPA in cooked meat. Thermal analysis results revealed that the characteristics of oven bags of different brands can affect the level of BPA that migrates from the packaging material to the food during cooking. Within this scope, it was evaluated that the thermal properties of the oven bags belonged to the brands 1, 2, and 3 and the oven bags belonged to the brands 4 and 5 are similar in themselves, but different from each other. However, it is thought that further research is needed to understand the relationship between the oven bag material properties and the BPA migration level.

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