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Climate Change Effects and Mechanisms on Nutritional Quality and Technological Performance of Major Agri-Food Products: A Critical Review

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ABSTRACT

Climate change is increasingly recognized as a major driver of alterations in food systems, affecting not only production yields but also the composition, nutritional quality, and technological performance of food raw materials. This review provides a critical synthesis of recent advances on the effects of climate change on major food matrices, including milk, cereals, vegetable oils, and fruits and vegetables. Across these systems, climate-induced stresses such as elevated temperatures, altered precipitation patterns, and increased atmospheric CO₂ levels have been shown to significantly modify physicochemical and biochemical properties. These changes include reductions in protein content (notably caseins in dairy systems), alterations in lipid profiles (decreased polyunsaturated fatty acids in vegetable oils), and modifications in protein quantity and functionality in cereals, as well as shifts in bioactive compounds and quality attributes in fruits and vegetables. These compositional changes are closely linked to modifications in technological performance, impacting key processing operations including breadmaking and cheesemaking, through alterations in dough rheology and milk coagulation behavior. This review also highlights the underlying mechanisms driving these climate-induced changes, as well as current knowledge gaps and future research directions to better understand and mitigate the impact of climate change on food quality and processing performance.

KEYWORDS

Agri-food products; climate change; food quality; nutritional composition; technological performance

Introduction

Since the beginning of the industrial era, human activities have led to a significant increase in the atmospheric concentration of greenhouse gases, particularly carbon dioxide (CO₂). The accumulation of these gases is the main cause of climate change, which has resulted in the intensification of extreme weather events including a significant increase of atmospheric temperature, a global rise in sea level, warming and acidification of the oceans, and a decline in biodiversity.^[1,2]

These disruptions of the climate system affect human health both directly, through rising temperatures and the increased frequency of extreme climatic events, notably contributing to respiratory allergies and asthma, and indirectly, mainly via their impacts on natural systems, including air pollution, water resource scarcity, and the exacerbation of food insecurity.

Therefore, climate change is expected to further aggravate this global crisis by affecting both the quantity and quality of many food products which are generated by agriculture, fisheries, and livestock production systems.^[3] Among these sectors, livestock production, and particularly dairy cattle farming, has been identified as highly vulnerable to climate-related stressors. Other food production

sectors, including vegetable oils, cereals, fruits and vegetables, are also significantly affected by climate change conditions.

Climate change has been associated with a deterioration in unsustainable food systems by directly impacting rain patterns, soil fertility, food production and food composition.^[4] Food quality is an essential parameter directly influenced by climate change, with important implications for human health. Indeed, alterations in nutrient composition of food products or the emergence of biological and chemical hazards can indirectly affect consumers, compromising nutritional intake and food safety.^[4,5] Understanding these impacts across different food matrices is therefore essential to anticipate risks, guide adaptation strategies, and ensure the production of safe and nutritious foods under changing climatic conditions.

To date, no comprehensive review has systematically examined the effects of climate change on both of nutritional quality and technological performance of food products across major agri-food sectors. Thus, this review aims to critically synthesize current evidence on the effects of climate change across major agri-food sectors, with a particular focus on food quality attributes. It examines how climate-related stressors impact the physicochemical composition, and nutritional value of diverse food products including dairy products, vegetable oils, cereals, fruits and vegetables. In addition, this review discusses how climate-induced compositional and nutritional changes impact and modify the technological performance of food materials, with particular emphasis on breadmaking and cheese-making as representative plant- and animal-based models, and outlines the adaptation strategies required to mitigate these technological alterations.

Methodology

In the current review, the systematic method which was adopted was used in the research, identification and selection of literature in order to cover the topic comprehensively and reproducibly. The methodology was created to indicate the interdisciplinary nature of the topic which comprises food science, food technology, agronomy, nutrition, and climate change. A comprehensive literature review was conducted to use two large electronic databases, namely, Scopus and Google Scholar. Only those published between 2010 and 2026 were considered as the most up to date literature, although seminal publications prior to the date were also considered.

The literature search was conducted using a combination of keywords and Boolean operators based on four main conceptual themes: (i) climate change-related factors, (ii) major agri-food products, (iii) nutritional and biochemical quality, and (iv) technological performance.

The first theme included keywords related to climate change and environmental stresses: (“climate change” OR “global warming” OR “climatic change” OR “temperature increase” OR “heat stress” OR “thermal stress” OR “drought stress” OR “water deficit” OR “heat wave” OR “precipitation variability” OR “extreme weather events”).

The second theme targeted the main food categories investigated in this review: (“milk” OR “dairy products” OR “dairy cows” OR “Holstein cows” OR “wheat” OR “cereal crops” OR “*Triticum aestivum*” OR “rice” OR “maize” OR “olive oil” OR “palm oil” OR “soybean oil” OR “*Olea europaea*” OR “vegetable oils” OR “fruits” OR “vegetables”).

The third theme focused on nutritional and biochemical changes induced by climate-related stresses: (“nutritional quality” OR “chemical composition” OR “protein content” OR “protein profile” OR “amino acid composition” OR “lipid composition” OR “fatty acid profile” OR “bioactive compounds” OR “phenolic compounds” OR “antioxidant capacity” OR “vitamins” OR “minerals” OR “secondary metabolites”).

The fourth theme included terms related to technological performance and functional properties: (“technological properties” OR “functional properties” OR “processing quality” OR “rheological properties” OR “texture” OR “cheesemaking” OR “breadmaking”).

Keywords within each theme were combined using the OR operator, while the four conceptual themes were combined using the AND operator. The literature search was performed using scientific

databases including Web of Science, Scopus, and PubMed. Studies published between 2010 and 2026 were considered. Original research articles and review papers were selected based on their relevance to the effects of climate-related stresses on the nutritional composition, biochemical mechanisms, and technological properties of milk, wheat, vegetable oils, fruits, and vegetables.

The selection of publications followed predefined eligibility criteria to ensure the relevance and scientific quality of the evidence included in this review. Peer-reviewed original research review papers, articles, and meta-analyses examining the influence of climate change and climate-related stressors, including heat stress, drought, water scarcity, and changes in precipitation patterns, on the nutritional composition and technological performance of agri-food products were considered. The review specifically focused on studies addressing two model matrices an animal-based matrix: milk and dairy products and plant-based matrix: wheat and cereal grains. Meanwhile other matrixes were presented including olive oil and other vegetable oils, as well as fruits and vegetables. Preference was given to studies providing quantitative data and/or mechanistic insights into the biochemical, physiological, or molecular processes underlying climate-induced changes in food quality. Only full-text articles published were included. Publications lacking sufficient methodological information, conference abstracts, editorials, dissertations, book chapters without accessible full data, and studies not directly related to the scope of this review were excluded.

Climate change trends and implications for agri-food systems

Over the past decades, the global climate system has undergone substantial changes, characterized by a continuous increase in temperature, modifications in precipitation patterns, and a growing frequency of extreme climatic events.^[66] The Sixth Assessment Report of Intergovernmental Panel on Climate Change (IPCC) concludes that human activities have unequivocally caused global warming, with the global surface temperature reaching approximately 1.1°C above the 1850–1900 average during 2011–2020, making the last decades the warmest since instrumental records began.^[7] However, this warming trend is not spatially uniform, with land areas and high-latitude regions warming faster than the global average. For instance, temperatures in Europe have risen above the global mean, resulting in more frequent and intense heatwaves, especially in southern regions, where prolonged droughts and reduced water availability pose major challenges to agricultural production. Conversely, northern European regions are generally projected to experience longer growing seasons and, in some areas, increased precipitation levels, which may temporarily create more favorable conditions for crop cultivation.^{[8][8]} Changes in precipitation patterns represent another major consequence of climate change, although regional variability remains high. While many regions are experiencing more frequent and intense heavy rainfall events, Mediterranean and subtropical regions are facing declining precipitation, prolonged droughts, and increasing water scarcity.^[7,9] These alterations in temperature and water availability directly affect agricultural systems by modifying crop development cycles, reducing soil moisture, and increasing the frequency of heat and water stress. Consequently, climate change impacts are expected to be particularly severe in low-latitude and Mediterranean regions, whereas some high-latitude areas may temporarily benefit from longer growing seasons and reduced cold limitations.^[10] Overall, the effects of climate change on agricultural production are highly region-dependent, reflecting the complex interactions between rising temperatures, precipitation variability, and local environmental conditions. These climate-driven changes not only affect agricultural productivity but also alter the nutritional composition and technological properties of agricultural commodities, thereby influencing food quality, processing performance, and ultimately food security.

Effects of climate change on food composition and nutritional quality

Dairy systems: bovine milk as a model matrix

Milk and dairy products are among the most climate-sensitive foods. Indeed, both milk yield and composition are directly influenced by environmental stressors such as temperature rise, water

scarcity, and feed availability. These factors can significantly affect producing cow and hence, alter milk quality, nutritional value, and processing characteristics (Fig. 1). The temperature-humidity index (THI) is widely used as an integrated indicator of heat stress, linking environmental conditions to physiological and metabolic responses in dairy cattle.

Overall, dairy cows (*Bos taurus*) are naturally adapted to both of cool and temperate environments, and their optimal performance occurs within a thermoneutral zone where the upper critical temperature ranges between 25 and 26°C and the THI index below 72.^[111,12] Above these parameters, cows exhibit reduced feed intake, milk production, and fertility.^[13] From a physiological perspective, heat stress triggers significant changes in dairy cattle, including increased respiration and heart rates, elevated core body temperature, and decreased dry matter intake, which collectively contribute to reduced milk yield.^[14]

First, heat stress induces profound physiological, metabolic, and cellular alterations in dairy cows, particularly during early lactation when nutrient and energy requirements are high. Previous studies have reported that exposure to moderate-to-severe heat stress conditions, corresponding to THI values ranging from 71 to 86, significantly impairs animal performance and physiological functions of Holstein dairy cows in republic of Korea.^[15] One of the earliest responses is a reduction in dry matter intake, which may decrease by approximately 12%, accompanied by an increase in water consumption of up to 23%, reflecting adaptive mechanisms aimed at reducing metabolic heat production and enhancing heat dissipation. These physiological adaptations are accompanied by marked increases in rectal temperature (40.25°C), skin temperature (33°C), heart rate (92.25 bpm), and respiration rate, reflecting intensified thermoregulatory efforts.^[15]

At the metabolic and endocrine levels, heat stress induces profound alterations in energy metabolism, as reflected by changes in circulating glucose and non-esterified fatty acid (NEFA) concentrations. On the other hand, thermal stress activates endocrine and inflammatory pathways, leading to increased plasma cortisol and haptoglobin concentrations, which are indicative of systemic stress and inflammation. Meanwhile, heat stress also affects hematological parameters, resulting in reductions in

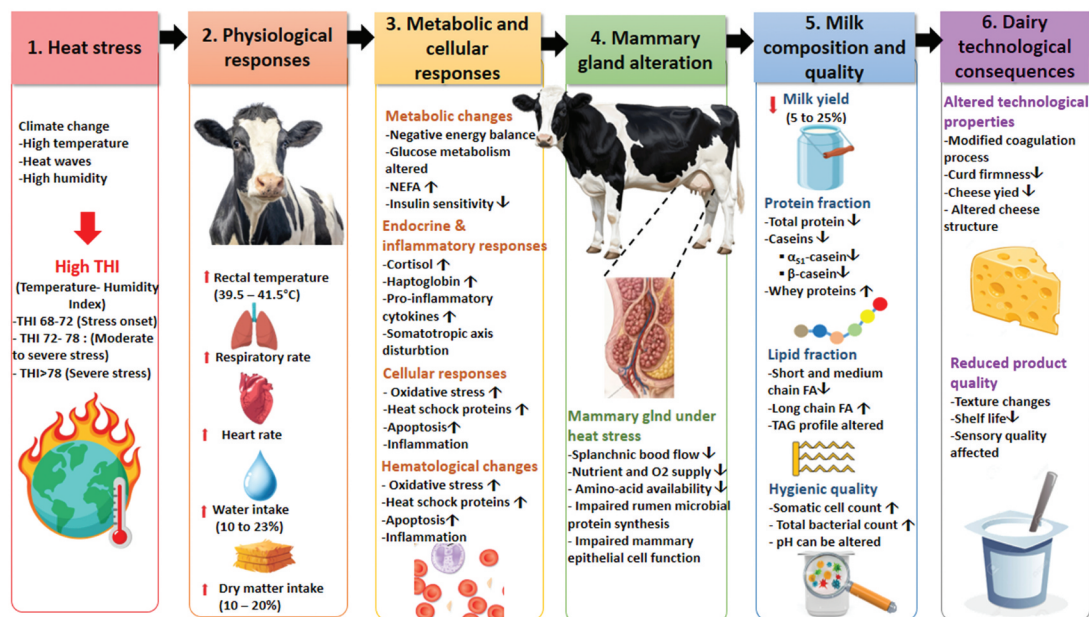


Figure 1. Physiological, cellular and biochemical mechanisms underlying the effects of heat stress on milk quality and technological performance.

white blood cell counts, hemoglobin concentration, mean corpuscular hemoglobin, and platelet counts, potentially compromising immune function and physiological resilience.^[16]

These physiological, metabolic, and cellular adaptations ultimately affect mammary gland function and milk synthesis. Consequently, milk yield and milk protein production may decrease by approximately 10% and 20%, respectively. The reduction in milk protein synthesis is attributed to multiple mechanisms, including disruption of the somatotrophic axis, decreased amino acid absorption resulting from reduced splanchnic blood flow, altered nutrient partitioning within the mammary gland, and impaired microbial crude protein synthesis in the rumen, which is essential for amino acid supply to the host animal.^[17,18]

Collectively, these findings demonstrate that as heat stress severity increases, dairy cows progressively shift their biological priorities from production toward the maintenance of homeostasis and survival, entering a physiological state primarily focused on coping with thermal challenge rather than sustaining optimal productive performance.

Thermal stress was therefore considered as a significant reason for reduced milk production in many countries. Indeed, the exposure of lactating dairy cows to solar radiation, high ambient temperatures and high relative humidity for extended periods decreases their ability to disperse heat and hence to produce milk.^[19] The energy cost of thermoregulatory mechanisms of producing cows is a major factor explaining this decline in productivity.^[20] Beyond yield, milk composition is also affected by climate change conditions: several studies report a decrease in total protein and fat contents under heat stress conditions though some authors observed no significant variation in fat percentage.^[14,21–25] On the other hand, protein reduction may result from altered nutrient partitioning and lower amino acid availability for mammary synthesis.^[14] In the same way, the meta-analysis conducted by São José et al.^[26] on the impact of global warming on the nutritional composition of mammalian milk confirmed that, among 14 studies investigating the direct effects of climate change on milk protein content, approximately 86% reported a reduction in protein concentration. Similarly, among 13 studies focusing on milk fat content, about 62% observed a decrease in fat concentration. Complementary findings from Bernabucci et al.^[21] further elucidated that this reduction is mainly attributable to decreased casein contents, particularly α - and β -caseins. Indeed, their study was conducted on mid-lactation Holstein cows in Central Italy and revealed that during the hot summer months, lactating cows showed higher rectal temperature level, lower feed intake, and hence, reduced milk yield. Correspondingly, under these thermal conditions, the produced milk exhibited lower reduced casein contents and higher proportions of whey proteins. Among individual caseins, κ -casein levels remained unaffected while α - and β -casein fractions declined remarkably (Table 1).

In addition to the protein fraction, the lipid component of milk is also significantly affected by heat stress led by climate change. Liu et al.^[14] demonstrated that the exposure of dairy cows to high THI values (up to 84) induces substantial alterations in milk lipid composition. Specifically, heat stress led to a reduction in triglycerides (TAG) containing short- and medium-chain fatty acids (FA), accompanied by a relative increase in TAGs enriched with long-chain FA. This shift in fatty acid distribution in TAG may modify the physical and technological properties of milk fat including its melting behavior as well as its creaming stability leading to different dairy fat based products such as creams and butter. Furthermore, the concentrations of five major polar lipid classes including phosphatidylethanolamine, phosphatidylcholine, phosphatidylserine, lysophosphatidylcholine, and glucosylceramide, were significantly reduced during heat stress exposure. Among these polar lipids, lysophosphatidylcholine exhibited the most pronounced decrease. The observed decrease in phospholipids not only reflects metabolic adaptations of lactating cows to heat stress but may also compromise the nutritional quality of milk.

In addition to the compositional changes in proteins and lipids, heat stress was reported to have significant influence on milk hygienic quality parameters such as somatic cell count and total bacterial count. In this regard, a large-scale retrospective study was carried out by Bertocchi et al.^[22] based on approximately 500,000 bulk milk records from more than 3,000 dairy farms in the Lombardy region of Italy. This study revealed a significant relationship between the THI range and these milk quality

Table 1. Effects of climate change drivers on composition, hygienic status, and technological properties of milk and dairy products. Abbreviations: THI, temperature-humidity index; SCC, somatic cell count; TBC.

Food sector	Food product	Affected component	Climate drivers	Observed impact	Key references
Dairy	Cow milk	Milk yield	Heat stress; elevated temperature; increased THI (THI = 84)	Reduced feed intake; decreased milk yield; increased metabolic stress	[13,20]
	Cow milk	Protein content (caseins)	Heat stress (THI higher 72); altered nutrient availability	Reduction in total protein content, particularly α _s -casein (from 1.36 to 1.12%) and β -casein (from 0.97 to 0.79%); altered casein/whey ratio; impaired cheese-making properties	[20]
	Cow milk	Fat content, fatty acid profile and polar lipids	Heat stress (THI up to 84); elevated ambient temperature	Decrease in milk fat content; alteration of fatty acid profile with reduced polyunsaturated fatty acids Reduction in phospholipid content, affecting nutritional and technological quality	[14]
	Cow milk	Hygienic quality (SCC, TBC)	Heat stress (THI values ranging between 57.3 and 72.8), high humidity	Increased somatic cell count and bacterial load ($369\,503 \pm 228\,377$ and $52\,054 \pm 183\,655$, respectively); deterioration of hygienic quality	[22]
	Goat milk	Yield and composition	High temperature	Decreased milk yield (of 16%); reduction in fat, protein, and total solids	[27,28]
	Camel milk	Total solids and fat	Heat, water scarcity	Seasonal variability in composition; reduction in total solids and fat due to increased water intake	[32,33]

indicators. The analysis showed that both somatic cell count and total bacterial count increased with rising THI level, leading to a deterioration of microbial quality of milk which is produced under heat stress conditions. The study also identified critical THI values of 57.3 and 72.8 for the increase in somatic cell count and total bacterial count, respectively. Furthermore, seasonal analysis highlighted summer, particularly July and August, as the most critical period, with the highest somatic cell count and total bacterial count values recorded. In the same way, Bokharaeian et al.^[23] reported that milk pH remained relatively stable across seasons, with only a significant increase in winter. In contrast, both somatic cell count and bacterial count increased markedly during warmer periods which are characterized by higher THI levels, reflecting the significant impact of heat stress on milk hygiene.

These findings confirmed that elevated thermal conditions not only reduce nutritional value of produced milk but also compromise its hygienic and technological quality. Therefore, identifying these climatic conditions is important to set up effective heat management strategies that could protect animal health, ensure milk safety, and finally maintain farm productivity.

Previous studies have also reported that milk from other mammalian species including goats and camels, can also be affected by climate-related heat stress. Elevated temperatures in goats have been associated with reduced milk production and lower fat and protein concentrations. For instance, Kis et al.^[1] investigated more than 2,000 goats in Croatia over a three-year period (between 2012 and 2014) reported a significant decrease in milk fat, protein, and total solids of caprine milk. This behavior can be explained by qualitative changes in feed and increased overall milk production. Complementing these findings, Zhu et al.^[28] studied 149 dairy goats in China throughout 2019 and reported that high temperatures in July and August caused daily milk yield decrease to 16%, along with reductions in milk fat, protein, and dry matter content. These studies confirmed that heat stress can substantially reduce both the quantity and quality of goat milk, highlighting the need for adapted management practices in farms and the potential of selecting thermotolerant animals to maintain production under rising global temperatures. Despite these changes, feeding practices appeared generally well adapted, indicating that most farmers maintained goats under conditions suitable for mitigating the effects of heat stress. Meanwhile, camel milk is one of the most famous mammalian milk by its high nutritional properties and therapeutic value related with a production quantity of 4.095 million tonnes representing 0.42% of total milk production in the world.^[29,30] The impact of heat stress on seasonal variation

has also been observed in camel milk as camel mainly live in desert areas.^[31] These studies noted an inverse relationship between total solids and water intake. Long-term studies of Konuspayeva et al.^[32] indicate temporal variations in the composition of camel milk from both of dromedary and Bactrian camels, influenced by several factors including diet, climate, water availability, and management practices. For instance, total solids decreased from 13.9% in December-January to 10.2% in August, largely due to increased water consumption by camels. Fat content was also found to significantly decline in response to higher milk water content produced by thirsty animals.^[33] Boudalia et al.^[34] reported that climate change affects significantly camel milk production. However, the implementation of genetic improvement can enhance productivity and support social and economic resilience in fragile Saharan ecosystems. Finally, these findings suggest that, as with goats and cows, heat stress can significantly affect camel milk composition in term of fat content, proteins, total solids and lactose. However, further studies are still needed, particularly under controlled conditions with consistent water availability, to fully confirm seasonal and environmental effects on camel milk composition.

Cereal systems: wheat grain as a model matrix

Cereal grains such as wheat, maize, and rice represent the most essential staple crops, providing the main source of food for a large proportion of the global population due to their high contents in nutrients including source of carbohydrates, proteins, minerals and vitamins essential for human. To meet the nutritional needs of an estimated 9.8 billion people by 2050, the global supply of cereals will need to increase by approximately 70–100%.^[35,36]

Similarly to other agri-food products, cereal crops are particularly vulnerable to the impacts of climate change (Fig. 2, Table 2). Indeed, variations in temperature, precipitation patterns, and atmospheric CO₂ levels can significantly influence their production yield, nutritional composition, and grain quality, with major implications for global food security and human nutrition. Wheat (*Triticum* spp.) is the most widely cultivated cereal crop in many regions of the world, with a global production estimated at approximately 798.9 million tonnes in 2023 according to the latest statistics of FAO.^[37]

Climate change factors such as temperature and precipitation greatly influence wheat quality, composition and technological properties. During grain filling, heat stress ($45/25 \pm 2^\circ\text{C}$ day/night), particularly when combined with drought (during 5 days), disrupts wheat grain development primarily through alterations in source-sink coordination. According to the recent findings of Lin et al.^[38] high temperatures impair photosynthetic activity by inducing chloroplast damage, lipid peroxidation, and inhibition of carbon fixation, thereby reducing the supply of photo-assimilates required for grain development. Thus, this decline in carbon assimilation is accompanied by profound changes in sucrose metabolism. Indeed, under combined heat and drought stress, leaf sucrose concentration reached 2.79 mg g^{-1} in the tolerant genotype, representing increases of 48.7% and 82.7% compared with drought and heat stress alone, respectively, reflecting an adaptive maintenance of carbohydrate turnover. In contrast, the chlorophyll-deficient genotype exhibited severe impairment of sucrose metabolism, with sucrose synthase activity decreasing to 569.51 U g^{-1} under heat stress, resulting in reduced sucrose availability and diminished sink activity. These metabolic disturbances, together with stress-induced hormonal adjustments, altered source-sink coordination and restricted the translocation of assimilates towards developing grains, thereby reducing grain-filling efficiency. Consequently, limitations in carbon remobilization and sink strength are expected to impair the deposition of storage compounds within the endosperm, ultimately modifying the accumulation and composition of storage proteins and predisposing wheat grains to subsequent deterioration in gluten quality and end-use functionality.

In this context, previous studies have demonstrated that elevated temperatures during the grain-filling stage significantly modify wheat grain composition and functional quality.^[39–43] Under controlled conditions, moderate temperatures ranging from 17 to 24°C favor gradual grain development and balanced accumulation of storage proteins, thereby contributing to superior flour quality. In contrast, exposure to high temperatures (37/28°C) accelerates grain maturation and shortens the

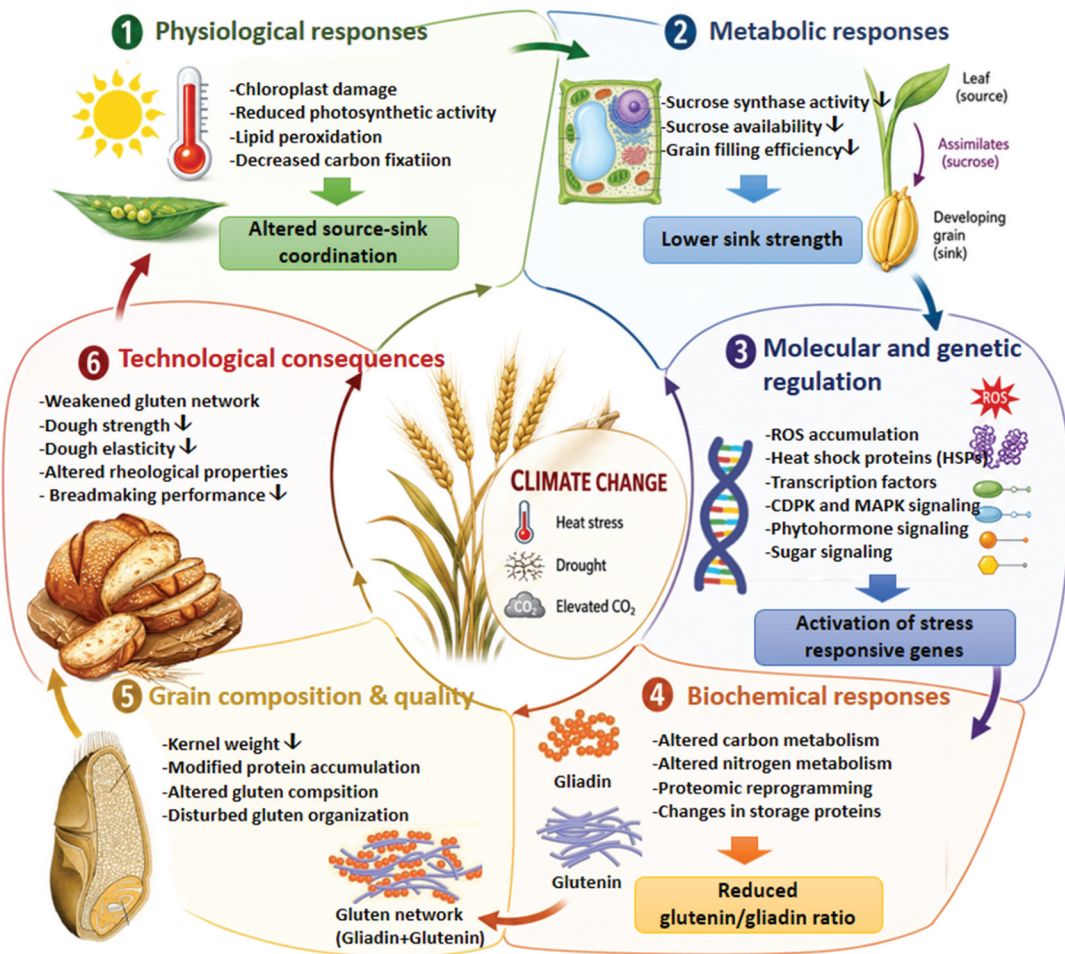


Figure 2. Mechanistic overview of climate change effects on wheat grain composition and technological quality: physiological, molecular, biochemical, and technological mechanisms.

Table 2. Effects of climate change drivers on composition and technological performance of cereals including maize, wheat and rice.

Food sector	Food product	Affected component	Climate drivers	Observed impact	Key references
Cereal crops	Wheat (<i>Triticum</i> spp.)	Gluten protein composition	Heat stress during grain filling (between 24/17°C and 37/28°C for day/night)	Increase in gliadin content; reduction in high-molecular-weight glutenins; weakened gluten network	[40]
	Wheat (<i>Triticum</i> spp.)	Grain yield	Heat stress; drought	Reduction in kernel weight and grain yield	[39]
	Maize (<i>Zea mays</i>)	Protein content	Heat stress; irregular precipitation	Decreased grain yield and protein content; altered nitrogen metabolism	[52]
	Rice (<i>Oryza sativa</i> L.)	Protein and amino acid composition	Elevated CO ₂ (540–958 μmol mol ⁻¹); high temperature	Reduction in grain protein concentration and essential amino acids (of 10–15%)	[53,54]

grain-filling period, reducing single kernel weight by up to 50%. Beyond these quantitative losses, heat stress induces profound proteomic reprogramming within developing grains.^[42] Although post-anthesis heat stress frequently increases total grain protein content, this increase is mainly associated with qualitative changes rather than improved technological performance.^[44]

Indeed, two-dimensional gel electrophoresis carried out by Dupont et al.^[40] showed that the content of α -gliadins, ω -gliadins, and high-molecular-weight glutenin subunits (HMW-GS) decreased under moderate temperatures (24/17 °C). On the contrary, higher temperatures (37/28 °C) led to an increase in some α -gliadins and HMW-GS, while a major low-molecular-weight glutenin subunit (LMW-GS) declined. Consequently, the glutenin-to-gliadin ratio decreases, leading to alterations in protein aggregation and reduced formation of high-molecular-weight gluten polymers. Since glutenins are primarily responsible for dough strength and elasticity, whereas gliadins contribute to viscosity and extensibility, such an imbalance weakens the gluten network and adversely affects rheological properties and bread-making quality.^[45] Moreover, the magnitude and nature of these proteomic changes are strongly influenced by the timing of heat exposure, with stress occurring during the early and middle stages of grain filling producing distinct patterns of storage protein accumulation. Therefore, heat-induced modifications in the composition and organization of storage proteins constitute a key biochemical mechanism linking climatic stress to the deterioration of wheat end-use quality.

At the molecular level, heat stress initiates a complex signalling cascade that underlies the metabolic disturbances observed during grain development. For instance, excessive accumulation of reactive oxygen species (ROS), including hydroxyl radicals, superoxide radicals and hydrogen peroxide, promotes oxidative stress, leading to lipid peroxidation and damage to cellular membranes, particularly chloroplasts and mitochondria.^[46] To counteract these effects, wheat activates an integrated defense network involving many factors including heat shock proteins (HSPs), transcription factors (TFs), and multiple signalling pathways mediated by calcium-dependent protein kinases (CDPKs), mitogen-activated protein kinases (MAPKs), phytohormones, and sugar signaling.^[47] These signalling components regulate the expression of stress-responsive genes, including transcriptional regulators such as DREB and heat shock factors (e.g., TaHSFA6f), thereby contributing to cellular homeostasis under heat stress.^[48] Beyond their protective role, these molecular responses also modulate carbon and nitrogen metabolism during grain filling, ultimately influencing starch biosynthesis, storage protein accumulation, and consequently the nutritional quality and technological performance of wheat grain. Despite these in-depth studies on the molecular mechanisms of heat stress response in wheat in a context of climate change, further studies integrating transcriptomics, proteomics, metabolomics, and functional genomics are still required to identify key regulatory genes and elucidate the molecular mechanisms linking heat stress to alterations in gluten composition and technological quality.

In addition to wheat, Maize (*Zea mays*) is a major cereal crop with a total world production of 1.24 billion tonnes in 2023 according to the latest statistics of FAO, surpassing rice and wheat. Used widely for food, feed, and biofuel production, maize is considered as one of the most important global crops. The ongoing rise in atmospheric CO₂ has intensified climate change, leading to a steady increase in global temperature averages which can affect both of quantitative and qualitative aspects of maize cultivation. Rising global temperatures upon changing climatic conditions are known to affect the physiological and biochemical defense systems of maize plant. Overall, plants rely on a wide array of chemical defenses strategies in order to mitigate stress conditions such as synthesis of some compounds including phytoanticipins and phytoalexins.^[49,50] Maize is distinguished by additional protective mechanisms that involve structural components such as lignin deposition within cell walls and the production of defense-related proteins known to enhance resistance to pathogens and insect pests.^[51] Following wheat and maize, rice (*Oryza sativa* L.) represents another major cereal crop that plays a key role in global food security with a production of 800 million tonnes. Rice production is highly sensitive to rising temperatures, with elevated CO₂ and heat stress.^[52] In addition to yield reduction, several studies noted remarkable alterations in the nutritional profile of rice, particularly in its protein fraction. Indeed, climatic factors such as elevated CO₂ levels and temperature lead and to

a reduction in protein and nitrogen concentrations in rice. The magnitude of this decline varies according to CO₂ level, cultivar, and phosphorus availability. Meta-analyses carried out by Taub et al.^[53] reported a significant decrease in grain protein concentration ranging from 8 to 10% under elevated CO₂. Similarly, amino acid composition is adversely affected, indeed, previous works noted a reduction of 30–40% in total amino acid content including both of essential and non-essential amino acids.^[54]

In conclusion, these findings highlight the complex and interrelated effects of climate change on major produced cereal crops including wheat, maize and rice, encompassing both yield and compositional quality. Rising temperatures and elevated CO₂ concentrations disrupt the metabolic pathways governing protein synthesis and nutrient accumulation of producing plants leading to reduce grain quality and global food security. Finally, to address these challenges, integrated adaptation strategies such as crop diversification, improved nutrient management, and the breeding of climate-resilient cultivars, are urgently needed. Sustained research efforts and the implementation of climate-smart agricultural practices will be essential to ensure the nutritional and technological integrity of cereals crops in the coming decades.

Other agr-food products

Vegetable oils

Vegetable oils represent one of the most important agricultural products worldwide. They serve as essential sources of dietary lipids and energy for human nutrition, as well as raw materials in food products, cosmetic, and biofuel industries. According to the latest statistics of Food and Agriculture Organization (FAO-STAT), global production of plant oils has greatly increased over the past decades, reaching 206.9 million tons in 2022, with palm, soybean, canola and sunflower oils being the most widely produced and traded varieties representing respectively 38.1, 28.1, 12.9 and 9.8% of total vegetable oil production of the world.^[37] However, the quality of these oils are increasingly challenged by climate change conditions, particularly through rising temperatures and irregular rainfall patterns that greatly influence both of crop's yield and biochemical composition. Therefore, understanding how these climatic conditions could affect the quantity and nutritional quality of various vegetable oils is essential for ensuring food security in a changing environment (Table 3).

For instance, olive oil stands out as one of the most nutritious and health-promoting edible oils worldwide, distinguished by its exceptional sensory qualities and nutritional profile. With a global production estimated at approximately 2.63 million tonnes according to FAOSTAT data about 90% of this output originates from Mediterranean countries including Spain, Italy, Greece and Tunisia contributing by 24.2%, 12.0%, 11.4% and 8.6% of total olive oil production. This vegetable oil holds a central place in the Mediterranean diet, not only for its culinary characteristics but also for its well-documented health benefits.^[55] Climate change represents a major threat to olive oil productivity. Indeed, rising temperatures and reduced rainfall have already led to noticeable declines in the production of olive fruits which will achieve a decrease level of 45% in key growing regions of the Mediterranean according to future projections. These climatic conditions disrupt the physiological balance and increase evapotranspiration of olive trees compromising fruit development and oil output.

Ben Hmida et al.^[56] investigated the influence of climatic change conditions on the composition of olive oil from *Olea europaea* L. cv. Zalmati cultivated in Zarzis (southern Tunisia) over a three-year period (2018–2020). Their findings confirmed that elevated temperatures led to significant reductions in total FA and polyphenols, reflecting a sensitivity of oil composition to thermal stress. On the other hand, statistical analysis revealed that mean temperature accounted for 57.8% of the variation observed in monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), the MUFA/PUFA ratio, and the relative proportions of OA (C18:1) and LA (C18:2). These results highlighted the strong link between rising temperature in context of climate change and olive oil's FA profile, underscoring the potential implications of climate change on its nutritional quality of this oil.

Table 3. Effects of climate change on composition and quality of vegetable oils: palm, soybean and olive oil. Abbreviations: LA, linoleic acid acid; ALA, α -linolenic.

Food sector	Food product	Affected component	Climate drivers	Observed impact	Key references
Vegetable oils	Soybean oil	Fatty acid composition	High temperature during seed development (ranging between 15 and 40°C)	Reduction in essential polyunsaturated fatty acids; Decrease of concentrations of LA and ALA from 55% to 30% and 13% to 3.5%, respectively. altered nutritional quality	[57]
	Sunflower oil	Fatty acid profile	Elevated temperature	Shift toward higher oleic acid and lower linoleic acid content	[58]
	Olive oil	Fatty acids and polyphenols	Heat stress (from 20 to 35°C); drought	Alteration of fatty acid composition; reduction in polyphenol content and oxidative stability	[56]
	Palm oil	Yield	Temperature increase ($\geq 27.83^\circ\text{C}$); rainfall variability	Decreased productivity; increased vulnerability of production systems	[57]

Lombardo et al. 56 conducted a comparative study on 188 Italian olive cultivars grown near the Ionian Sea (southern Italy) between 2001 and 2005 in order to evaluate the effect of temperature on triacylglycerol and FA composition. These authors showed marked variability in the proportions of OA, LA, and other FA among cultivars and across years. For instance, OA proportion decreased to an average of 67.5% in warmest year (2003), compared with 73.4% in the cooler year (2005), while LA increased from approximately 3.9% to 23.9% depending on the cultivar. Furthermore, heat stress increased the contents of saturated fatty acids (SFA) and decreased those of MUFA, confirming a significant reduction in nutritional and oxidative stability of olive oil as a function of raising temperatures in a context of climate change.

Similar climate-induced alterations in lipid composition have been reported in other major vegetable oils. Soybean oil shows significant reductions in PUFA such as LA and α -linolenic acids under elevated temperatures, while palm oil composition is also affected by temperature and precipitation variability.^[57] Likewise, sunflower oil exhibits marked shifts FA profiles, particularly an increase in OA accompanied by a decrease in LA.^[58] Overall, these findings suggest that climate change consistently affects the nutritional quality and oxidative stability of major vegetable oils, although the extent of these changes depends on the specific lipid matrix.

Finally, climate warming disrupts plant physiology, affecting not only production yield of vegetable oils such as olive, soybean, sunflower, and palm oils, but also their nutritional characteristics. Elevated temperatures can reduce the content of essential fatty acids, particularly OA and LA, thereby lowering their nutritional quality. These modifications highlight the urgent need for farmers to implement adaptive strategies to preserve both production and oil quality under heat stress.

Fruits and vegetables

Fruits and vegetables have historically occupied a key place in a healthy diet because of their concentrations of minerals, antioxidants, dietary fiber. And vitamins, especially vitamins C and A. The production and quality of fruits and vegetables produced in agricultural systems around the world are being impacted by changing climatic conditions (Table 4), which have significant effects on farmer incomes and human nutrition.^[59,60]

In this context, Mattos et al.^[64] highlighted that climate change through increased temperature significantly influences fruit and vegetable production and quality. For instance, elevated CO₂ levels influence photosynthesis and secondary metabolism of trees, leading to potential changes in many components including sugar, acid, pigment, and antioxidant contents. These alterations compromise the nutritional and sensory characteristics of horticultural crops, emphasizing the need for adaptive cultivation and post-harvest practices to sustain quality under changing climatic conditions.

Table 4. Effects of climate change on and quality, composition of fruits and vegetables.

Food sector	Food product	Affected component	Climate drivers	Observed impact	Key references
Fruits and vegetables	Fruits (apple, grape, citrus)	Sugars and organic acids	High temperature; altered rainfall patterns	Increased sugar accumulation; reduced acidity; modified flavor balance	[61]
	Fruits (Strawberries)	Bioactive compounds	Moderate heat stress between 18/12°C and 30/22°C of day/night temperatures	Enhanced synthesis of flavonoids and antioxidants	[63]
	Fruits	Visual and textural quality	Extreme heat events	Increased incidence of sunburn, discoloration, and softening	[64]
	Vegetables (tomato, cucumber, potato)	Pigments, minerals, texture	Heat stress (<22°C)	Reduction in carotenoids and mineral content; increased quality defects	[66]

Fruit crops are well known to be highly sensitive to temperature fluctuations. Therefore, changing climate conditions have shown to significantly affect their growth, composition, and quality. Overall, elevated temperatures affect photosynthesis and metabolic pathways, and influence sugar-acid balance, flavor and firmness. Early investigations demonstrated that direct sunlight exposure increased sugar concentration in both of apples and grapes, while simultaneously reducing tartaric and malic acids, thus modifying flavor perception. High temperatures also influence structural properties, as reported for avocados fruits as their firmness increased with exposure to temperature value of 35°C due to modifications in cell wall integrity and turgor pressure.^[61,62] On the other hand, relatively high temperatures significantly affect the synthesis of bioactive compounds as prolonged exposure generally leads to a significant increase in vitamins and antioxidant levels. For instance, Strawberries grown under warm days and nights showed higher flavonoid accumulation and antioxidant activity.^[63] However, excessive heat exposure can cause undesirable adverse effects on fruits such as pigment degradation, softening, and metabolic imbalances. Indeed, under extreme heat conditions, physiological disorders such as sunburn, discoloration, or water core are commonly observed in fruits especially apples and avocados emphasizing the vulnerability of fruit quality to thermal stress.^[64]

Similarly, vegetable crops experience significant physiological and compositional changes under high temperature conditions. Overall, heat stress interferes with nutrient accumulation, pigment biosynthesis and water balance, leading to alter vegetable characteristics including flavor, color, and texture.^[60,64] First, tomato (*Lycopersicon esculentum*) heat induced damage of a temperature of $34 \pm 2^\circ\text{C}$ is shown by yellowish-white side spots on this fruit. Furthermore, tomatoes grown under high light and heat stress (38°C) exhibit chlorophyll loss and decreased carotenoid synthesis as part of plant's adaptive defense systems.^[65] In the same way, Singh et al.^[66] reported that climate change, particularly rising temperatures, exerts adverse effects on both of potato (*Solanum tuberosum*) tuber quality and composition. For instance, heat stress reduces yield and marketable grade while inducing internal disorders such as deformities and discoloration. In addition, a reduction in essential mineral nutrients and citric acid content were noted, increasing the risk of post-cooking browning. Collectively, these findings highlight that rising temperatures due to climate change negatively affect vegetable and fruits physiology leading to reduce both of crop flavor and quality and translate probably into measurable economic losses.

Effects of climate change on food technological properties

Building on the evidence that climate change can significantly change the composition of major food materials, it is important to admit that such compositional modifications have direct implications for their technological aptitude. Indeed, changes in proteins, fats, carbohydrates, and moisture content, as well as biochemical organization, may influence key functional characteristics of the resulted food products such as rheological characteristics, texture, gelation and emulsification. Consequently, climate-induced alterations in key compositional components such as proteins and lipids of food materials, can modify their techno-functional behavior during processing, eventually impacting the technological properties and quality of the final food products. Therefore, understanding these links is required to anticipate how ongoing climate change may challenge the production and quality of processed foods, and to inform strategies for adaptation in food systems. Due to limited available data, technological implications are mainly illustrated using dairy and cereal systems.

Cereal systems: impact on breadmaking

Wheat represents a particularly relevant food model to explore the induced modifications by climate change in the composition raw material that could be translated into changes in technological functionality especially in breadmaking. Indeed, gluten proteins including gliadins and glutenin play a key role in dough rheological characteristics (viscous nature and elasticity) and hence, in final product quality.^[67,68] In this regard, Dupont et al.^[40] who studied the effect of ambient temperature

(ranging between 24/17°C and 37/28°C, day/night) on wheat cultivars in US noted less cohesive and more extensible gluten network because of the increase in the proportions of gliadins and the decrease of HMW-GS. As a result, the obtained dough became less elastic and more difficult to handle, which reduced loaf volume and baking quality. This clearly shows that heat stress disrupts the synthesis and assembly of gluten proteins, affecting the technological properties of wheat (Fig. 3). Marinciu et al.^[67] investigated also the effect of environmental variations upon 20 different Romania environments on bread-making quality of nine wheat cultivars using Reomixer parameters. These authors noted a significant variation of 10% in main rheological characteristics including peak time and breakdown, as well as estimated bread volume. Additionally, these properties were significantly influenced by the temperature range of wheat growing temperature (between 14 and 24°C). For instance, the bread volume was reduced in most of the main wheat varieties studied in Romania.^[63]

In the same way, Maças et al.^[69] have evaluated four bread-making wheat cultivars (Antequera, Roxo, Paiva, and Valbona) over nine years across multiple environmental conditions in Portugal. These authors reported that protein content, wet gluten, dough tenacity, and extensibility were greatly influenced by environmental circumstances. Antequera was the most resilient cultivar in terms of both yield and flour quality, while Roxo performed the worst. These findings confirm that climatic conditions not only affect wheat protein composition, as discussed in Section 2.3, but also have a direct impact on its technological aptitude including dough rheology and breadmaking performance.

Following these technological findings, various adaptation strategies have been suggested to counteract the adverse effects of climate-induced changes on wheat technological performance. Rumler et al.^[70] investigated practical approaches that aimed to mitigate the adverse effects of climate-induced alterations in wheat flour functionality. These authors reported that enriching wheat flour with alternative grains such as sorghum, millet, amaranth, or buckwheat at low proportions (5–15%) improved dough rheology and bread quality. Therefore, cereal blending represents an efficient adaptation strategy to counteract the impact of climate change on wheat gluten technological and nutritional properties in cereal-based products.

Dairy systems: impact on cheesemaking

For dairy products, modifications in casein proportions upon changing climatic conditions such as the reduction in caseins as observed by Bernabucci et al.^[21] and discussed in section 2.1 would effectively alter technological aptitude of milk as well as the characteristics of obtained dairy products. Nonetheless, up to now there to date, few studies have directly investigated the effect of heat stress on technological properties of milk either concerning cheese products nor fermented

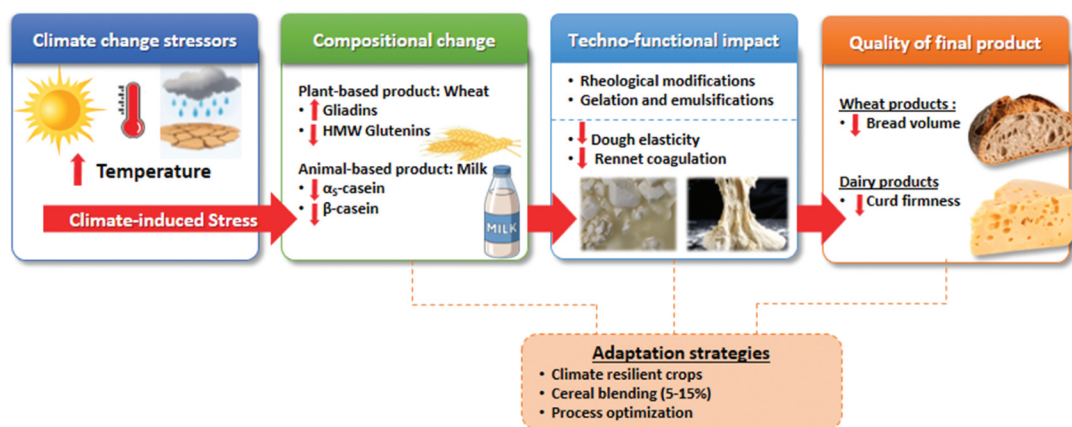


Figure 3. Mechanism underlying the impact of climate change on raw material composition and technological properties of processed foods: wheat and dairy products as case studies.

dairy products. These compositional changes are believed to affect the impaired cheese-making properties and decreased cheese yield commonly observed during the periods in which thermal stress was applied to cows. The decrease of the proportions both of α -casein and β -casein can strongly affect renneting properties of milk, due to the elevated sensitivity of these proteins towards precipitation by calcium ions. Additionally, heat stress-induced reductions in α - and β -caseins may significantly affect cheese-making performance by modifying rennet coagulation properties and curd structure. As demonstrated by St-Gelais and Haché^[71] cheese quality depends not only on total casein amounts but also on the relative proportions of individual caseins including α -caseins and β -casein in milk. Thus, a decrease in α -caseins content can weaken curd firmness, while alterations in β -casein levels may affect coagulation properties (Fig. 1). Consequently, heat stress-related changes in casein composition are expected to influence texture development, proteolysis during ripening, and hence, cheese quality. Therefore, adaptation strategies are essential to preserve milk composition and maintain dairy technological quality. Although previous studies have mainly focused on compositional modifications that can be induced by heat stress, limited attention has been given to practical technological mitigation approaches in dairy sector. This review proposes a classification of potential adaptation strategies into two main categories: upstream biological adaptations strategies and downstream technological interventions. Thus, the first category includes genetic selection of dairy livestock which are more resilient to heat stress in order to stabilize casein synthesis and then, to maintain milk protein quality under elevated temperature conditions. On the other hand, the second category consists of process-based technological strategies, including raw material standardization and technological optimization. These approaches involve standardization of protein fraction through membrane technologies such as ultrafiltration and microfiltration, incorporation of some functional dairy ingredients and hydrocolloids to rebalance protein composition, and finally optimization of parameters in milk coagulation process (rennet dosage, pH adjustment, calcium supplementation, and temperature control) in order to improve both of curd firmness and cheese yield despite climate-induced alterations in casein profiles.

Finally, further studies are still needed to elucidate the impact of climate change on the technological aptitude of milk, as well as on other agri-food products across different processing systems.

Climate change and European quality designation schemes

Beyond their effects on nutritional composition and technological performance, climate-induced alterations in food raw materials may also have important implications for European quality designation schemes including Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI). Indeed, these quality labels are based on preserving specific physicochemical, sensory, and technological characteristics closely associated with environmental conditions (terroir), geographical origin, and traditional production practices.^[72,73] Consequently, changes in temperature, precipitation patterns, and other environmental factors in a context of climate change may compromise the maintenance of the quality attributes required by these certification schemes.^[74] For example, in the dairy sector, heat stress has been associated with reductions in casein synthesis and alterations in milk coagulation properties, which may affect the technological characteristics and consistency of PDO cheeses. Thus, numerous European cheeses, including PDO products, depend on strict specifications related to milk composition and cheesemaking performance. As discussed throughout this review, heat stress alters mammary gland metabolism through reductions in feed intake, endocrine and metabolic adaptations, and increased oxidative stress, leading to decreased milk protein synthesis, particularly caseins, together with modifications in mineral balance and milk coagulation properties. These biochemical changes are associated with modification in rennet coagulation time and curd firmness, which may potentially compromise the technological characteristics required for the manufacture of PDO cheeses and increase variability in product quality. Because many traditional cheeses derive their unique identity from the interaction between local breeds, feeding systems, environmental

conditions, and artisanal processing, maintaining the compositional and functional quality of milk under future climate scenarios represents an important challenge for preserving their authenticity and consistency.

Similarly, many European virgin olive oils are protected under PDO or PGI labels, for which certification requires compliance with strict specifications related to olive cultivars, cultivation practices, and physicochemical and organoleptic characteristics.^[73] Climate-induced modifications in flowering phenology, fruit development, and oil composition may therefore challenge the preservation of the distinctive quality traits associated with these geographical indications.^[74] In addition, adaptation strategies such as changes in agronomic practices or revisions of production specifications may become necessary to preserve product quality under future climate change scenarios, although such modifications may also raise concerns regarding the preservation of authenticity, terroir identity, and consumer perception^[75,76] Finally, climate change represents not only a challenge for food composition and processing performance but also for the long-term sustainability and added value of European quality-labelled agri-food products.

Conclusion and future trends

Climate change has a reciprocal adverse impact on food composition and nutritional quality technological performance. Indeed, climate change impacts agri-food products through multiple pathways, including water availability, soil fertility, reduced food yield, reduced food nutrient concentration and bioavailability. Food material has witnessed significant changes overtime because of climate change. For dairy sector, milk yield is reduced due to heat stress and altered animal physiology. Physicochemical composition is also affected particularly by a significant decrease in protein (caseins) and fat content affecting nutritional and technological quality of milk under climate change. Similarly, cereals such as maize, wheat and rice, have shown a reduction in grain yield and protein quality associated with heat and drought stress affecting nutritional density. Vegetable oils including palm, olive, sunflower and soybean oil, undergo remarkable alteration in fatty acid profiles by a reduction in unsaturated fatty acids due to elevated temperatures in a context of climate change. Oil yield and its oxidative stability have also decreased affecting both of its nutritional value and shelf life. On the other hand, studies revealed that climate change affected food quality and safety of fruits and vegetables. Indeed, contents of antioxidants and vitamins are reduced, meanwhile, susceptibility to microbial spoilage and pests has raised compromising both of food quality and safety.

Climate change induced also reductions in key structural components responsible for technological functionality if food products, particularly HMW glutenins in wheat and α - and β -caseins in milk, directly alter dough elasticity and milk rennet coagulability, leading to decreased bread volume and reduced cheese firmness. These findings demonstrate that nutritional and compositional modifications that are caused by climate change extend beyond food quality and human nutrition to fundamentally affect processing performance.

Climate change may also threaten the preservation of the physicochemical, organoleptic, and technological characteristics required by European quality designation schemes such as PDO and PGI, whose specifications rely on stable interactions between terroir, raw material composition, and traditional processing practices. Therefore, adaptation strategies will need to balance resilience to climate change with the preservation of food product authenticity, geographical identity, and hence, consumer trust.

Addressing these challenges requires integrated adaptation strategies combining genetic selection of heat-resilient crops varieties and livestock with technological interventions such as raw material standardization and process optimization to preserve product quality under future climatic conditions.

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References

- [1] Hachad, H.; Depoux, A. Impacts Sanitaires Du Changement Climatique: Données Récentes, Éléments de Réflexion. *La Press. Médicale Form* **2021**, *2*(6), 598–605. DOI: [10.1016/j.lpmfor.2021.10.020](https://doi.org/10.1016/j.lpmfor.2021.10.020).
- [2] IPCC. Climate Change 2014: Synthesis Report. Core Writing Team; Intergovernmental Panel on Climate Change (IPCC): Geneva, Switzerland, **2014**; pp 151, and L.A. Meyer (Eds..
- [3] Myers, S. S.; Smith, M. R.; Guth, S.; Golden, C. D.; Vaitla, B.; Mueller, N. D.; Dangour, A. D.; Huybers, P. Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition. *Annu. Rev. Public Health* **2017**, *38*(1), 259–277. DOI: [10.1146/annurev-publhealth-031816-044356](https://doi.org/10.1146/annurev-publhealth-031816-044356).
- [4] Owino, V.; Kumwenda, C.; Ekesa, B.; Parker, M. E.; Ewoldt, L.; Roos, N.; Lee, W. T.; Tome, D. The Impact of Climate Change on Food Systems, Diet Quality, Nutrition, and Health Outcomes: A Narrative Review. *Front. Clim.* **2022**, *4*, 941842. DOI: [10.3389/fclim.2022.941842](https://doi.org/10.3389/fclim.2022.941842).
- [5] Tirado, M. C.; Clarke, R.; Jaykus, L.-A.; McQuatters-Gollop, A.; Frank, J. M. Climate Change and Food Safety: A Review. *Food Res. Int.* **2010**, *43*(7), 1745–1765. DOI: [10.1016/j.foodres.2010.07.003](https://doi.org/10.1016/j.foodres.2010.07.003).
- [6] Bhattacharya, N.; Bansal, D.; Dutta, P.K.; Hamad, A.; Haghi, A.K.; Prabhakar, P.K., Eds. *Redefining the Agri-Food Landscape: The Role of Digital Agriculture and Precision Farming in Mitigating Climate Change Impacts on Agri-Food Sector. In Food and Industry 5.0: Transforming the Food System for a Sustainable Future*; Springer: Cham, Switzerland, **2025**; pp. 317–341.
- [7] IPCC. Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In Core Writing Team, Lee, H. and Romero, J., Eds.; Intergovernmental Panel on Climate Change: Geneva, Switzerland, **2023**. 184p.
- [8] Bhowmick, S.; Mayra, S. Climate Change Impacts on Global Agri-Food Systems: Mitigation and Adaptation Strategies for Sustainable Resilience. In *Agriculture Re-Imagined: Innovative Strategies for Sustainable Growth*, Sarkar, T. and Sengupta, S., Eds.; Swami Vivekananda University: Barrackpore, India, **2024**; pp. 69–86.
- [9] Smedo, J. N.; Rodrigues, W. P.; Dubberstein, D.; Martins, M. Q.; Martins, L. D.; Pais, I. P.; Rodrigues, A. P.; Leitão, A. E.; Partelli, F. L.; Camprostrini, E. Coffee Responses to Drought, Warming and High [CO₂] in a Context of Future Climate Change Scenarios. In *Theory and Practice of Climate Adaptation*, Alves, F., Leal Filho, W. and Azeiteiro, U., Eds.; Springer: Cham, Switzerland, **2018**; pp. 465–477.
- [10] Zhao, C.; Liu, B.; Piao, S.; Wang, X.; Lobell, D. B.; Huang, Y.; Huang, M.; Yao, Y.; Bassu, S.; Ciaia, P. Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates. *Proc. Natl. Acad. Sci.* **2017**, *114* (35), 9326–9331.
- [11] Boland, M. Milk Proteins: The Future. In *Milk Proteins: From Expression to Food*, Boland, M. and Singh, H., Eds.; Elsevier (Academic Press): London, UK, **2020**; pp. 715–730.
- [12] Berman, A.; Folman, Y.; Kaim, M.; Mamen, M.; Herz, Z.; Wolfenson, D.; Arieli, A.; Graber, Y. Upper Critical Temperatures and Forced Ventilation Effects for High-Yielding Dairy Cows in a Subtropical Climate. *J. Dairy. Sci.* **1985**, *68*(6), 1488–1495. DOI: [10.3168/jds.S0022-0302\(85\)80987-5](https://doi.org/10.3168/jds.S0022-0302(85)80987-5).

- [13] Kadzere, C. T.; Murphy, M. R.; Silanikove, N.; Maltz, E. Heat Stress in Lactating Dairy Cows: A Review. *Livest. Prod. Sci.* **2002**, *77*(1), 59–91. DOI: [10.1016/S0301-6226\(01\)00330-X](https://doi.org/10.1016/S0301-6226(01)00330-X).
- [14] Liu, Z.; Ezernieks, V.; Wang, J.; Arachchillage, N. W.; Garner, J. B.; Wales, W. J.; Cocks, B. G.; Rochfort, S. Heat Stress in Dairy Cattle Alters Lipid Composition of Milk. *Sci. Rep.* **2017**, *7*(1), 961. DOI: [10.1038/s41598-017-01120-9](https://doi.org/10.1038/s41598-017-01120-9).
- [15] Jo, J.-H.; Nejad, J. G.; Kim, H.-R.; Lee, H.-G. Effect of Seven Days Heat Stress on Feed and Water Intake, Milk Characteristics, Blood Parameters, Physiological Indicators, and Gene Expression in Holstein Dairy Cows. *J. Therm. Biol.* **2024**, *123*, 103929. DOI: [10.1016/j.jtherbio.2024.103929](https://doi.org/10.1016/j.jtherbio.2024.103929).
- [16] Gao, S. T.; Ma, L.; Zhou, Z.; Zhou, Z. K.; Baumgard, L. H.; Jiang, D.; Bionaz, M.; Bu, D. P. Heat Stress Negatively Affects the Transcriptome Related to Overall Metabolism and Milk Protein Synthesis in Mammary Tissue of Midlactating Dairy Cows. *Physiol. Genomics* **2019**, *51*(8), 400–409. DOI: [10.1152/physiolgenomics.00039.2019](https://doi.org/10.1152/physiolgenomics.00039.2019).
- [17] Rhoads, M. L.; Rhoads, R. P.; VanBaale, M. J.; Collier, R. J.; Sanders, S. R.; Weber, W. J.; Crooker, B. A.; Baumgard, L. H. Effects of Heat Stress and Plane of Nutrition on Lactating Holstein Cows: I. Production, Metabolism, and Aspects of Circulating Somatotropin. *J. Dairy. Sci.* **2009**, *92*(5), 1986–1997. DOI: [10.3168/jds.2008-1641](https://doi.org/10.3168/jds.2008-1641).
- [18] Li, Y.; Lin, X.; Liu, C.; Hu, Z.; Hou, Q.; Wang, Z. Assessing Amino Acid Metabolism in Splanchnic Tissues and Mammary Glands to Short-Term Graded Removal of Lys from an Abomasal-Infused Amino Acid Mixture in Lactating Goats. *Front. Vet. Sci.* **2022**, *9*, 929587. DOI: [10.3389/fvets.2022.929587](https://doi.org/10.3389/fvets.2022.929587).
- [19] Promket, D.; Kenchaiwong, W.; Ruangwittayanusorn, K. Effects of Climate Change on Milk Yield and Milk Composition in Thai Crossbred Holstein Cows. *Geomat. J.* **2020**, *18*(67), 108–113.
- [20] Bernabucci, U.; Bani, P.; Ronchi, B.; Lacetera, N.; Nardone, A. Influence of Short-And Long-Term Exposure to a Hot Environment on Rumen Passage Rate and Diet Digestibility by Friesian Heifers. *J. Dairy. Sci.* **1999**, *82*(5), 967–973.
- [21] Bernabucci, U.; Lacetera, N.; Ronchi, B.; Nardone, A. Effects of the Hot Season on Milk Protein Fractions in Holstein Cows. *Anim. Res.* **2002**, *51*(1), 25–33. DOI: [10.1051/animres:2002006](https://doi.org/10.1051/animres:2002006).
- [22] Bertocchi, L.; Vitali, A.; Lacetera, N.; Nardone, A.; Varisco, G.; Bernabucci, U. Seasonal Variations in the Composition of Holstein Cow's Milk and Temperature–Humidity Index Relationship. *Animal* **2014**, *8*(4), 667–674. DOI: [10.1017/S1751731114000032](https://doi.org/10.1017/S1751731114000032).
- [23] Bokharaeian, M.; Toghdory, A.; Ghoorchi, T.; Ghassemi Nejad, J.; Esfahani, I. J. Quantitative Associations Between Season, Month, and Temperature–Humidity Index with Milk Yield, Composition, Somatic Cell Counts, and Microbial Load: A Comprehensive Study Across Ten Dairy Farms Over an Annual Cycle. *Animals* **2023**, *13*(20), 3205. DOI: [10.3390/ani13203205](https://doi.org/10.3390/ani13203205).
- [24] Jeon, E.; Jang, S.; Yeo, J.-M.; Kim, D.-W.; Cho, K. Impact of Climate Change and Heat Stress on Milk Production in Korean Holstein Cows: A Large-Scale Data Analysis. *Animals* **2023**, *13*(18), 2946. DOI: [10.3390/ani13182946](https://doi.org/10.3390/ani13182946).
- [25] Lacetera, N.; Bernabucci, U.; Ronchi, B.; Nardone, A. Physiological and Productive Consequences of Heat Stress. The Case of Dairy Ruminants. *Interact. Between Clim. Anim. Prod.* **2003**, *7*, 45–59.
- [26] de São José, A. N.; Viana, M. C. F. B.; Machado, M. G. P.; de Moraes Almeida, S. L.; Do Carmo Resende, U.; de Oliveira Mota, H.; Júnior, M. L. P.; da Rocha, A. F.; de Carvalho, D. O.; Nader, P. D. J. H. Global Warming Impacts on Lactating Mammalian Milk: A Systematic Review. *Sci. Total Environ.* **2025**, *1003*, 180757.
- [27] Kis, G.; Mulc, D.; Barac, Z. The Impact of Climate Change on the Production and Composition of Goat Milk in Northwest of Croatia. In *Book of Abstracts of the 68th Annual Meeting of the European Federation of Animal Science; EAAP Scientific Committee*; Wageningen Academic Publishers: Wageningen, The Netherlands, **2017**; Vol. 23, p. 359, Ed.; EAAP Book of Abstracts.
- [28] Zhu, X.; Wen, J.; Wang, J. Effect of Environmental Temperature and Humidity on Milk Production and Milk Composition of Guanzhong Dairy Goats. *Vet. Anim. Sci.* **2020**, *9*, 100121. DOI: [10.1016/j.vas.2020.100121](https://doi.org/10.1016/j.vas.2020.100121).
- [29] Lajnaf, R.; Attia, H.; Ayadi, M. A. A Review of Camel β -Casein: From Purification Processes, to Bioactivity and Techno-Functionality. *Food Biosci.* **2024**, *62*(June), 105060. DOI: [10.1016/j.fbio.2024.105060](https://doi.org/10.1016/j.fbio.2024.105060).
- [30] Lajnaf, R.; Attia, H.; Ayadi, M. A. Development and Characterization of Spirulina (*Arthrospira Platensis*)-Fortified Cheeses from Camel and Bovine Milk. *Algal Res.* **2025**, *91*, 104291. DOI: [10.1016/j.algal.2025.104291](https://doi.org/10.1016/j.algal.2025.104291).
- [31] Al Haj, O. A.; Al Kanhal, H. A. Compositional, Technological and Nutritional Aspects of Dromedary Camel Milk. *Int. Dairy J.* **2010**, *20*(12), 811–821. DOI: [10.1016/j.idairyj.2010.04.003](https://doi.org/10.1016/j.idairyj.2010.04.003).
- [32] Konuspayeva, G.; Faye, B.; Loiseau, G. The Composition of Camel Milk: A Meta-Analysis of the Literature Data. *J. Food Compos. Anal.* **2009**, *22*(2), 95–101. DOI: [10.1016/j.jfca.2008.09.008](https://doi.org/10.1016/j.jfca.2008.09.008).
- [33] Yagil, R.; Etzion, Z. Effect of Drought Condition on the Quality of Camel Milk. *J. Dairy Res.* **1980**, *47*(2), 159–166. DOI: [10.1017/S0022029900021026](https://doi.org/10.1017/S0022029900021026).
- [34] Boudalia, S.; Gueroui, Y.; Zebba, R.; Arbia, T.; Chiheb, A. E.; Benada, M.; Hadri, Z.; Youcefi, A.; Bousbia, A. Camel Livestock in the Algerian Sahara Under the Context of Climate Change: Milk Properties and Livestock Production Practices. *J. Agric. Food Res.* **2023**, *11*, 100528. DOI: [10.1016/j.jafr.2023.100528](https://doi.org/10.1016/j.jafr.2023.100528).
- [35] Farooq, A.; Farooq, N.; Akbar, H.; Hassan, Z. U.; Gheewala, S. H. A Critical Review of Climate Change Impact at a Global Scale on Cereal Crop Production. *Agronomy* **2023**, *13*(1), 162. DOI: [10.3390/agronomy13010162](https://doi.org/10.3390/agronomy13010162).

- [36] Wang, J.; Vanga, S. K.; Saxena, R.; Orsat, V.; Raghavan, V. Effect of Climate Change on the Yield of Cereal Crops: A Review. *Climate* **2018**, *6*(2), 41. DOI: [10.3390/cli6020041](https://doi.org/10.3390/cli6020041).
- [37] FAOTSTAT. FAOSTAT, Food and Agriculture Organization. s2023. <https://www.fao.org/faostat/en/#data/QC>. (accessed Jan 30, 2026).
- [38] Lin, T.; Wang, B.; Wang, S.; Haider, F. U.; Zhang, P.; Li, X. Integrated Physiological, Hormonal, and Metabolic Mechanisms Regulating Wheat Yield Quality Under Combined Drought and Heat Stress. *Plant. Stress* **2026**, *101257*. DOI: [10.1016/j.stress.2026.101257](https://doi.org/10.1016/j.stress.2026.101257).
- [39] Broberg, M. C.; Hayes, F.; Harmens, H.; Uddling, J.; Mills, G.; Pleijel, H. Effects of Ozone, Drought and Heat Stress on Wheat Yield and Grain Quality. *Agric. Ecosyst. Environ.* **2023**, *352*, 108505. DOI: [10.1016/j.agee.2023.108505](https://doi.org/10.1016/j.agee.2023.108505).
- [40] Dupont, F. M.; Hurkman, W. J.; Vensel, W. H.; Tanaka, C.; Kothari, K. M.; Chung, O. K.; Altenbach, S. B. Protein Accumulation and Composition in Wheat Grains: Effects of Mineral Nutrients and High Temperature. *Eur. J. Agron.* **2006**, *25*(2), 96–107. DOI: [10.1016/j.eja.2006.04.003](https://doi.org/10.1016/j.eja.2006.04.003).
- [41] Labuschagne, M. T.; Elago, O.; Koen, E. The Influence of Temperature Extremes on Some Quality and Starch Characteristics in Bread, Biscuit and Durum Wheat. *J. Cereal Sci.* **2009**, *49*(2), 184–189. DOI: [10.1016/j.jcs.2008.09.001](https://doi.org/10.1016/j.jcs.2008.09.001).
- [42] Ashraf, M. Stress-Induced Changes in Wheat Grain Composition and Quality. *Crit. Rev. Food Sci. Nutr.* **2014**, *54* (12), 1576–1583. DOI: [10.1080/10408398.2011.644354](https://doi.org/10.1080/10408398.2011.644354).
- [43] Zhou, W.; Ata-Ul-Karim, S. T.; Kato, Y.; Liu, H.; Wang, K. Exploring the Climate Signal in the Variation of Winter Wheat Quality Records in the North China Plain. *Agric. For. Meteorol.* **2025**, *369*, 110567. DOI: [10.1016/j.agrformet.2025.110567](https://doi.org/10.1016/j.agrformet.2025.110567).
- [44] Hurkman, W. J.; Vensel, W. H.; Tanaka, C. K.; Whitehand, L.; Altenbach, S. B. Effect of High Temperature on Albumin and Globulin Accumulation in the Endosperm Proteome of the Developing Wheat Grain. *J. Cereal Sci.* **2009**, *49*(1), 12–23. DOI: [10.1016/j.jcs.2008.06.014](https://doi.org/10.1016/j.jcs.2008.06.014).
- [45] Bencze, S.; Veisz, O.; Bedő, Z. Effects of High Atmospheric CO₂ and Heat Stress on Phytomass, Yield and Grain Quality of Winter Wheat. *Cereal Res. Commun.* **2004**, *32*(1), 75–82. DOI: [10.1007/BF03543283](https://doi.org/10.1007/BF03543283).
- [46] Caverzan, A.; Casassola, A.; Brammer, S. P. Antioxidant Responses of Wheat Plants Under Stress. *Genet. Mol. Biol.* **2016**, *39*, 1–6. DOI: [10.1590/1678-4685-GMB-2015-0109](https://doi.org/10.1590/1678-4685-GMB-2015-0109).
- [47] Yadav, M. R.; Choudhary, M.; Singh, J.; Lal, M. K.; Jha, P. K.; Udawat, P.; Gupta, N. K.; Rajput, V. D.; Garg, N. K.; Maheshwari, C. Impacts, Tolerance, Adaptation, and Mitigation of Heat Stress on Wheat Under Changing Climates. *Int J Mol Sci.* **2022**, *23*(5), 2838.
- [48] Todaka, D.; Nakashima, K.; Maruyama, K.; Kidokoro, S.; Osakabe, Y.; Ito, Y.; Matsukura, S.; Fujita, Y.; Yoshiwara, K.; Ohme-Takagi, M. Rice Phytochrome-Interacting Factor-Like Protein OsPIL1 Functions as a Key Regulator of Internode Elongation and Induces a Morphological Response to Drought Stress. *Proc. Natl. Acad. Sci.* **2012**, *109*(39), 15947–15952.
- [49] Yactayo-Chang, J. P.; Block, A. K. The Impact of Climate Change on Maize Chemical Defenses. *Biochem J.* **2023**, *480*(16), 1285–1298. DOI: [10.1042/BCJ20220444](https://doi.org/10.1042/BCJ20220444).
- [50] Erb, M.; Kliebenstein, D. J. Plant Secondary Metabolites as Defenses, Regulators, and Primary Metabolites: The Blurred Functional Trichotomy. *Plant. Physiol.* **2020**, *184*(1), 39–52. DOI: [10.1104/pp.20.00433](https://doi.org/10.1104/pp.20.00433).
- [51] Godson, A.; van der Hoorn, R. A. L. The Front Line of Defence: A Meta-Analysis of Apoplastic Proteases in Plant Immunity. *J. Exp. Bot.* **2021**, *72*(9), 3381–3394. DOI: [10.1093/jxb/eraa602](https://doi.org/10.1093/jxb/eraa602).
- [52] Saud, S.; Wang, D.; Fahad, S.; Alharby, H. F.; Bamagoos, A. A.; Mjrashi, A.; Alabdallah, N. M.; AlZahrani, S. S.; Abdelgawad, H.; Adnan, M. Comprehensive Impacts of Climate Change on Rice Production and Adaptive Strategies in China. *Front. Microbiol.* **2022**, *13*, 926059. DOI: [10.3389/fmicb.2022.926059](https://doi.org/10.3389/fmicb.2022.926059).
- [53] Taub, D. R.; Miller, B.; Allen, H. Effects of Elevated CO₂ on the Protein Concentration of Food Crops: A Meta-Analysis. *Glob. Chang. Biol.* **2008**, *14*(3), 565–575.
- [54] Yang, L.; Wang, Y. Impact of Climate Change on Rice Grain Quality. In Fourth ed.; Chemistry and Technology; Elsevier, **2019**; pp. 427–441.
- [55] Jiménez-Sánchez, A.; Martínez-Ortega, A. J.; Remón-Ruiz, P. J.; Piñar-Gutiérrez, A.; Pereira-Cunill, J. L.; García-Luna, P. P. Therapeutic Properties and Use of Extra Virgin Olive Oil in Clinical Nutrition: A Narrative Review and Literature Update. *Nutrients* **2022**, *14*(7), 1440. DOI: [10.3390/nu14071440](https://doi.org/10.3390/nu14071440).
- [56] Ben Hmida, R.; Gargouri, B.; Chtourou, F.; Abichou, M.; Sevim, D.; Bouaziz, M. Study on the Effect of Climate Changes on the Composition and Quality Parameters of Virgin Olive Oil “Zalmati” Harvested at Three Consecutive Crop Seasons: Chemometric Discrimination. *ACS Omega.* **2022**, *7*(44), 40078–40090. DOI: [10.1021/acsomega.2c04813](https://doi.org/10.1021/acsomega.2c04813).
- [57] Bukowski, M. R.; Goslee, S. Climate-Based Variability in the Essential Fatty Acid Composition of Soybean Oil. *Am. J. Clin. Nutr.* **2024**, *119*(1), 58–68. DOI: [10.1016/j.ajcnut.2023.08.024](https://doi.org/10.1016/j.ajcnut.2023.08.024).
- [58] Adeleke, B. S.; Babalola, O. O. Oilseed Crop Sunflower (*Helianthus Annuus*) as a Source of Food: Nutritional and Health Benefits. *Food Sci. Nutr.* **2020**, *8*(9), 4666–4684. DOI: [10.1002/fsn.3.1783](https://doi.org/10.1002/fsn.3.1783).
- [59] Slavin, J. L.; Lloyd, B. Health Benefits of Fruits and Vegetables. *Adv Nutr.* **2012**, *3*(4), 506–516. DOI: [10.3945/an.112.002154](https://doi.org/10.3945/an.112.002154).

- [60] Manzoor, M. A.; Xu, Y.; Xu, J.; Shah, I. H.; Sabir, I. A.; Wang, Y.; Sun, W.; Liu, X.; Wang, L.; Liu, R. Horticulture Crop Under Pressure: Unraveling the Impact of Climate Change on Nutrition and Fruit Cracking. *J. Environ. Manage.* **2024**, *357*, 120759.
- [61] Lakso, A. N.; Kliever, W. M. The Influence of Temperature on Malic Acid Metabolism in Grape Berries: I. Enzyme Responses. *Plant. Physiol.* **1975**, *56*(3), 370–372. DOI: [10.1104/pp.56.3.370](https://doi.org/10.1104/pp.56.3.370).
- [62] Woolf, A. B.; Wexler, A.; Prusky, D.; Kobiler, E.; Lurie, S. Direct Sunlight Influences Postharvest Temperature Responses and Ripening of Five Avocado Cultivars. *J. Am. Soc. Hortic. Sci.* **2000**, *125*(3), 370–376. DOI: [10.21273/JASHS.125.3.370](https://doi.org/10.21273/JASHS.125.3.370).
- [63] Marinciu, C. M.; Lazăr, C.; Șerban, G.; Tilihoi, M.; Păunescu, G.; Bănățeanu, C.; Andraș, B.-E.; Melucă, C.; Lobontiu, I.; Domokoș, Z. I Poster Presented at the International Conference Management of Genetic Biodiversity by Plant Breeding and Sustainable Agricultural Technologies, Fundulea, Romania, Nov 22, **2024**.
- [64] Mattos, L. M.; Moretti, C. L.; Jan, S.; Sargent, S. A.; Lima, C. E. P.; Fontenelle, M. R. Climate Changes and Potential Impacts on Quality of Fruit and Vegetable Crops. In *Emerging Technologies and Management of Crop Stress Tolerance*; Ahmad, P.; Rasool, S., Eds.; Academic Press (Elsevier): San Diego, USA, **2014**; pp. 467–486.
- [65] Zhou, R.; Yu, X.; Li, X.; Dos Santos, T. M.; Rosenqvist, E.; Ottosen, C.-O. Combined High Light and Heat Stress Induced Complex Response in Tomato with Better Leaf Cooling After Heat Priming. *Plant. Physiol. Biochem.* **2020**, *151*, 1–9. DOI: [10.1016/j.plaphy.2020.03.011](https://doi.org/10.1016/j.plaphy.2020.03.011).
- [66] Singh, B. P.; Dua, V. K.; Govindakrishnan, P. M.; Sharma, S. Impact of Climate Change on Potato. In *Climate-Resilient Horticulture: Adaptation and Mitigation Strategies*; Springer: New Delhi, India, **2013**; pp. 125–135.
- [67] Marinciu, C. M.; Lazar, C.; Șerban, G.; Tilihoi, M.; Paunescu, G.; Banateanu, C.; Andras, B.-E.; Meluca, C.; Lobontiu, I.; Domokos, Z. Influence of Environmental Conditions on Rheological Parameters in Several Romanian Winter Wheat Varieties Released by Nardi Fundulea. *Environments* **2025**, *59*(76.6), 41–47.
- [68] Gras, P. W.; Anderssen, R. S.; Keentok, M.; Békés, F.; Appels, R. Gluten Protein Functionality in Wheat Flour Processing: A Review. *Aust. J. Agric. Res.* **2001**, *52*(12), 1311–1323. DOI: [10.1071/AR01068](https://doi.org/10.1071/AR01068).
- [69] Maças, B.; Costa, R.; Gomes, C.; Bagulho, A. S.; Pinheiro, N.; Moreira, J.; Costa, A.; Patanita, M.; Doros, J.; Rodrigo, S. Breeding in Bread-Making Wheat Varieties for Mediterranean Climate: The Need to Get Resilient Varieties. *Front. Nutr.* **2024**, *11*, 1393076. DOI: [10.3389/fnut.2024.1393076](https://doi.org/10.3389/fnut.2024.1393076).
- [70] Rumler, R.; Bender, D.; Schoenlechner, R. Mitigating the Effect of Climate Change within the Cereal Sector: Improving Rheological and Baking Properties of Strong Gluten Wheat Doughs by Blending with Specialty Grains. *Plants* **2023**, *12*(3), 492. DOI: [10.3390/plants12030492](https://doi.org/10.3390/plants12030492).
- [71] St-Gelais, D.; Haché, S. Effect of β -Casein Concentration in Cheese Milk on Rennet Coagulation Properties, Cheese Composition and Cheese Ripening. *Food Res. Int.* **2005**, *38*(5), 523–531. DOI: [10.1016/j.foodres.2004.11.006](https://doi.org/10.1016/j.foodres.2004.11.006).
- [72] Giovannucci, D.; Josling, T. E.; Kerr, W.; O'Connor, B.; Yeung, M. T. *Guide to Geographical Indications: Linking Products and Their Origins*; International Trade Centre: Geneva, Switzerland, **2009**.
- [73] Bajoub, A.; Fernández-Gutiérrez, A.; Carrasco-Pancorbo, A. Evaluating the Potential of Phenolic Profiles as Discriminant Features Among Extra Virgin Olive Oils from Moroccan Controlled Designations of Origin. *Food Res. Int.* **2016**, *84*, 41–51.
- [74] Clark, L. F.; Kerr, W. A. Climate Change and Terroir: The Challenge of Adapting Geographical Indications. *J. World Intellect. Prop.* **2017**, *20*(3–4), 88–102. DOI: [10.1111/jwip.12078](https://doi.org/10.1111/jwip.12078).
- [75] Rodríguez-Entrena, M.; Arriaza, M. Adoption of Conservation Agriculture in Olive Groves: Evidences from Southern Spain. *Land Policy* **2013**, *34*, 294–300. DOI: [10.1016/j.landusepol.2013.04.002](https://doi.org/10.1016/j.landusepol.2013.04.002).
- [76] Hinojosa-Rodríguez, A.; Parra-Lopez, C.; Carmona-Torres, C.; Sayadi, S. Protected Designation of Origin in the Olive Growing Sector: Adoption Factors and Goodness of Practices in Andalusia, Spain. *New Medit* **2014**, *13*(3), 2–12.