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Review

Mediterranean Diet and Incidence of Global Warming on Food Habits and Plant Growth in Northern Mediterranean Latitudes: A Narrative Review

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Abstract: This narrative review was realized by consulting PubMed, EM-BASE, Scopus, Web of Science, Science Direct, and Google Scholar databases i) to identify the relevant studies related to climate changes which could favor a progression of the Mediterranean climat in the highest latitudes of Europa, mainly in France, and ii) to estimate which could be the consequences of these changes on human diet, especially on the concept of Mediterranean diet, with subsequent impacts on health, farming, and eating habits. The key points developed in this review are: - healthy diet: Mediterranean diet, evidence supporting health benefit proofs and perspectives; - similarities with other world places at the same Mediterranean latitudes; - climate change and resulting consequences on plant growth, farming and food habits; - perspectives towards a need of societal adaptations of populations towards agriculture, food and cooking changes. As climate change facilitates the development of new farming practices with more or less environmental impacts, the growth of Mediterranean plants in highest latitudes from Europa, such as olive trees, pomegranate, and almond has already begun for economic reasons. It is therefore questionable whether these climate changes, behind economic interests, will also facilitate an expansion of the Mediterranean diet, and preserve its benefits. In this context, the roles of producers and consumers are major.

Keywords: climate change; global warming; mediterranean diet; food habits; northern mediterranean latitudes

1. Introduction

The early history of the earth includes a succession of cooling and warming periods with major changes for life: disappearance, survival and evolution of plant and animal species [1,2]. For the last 1,000 years, in temperate latitudes of western Europe, there has been cycles changes of 150-200 year-periods length, and the last one started around 100 years ago. Based on the consequences of global warming within 50 years from now, it is supposed that a progression of the Mediterranean climate, currently observed around the Mediterranean Sea, could move to higher latitudes, especially in France. Unfortunately, the area currently characterized by a Mediterranean climate could progressively become semi-arid and arid with several negative social and economic impacts on the countries concerned [3]. In the south of Europa, one of the major impacts of global warming concerns notably vines and corn cultivation; indeed, the vine is sensitive to dehydration and warm and sunny days, and the cultivation of corn requires a high quantity of water [4]. This negative impact on vine growth has already negative economic impacts in several wine regions in France. At the opposite, in

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the highest latitudes of Europa, this situation of global warming could favor modifications of agricultural practices, with the development of new cultures (olive, pomegranate, almond) and white oaks new forests <https://www.oliveoiltimes.com/production/climate-change-leads-some-bordeaux-wine-producers-to-plant-olives/116924)>, and subsequently to food habits leading to a most important consumption of fruits and vegetables which are major compounds of the Mediterranean diet. The notion of healthy diet has emerged from 1950 to 1990 with the work of the american physiologist Ancel Keys who looked at men in their 40's and 50's living in Greece, the US, Finland, Japan, Italy, Yugoslavia and the Netherlands. Ancel Keys showed that despite a diet very rich in fat (over 40% of their calorie intake daily came from olive oil in Greece and), cardio vascular diseases that resulted in heart attack and stroke in these countries were almost unheard of, and cancer was even rarer (https://borakisgreekfood.co.uk/pages/the-cretan-diet, consulted november 28, 2024 ; and [5]). This pionnering work of Ancel Keys contributed to the notion of Mediterranean diet and to the emergence of the work of Serge Renaud on the French paradox [6]. It is now well admitted that Mediterranean diet has several health benefits [7], and in association with the current environmental changes which have several negative aspects [8], some modifications of diet habits, including more Mediterranean compounds (vegetables, fruits) can be expected [9]. It is important to underline that the so called Mediterranean cooking is currently not restricted to the Mediterranean basin, but also found in other regions of the globe at the same latitude, between the 39-40th parallels from the northern and southern hemisphere including California (USA), certain regions of China, Chile and South Africa [10].

Climate change, which is currently a dramatic situation for several countries, must be rapidly taken in consideration to transform this change into an opportunity for innovation in different fields: adapt plant species (vegetables, trees, herbs, spices), and vineyards to climate change with methods having no or few minor environmental impacts and no negative consequences on human and animal health. The development of innovative methods of cultures without environmental impact with new socio-economical concepts seems crucial [11]. The following objectives to consider are the advantage of keeping a local production associated with a reduction of the carbon footprint included in a circular economy [12]. An important question is how can we stimulate people to embrace this health-food approach based on Mediterranean diet, and encourage them to adopt it. In this context, some proposals have been presented on a round table organized by «Nutrition Méditerranéenne et Santé» (NMS) association [13] on the topic: “Which agriculture and food of the Mediterranean diet in the next 50 years, in the septentrional area of France”.

The present narrative review focuses on the aspect of climate change which could favor an extension of the Mediterranean climate in the highest latitudes of Europe, especially in France, with an impact on diet habits. The key points developed in this review are: - healthy diet: Mediterranean (and Cretan) diet, health benefit proofs and perspectives; - similarities of other world places at the same mediterranean latitudes; - climate change and resulting consequences on food habits and plant growth; - perspectives towards a need of societal adaptations of populations towards agriculture, food and cooking changes.

2. Methods

This narrative review was performed following different steps as previously reported [14]. For this, the PubMed, EM-BASE, Scopus, Science Direct, Web of Science, Science Direct, and Google Scholar databases were consulted to identify the relevant studies. The final search was conducted in December 2024 and included English language-based international articles, online reports, and electronic books. The keywords (identified in the title, abstract and key words) global warming, food habits, and mediterranean diet were used and combined; they were also combined with economic impact, social impact, and environmental impact. After the complete search, the abstracts were read to ensure that they address the topic of interest. All duplicates were removed, and the abstracts of the remaining articles were reviewed to ensure that they address the review inclusion criteria.

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3. The Mediterranean As a Healthy Diet: Benefits and Perspectives

A diet especially rich in antioxidants is the Mediterranean diet [15,16]. It is well recognized that regular consumption of green vegetables, fruits, fibers and fishes, combined with daily exercises and social activities, has a protective effect against the onset of age-related diseases (mainly cardiovascular diseases), and consequently is a factor of longevity [17]. Conversely, a high-calorie diet (rich in refined sugars and fats), combined with deleterious life habits (smoking, excessive alcohol consumption, stress), will increase the risk of vascular pathologies, diabetes, obesity, and cancer. In fact, plant-based foods contain several types of microconstituents present in fruits and vegetables such as polyphenols with anti-oxidant, and anti-aging properties [4], and phytosterols with hypocholesterolemic properties [18]. Examples of antioxidant-rich fruits and vegetables are: grapes, tea/coffee, soy, peanuts, cocoa, apples, onions, cabbages, broccoli, tomatoes, almonds, olive oil, pomegranates, red berries (blueberries, blackcurrants, raspberries), etc. These products and some of their derivatives including wine, juices and/or oils offer powerful anti-oxidant properties and sometimes anti-inflammatory properties. Anti-oxidants and anti-inflammatory compounds are extremely important to vital processes, since cellular ageing seems directly linked to increased levels of free radicals and inflammatory cytokines [19].

In 2010, United Nations Educational, Scientific and Cultural Organization **(**UNESCO) declared the Mediterranean diet to be part of humanity's intangible cultural heritage: "The Mediterranean is characterized by a nutritional model that has remained constant over time and space, and whose main ingredients are olive oil; cereals; fruit and vegetables, fresh or dried; a limited proportion of fish, dairy products and meat, and numerous condiments and spices (such as might be found in a stall in a Mediterranean town or village). All accompanied by drinks or infusions, always respecting the beliefs of each community." Another edict: "the Mediterranean diet is defined as a set of skills, knowledge, practices and traditions that go beyond vegetables and fruits, all accompanied by wine or infusions". Currently, there are several scientific evidences of the benefits of the Mediterranean diet in protecting against several pathologies.

The Mediterranean diet is based on the famous food pyramid established from the Cretan or Sardinian diet (**Figure 1**), where the two plant pillars are the olive tree (olive oil) and the vine plants (mainly red wine) [20]. In the cardiovascular field, the Mediterranean diet leads to an 8% reduction in general mortality and a 10% reduction in the risk of developing cardiovascular diseases [21]. Regarding vascular events, the Spanish PREDIMED (Prevention by Mediterranean diet) study shows that the Mediterranean diet with added olive oil or 30 g/day

of nuts reduces the risk of cardiovascular events (heart attack, stroke and death from cardiovascular diseases) by around 30% [22].

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Figure 1. Pyramid of a healthy diet which characterizes the Mediterranean diet. Copyright ownership from MDPI [23].

For breast cancer, the adoption of a strict Mediterranean diet is associated with a 30-50% reduction in the incidence of developing breast cancer [24]; for colorectal cancer, the significant association between the strict adoption of a Mediterranean diet and a reduction in the relative risk of developing colorectal cancer is 0.46 [25]. It is estimated that 40% of cancers can be prevented by a healthy diet and a healthy lifestyle (regular walking, no smoking) [26]. When it comes to maintaining brain health, people with good adherence to the Mediterranean diet are 46% less likely to experience a decline in their cognitive abilities, particularly their ability to think [27]. In the longevity register, with the strict Mediterranean diet, leukocytes show the greatest telomere length ($p = 0.003$) and telomere-maintaining telomerase enzyme activity ($p = 0.013$) [28].

4. Healthy Aging at Mediterranean Latitudes

The impact of the diet on healthy aging is crucial. From an economic point of view, healthy aging is a major priority to reduce the cost of aging pathologies which also have an negative societal impact. The urgency to address both population ageing and climate change necessitates a rethink and assessment of the impact of climate change on older people [29]. Healthy aging could secondarily favor an increase of longevity. At the moment, in France and Italy, an exceptional longevity has been observed for few people. Jeanne Calment, aged 122 (France, died August 4, 1997), Robert Marchand, sportsman (cyclist), aged 109 (France, died May 20, 2021), Colette Maze, pianist, aged 108 (France, died November 2023), or the Venice-Padua philosopher Alvise Cornaro (Italy), who advocated a sober lifestyle in the second half of his life, when he died aged 102 in 1566. All these centenarians followed a low-calorie diet which is also a hall mark of the Mediterranean diet. Elevated percentages of centenarians are also found in Okinawa (Japan), Crete and Sardinia [30]. In Japan, life expectancy in 2021 was 86 for women and 78 for men. In relation to dietary intake, the longevity of the Japanese

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in Okinawa is 10/100,000 inhabitants. Interestingly, this characteristic of longevity and healthy aging does not seem under the control of genetic characteristics but rather of the exposome, including several social and environmental factors impacting physiological processes which act on aging biology [31]. Thus, among the descendants of these populations who emigrated from Okinawa to Brazil no more than 2 centenarians /100,000 inhabitants were reported underlying the importance of environmental factors and diet in aging. In this hybrid Japanese / Brazilian population, energy intake had increased by 30%, in line with the Brazilian lifestyle. In the Gers (south-west region of France), the proportion is 11 centenarians per 100,000, compared with 14 centenarians/100,000 in Japan has been relied with diet habits and especially with the consumption of duck fat reducing the incidence of cardiovascular diseases.

Interestingly, the so called Mediterranean cooking is not restricted to the Mediterranean rim, but also found in other regions of the globe at the same latitude, i.e., between the 39-40th parallels from the northern and southern hemisphere including California (USA), certain regions of China, Chile and South Africa.

Interestingly, Okinawa diet contains similar ingredients than Mediterranean diet known for their major benefits on human health such as omega-3 fatty acids found in oily fish and edible oils (olive and argan oils, several vitamins and fibers found in fruits and vegetables as well as several polyphenols with important anti-oxidant and anti-inflammatory properties found in tea as epigallocatechin gallate and resveratrol abundant in red wine [32]. Consequently, aging in good health does not depend on the population considered but rather on the characteristics of the diet adopted which strongly impact aging in good health.

In terms of nutrition, the alimentation of the future will require several adaptations due to global warming with the simultaneous necessity to reduce carbon footprint; despite these constraints, the food supply of the future will still have to provide enough foods of good nutritional qualities meeting the justified demands of consumers in terms of food safety [33]. The impact of climate changes on healthy aging is still not well known. However, as the Mediterranean diet is known to have health benefits [34]. The extension of this diet at higher latitudes is expected to have a positive impact on longevity in good health (**Figure 2**).

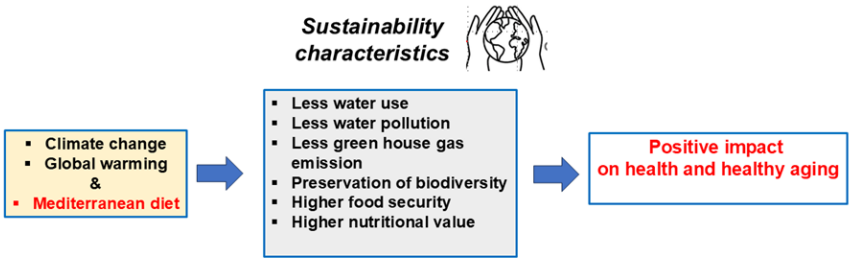

Figure 2. Sustainability features of the Mediterranean diet contributing to its positive ecological footprint (copyright ownship).

5. Climate Changes and Modifications of Food Habits

Climate change and media pressure should theorically contribute to dietary changes and these changes should influence the reduction of the global carbon footprint. These changes must be supported by public politics. This applies in particular to meat consumption, which is decried not only for its environmental impact but also for the often-disastrous living conditions of farm animals.

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Paradoxically, this does not deter consumers to eat imported food, which often requires extensive irrigation, financial exploitation of farm workers and numerous means of transport before arriving in our plates. As a result, virtuous practices are often associated with opposite practices that ultimately fail to have environmental benefits. A more reasoned marketing approach that does not focus solely on financial gain is worth considering.

In the context of climate change, which is being taken into account because of its harmful environmental impact, the notion of consumption summarized by the formula 'from fork to farm' is relevant. We need to adapt our diet as much as possible to suit our region and seasonal produce, which does not mean we should stop eating manufactured products. In this context, the 'Nutriscore' [30] introduced in France enables consumers to make a choice that takes into account the benefits and harms of the products they choose.

The consequences of climate change for human health are more closely linked to agricultural practices that use pollutant molecules (pesticides, fungicides, fertilizers, antibiotics, hormones, etc) to optimize plant and animal production in the short and medium term, without taking the long view. Since humans are at the end of the food chain, these products end up in our food, with consequences for health at several levels, including fertility, the emergence of new diseases and an increase in pathologies neurodegenerative diseases, cancers.

In the face of climate change, consumer education is a major challenge if we are to respond to the changes in eating habits that are likely to occur. In any case, if changes in eating habits are to occur, they must be made with a view to preserve human health by providing sufficient quality food for all social categories of the populations worldwide [32].

6. Impact on Plant Growth and Characteristics

Thorough the history of the earth, there has been successions of cooling and warming periods associated with major changes for life, disappearance, survival and evolution of species. In the last millenar in temperate latitudes of western Europa, there has been cycles changes of 150-200 year-period length. The last one started around 100 years ago. For western Europa, the landmark is the height changes of the Aletsch glacier in Switzerland and of the "Mer de glace" in Chamonix (France) [35]. (Adapted by M. Hudelot, B. Winemaker and historian from Burgundy, France, 2019✝)

Thus, it seems that there were always alternations of several centuries of cooling periods and temperate or heating periods. The alternance is however accentuated by the human activities, and to survive the humans have to find rapid solutions. As an example, in terms of culture, the red wine cepages in Burgundy are mainly «Pinot noir» in cool periods, and «Gamay» in heat periods, and the modification of the cepage does not affect the wine quality.

Michel Magny and Hervé Richard [36] from the area of Bourgogne France-Comté (East of France) report on global warming: "We realize that things are moving at breakneck speed". Their book "Histoire du climat dans les montagnes du Jura" (History of climate in the Jura mountains) is a regional overview on the climate issue. It is the result of a compilation of information from 50 French and Swiss contributors. What emerges is the diversity of the types of impact that global warming could have. Michel Magny says: "We like the figure that compares the city of Lyon (Middle east of France) to Besançon (North east of France). In 1980, Besançon caught up with the temperature experienced by Lyon in 1930, only to overtake it today. It's as if we had travelled 200 kms southwards in latitude. Global warming has made us immobile travelers. We're moving south without moving."

Consequently, in this current global warming period, we can expect to see a Mediterranean-type of climate in the North-East of France, where drought rainy and windy spells, the disappearance of snow and heavy frosts will predominate. Beside an actual picture of Burgundy landscape with green fields, wineyard, and trees form temperate regions, we can imagine appearance of olive trees and agrum trees (**Figure 3**). The key question will be whether the local products will resist or not to the climate change. In Burgundy and in Savoy area, grass is already limitant for dairy products which are associated with important industrial activities. The temperature also increases sugar content in the fruits including the grapes used to produce wine also associated with important economic

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activities. Innovative solutions must be found to overcome these problems. Innovative solutions have to be considered as a challenge.

Figure 3. Imaginary landscape from northern mediterranean latitudes. With the global warming expected in upcoming years important changes in northern mediterranean latitudes will probably occur and impact the growth of plants and their characteristics (ownship, original picture from the laboratory, 2024).

Thus, in agreement with the observations of Michel Magny and Hervé Richard [36], in 30 years, the Mediterranean climate has moved 70 to 100 kms north and west in France, and should soon extend as far as in Orléans not far from Paris. We are also observing a gradual shift from 4 well-marked seasons - spring, summer, autumn and winter - to two major seasons of unequal length: an increasingly shorter winter that is less cold and less rainy or snowy, and a hot summer season with intense rainfalls, thunderstorms and runoff. The spring and autumn seasons are tending to disappear. The climate statistics show: - Rising temperatures: +1.5°C on average (+0.5°C on average per decade) and +2.4°C for the months of May, June, July and August (+0.8°C per decade). From May to August, Lyon (Middle east of France) is now hotter than Avignon or Montpellier (south of France) were 30 years ago; - an increase in the evaporative capacity of the climate (humidity, air temperature, solar radiation and wind) of +20 to +25%; - a downward trend in rainfall: cumulative rainfall from January to August has fallen by -50 to -60 (-10%); - increasingly frequent and severe droughts (2003, 2005, 2006, 2009, 2011, 2022) that are gradually becoming the norm. The arrival of this Mediterranean climate in our northern regions of France will have a huge impact on both natural vegetation and agriculture, and water resources and plant species' ability to adapt have not kept pace, hence the development of new varieties that are more resistant to water and heat stress.

Temperature trends are much more marked: four times faster in May, June, July and August than in the winter months, leading to a sharp increase in evapo-sweating, a major factor in agricultural production. As a result, aridity is becoming increasingly pronounced, leading to droughts that jeopardize harvests (cereals, forage) and cause fires which modifies the landscape. We are at the very beginning of the climate change caused by our massive greenhouse gas emissions (see the report by the IPCC (Inter-governmental Panel on Climate Change) [37] and the repercussions are not only global but also local.

7. Perspectives Given by Experts

The climate projection for Burgundy (Bourgogne) in the next 50 years, and its consequences for vine and food, with the role of climate disruption in the potential development of a Mediterranean diet represents an important field of study at the University of Burgundy (Bourgogne) in Dijon, France) (**Figure 4**).

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Figure 4. Map of Burgundy (Bourgogne) region in France located south at 500 km. of Mediterranean sea (free access illustration from the net).

The climatologists from Dijon (Burgundy) suggest the existence of a safe limit below 2°C of global warming for the European winemaking sector (including Burgundy), while adaptation might become far more challenging beyond this threshold [38]. There are several arguments supporting that climate change will not dramatically decrease viticultural suitability in main wine-producing areas in France by 2050 [39]. To cultivates 400 varieties of tomatoes using the methods of the old gardeners is an aspect of ongoing experimentation in the garden in the face of climate changes. Ongoing climate change (rising temperatures, winds, irregular and abundant rainfall) is having a profound impact on plants growth in the vegetable garden. The concept of climate change is obviously very anxiety-provoking, but when it comes to gardening, the rapid changes underway should lead us to operate differently, in a positive way. For, while they disrupt certain crops, they also allow others to flourish. Summer is becoming a very difficult season for many vegetables, but the three other seasons are opening up new possibilities unknown until now. It's now easier than ever to have fresh vegetables all the year. In agreement with these observations realized in Burgundy and in the east of France, several works report that gardening has solutions to face climate changes in the different world regions [39]. Efforts will result in the introduction of new crops, new gardening practices and new ways of eating and cooking, leading to the consumption of seasonal fruits and vegetables and the use of short distribution channels using local production for the reduction the carbon footprint (circular economy) [41,42]. In gardening and agriculture it is however known that the soil microbiome governs biogeochemical cycling of macronutrients, micronutrients and other elements vital for the growth of plants and animal life. A better understanding and a better control of soil microorganisms could help mitigate the negative consequences of climate change [43].

The rise of sustainable food and its media coverage in recent years has led to a paradigmatic shift from eating well to eating well, resulting in changes in public policies and social representations. This research is being carried out as part of the implementation of a territorial policy for Dijon (France), a medium-sized French metropolis, in order to highlight the political and communicational dimensions of sustainable food in response to contemporary climate issues. The leimotiv is "Less meat, more proteinaceous: political, climatic and communicational issues" [41]. This assumption is not shared who considers not credible to recommend consumers do not eat meat to decrease carbon footprint but to stop intensive farming and to develop extensive one. An evolution towards a Mediterranean-style diet and its beneficial effects carbon footprint on health and has been reported in several studies. The development of the Mediterranean diet will clearly favor a decrease of carbon footprint [44] whereas a great diversity will probably persist between the countries concerned. The most important carbon footprint is reported with cereals and bovine meat [44]. Acting at this level, with international and local actions, therefore seems essential. A reduced consumption of red meat, and of ultra-processed foods realized with red meat will not only decrease the carbon footprint but also the price of meals with consequently a beneficial economic impact for the consumer [45–48]. To

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obtain these protein-rich proteinaceous, conventional cultivation techniques, with a low environmental impact and supporting local agriculture, will be preferred to industrial agriculture, with a high carbon impact and sometimes questionable nutritional qualities. In those conditions, if lower prices are associated with food quality and lower carbon footprint, the consumer will easily move towards the Mediterranean diet and progressively change its diet habits.

8. Towards Adaptation of Populations Towards Agriculture, Food and Cooking Changes to the Mediterranean Diet Adoption

Climate change will undoubtedly lead to changes in crop production across the globe, with periods of rainfall and drought being severely disrupted [49]. In the short term, this may result in a reduction in the production of certain basic products that are essential for feeding people and the animals they consume, leading to an increase in the cost of basic products and more or less serious socio-economic problems. To remedy this situation, we need to develop innovative crop and livestock farming techniques. Limiting the impact of climate change on agricultural production is vital for the future of humanity [50,51].

Another aspect is the energy required to produce food raw materials and the processed products derived from them [52]. Highly recommended is to limit transport, produce locally and reduce fossil fuel consumption [53]. In the agri-food industry, the energy required for production lines will have to be reduced, and packaging optimized to adapt consumption to individual needs without encouraging over-consumption, which is a cause of many illnesses, particularly cardiovascular diseases, diabetes and metabolic syndrome [54].

Finally, at the consumer level, the later are looking for food that is quick, not expensive and easy to eat on a daily basis (such as street food), and that consumes little energy. A shift in culinary practices is taking place, supported by major industrial groups of food industry, which propose cooking appliances that can be used to produce classic, high-quality recipes with reduced energy consumption.

It is noteworthy that faced with climate change, the concept of planetary nutrition so called “Planeterranean diet ‘’ has emerged including an important part of Mediterranean diet [55] characterized by food diversity and high content of anti-oxidants [56].

8. Conclusion

Climate change which favors a progression of the Mediterranean climat in the highest latitudes of Europa has progressively important impact on agricultural practices, and eating behaviors. This narrative review shows that several actions are realized to minimize the social and economic impact of global warming which will also lead to several innovations in many domains. Whereas climate change affects all world area, including Burgundy (Bourgogne) area in France, which has lot of traditions in nutrition and cooking habits, the challenge of this French area shall be to continue to provide high quality food products such as cereal, meat, cheese and wine also suitable for Mediterranean diet cooking.

As eating behaviors differ between regions within the same country, and even more from one country to another, the measures implemented to guarantee food security will also have to take dietary diversity into account. There is therefore a considerable challenge for the agriculture and the food industry to deal with climate change in the agri-food sector, taking into account nutritional and cultural aspects whereas an effort from the consumer is also required to adapt his food habits.

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