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# Effects of climate change on functional health foods and medicinal plants – a short review

## Abstract

There is a growing opportunity to initiate studies to address the effects of climate change on medicinal plants' phenology, habitat alteration, species range shifts, and secondary metabolite production. Awareness of the potential effects of warming (increased $CO_2$, and ultraviolet radiation due to ozone layer depletion) on secondary plant components and metabolites is an influential task for the future. There is information that climate change causes remarkable effects on life cycles and the distribution of plant species. There are also forcing ecosystems to adopt the changing life cycle of plants and the development of new physical traits. A quickly changing climate might benefit species that can extend their ranges rapidly or that can tolerate a wide range of climatic conditions, both traits shared by various invasive plants taxon. This review provides a summary of the impact of climate change on medicinal and functional health food plants.

**Keywords:** climatic factors, global warming, plant yields, species ranges

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## Introduction

Climate change is one of the most widespread global environmental changes, which are threatening the biodiversity and functioning of terrestrial ecosystems (Bates et al., 2019; Yin et al., 2019). Three main components define it – global warming, changes in precipitation patterns, and increased occurrence of extreme weather events (Ruszkiewicz et al., 2019).

Climatic parameters including natural disasters are projected to alter and directly influence fishery, and livestock and plant production in multiple ways (Ayllon et al., 2019). Changes in global climate variables have already significantly affected the growth and productivity of plants. Crops are vulnerable to extreme events caused by climate change, especially drought, which is already has negative consequences for food production and food insecurity (Katsini et al., 2022). Heat stress, excessive $CO_2$ concentrations, and fluctuating precipitation patterns have changed the plant nutrient interactions

(Lemes et al., 2022). This has a negative impact on plant nutrition, which serves as a basic hurdle in the production of enough nutritious food to meet the demands of the growing global population (Shahzad, Rouached, 2022). In addition, these phenomenons can increase among others: occurrence and virulence of food-borne pathogens, increase in food-borne infections and poisoning, risk of food contamination with chemical factors.

Climate variability associated with climate change influences agricultural production and rural livelihoods throughout the world, and climate services address this issue by making new information products available to agricultural technicians, policymakers, and farmers in order to enhance their adaptive capability (Green et al., 2022; Raiten, Bremer, 2023). Ensuring food safety under a changing climate requires adaptation techniques (Duchenne-Moutien, Neetoo, 2021). Managing climate change effects is a global concern that needs local action, and the ability of governments and city authorities to start and implement interventions remains a potential pathway toward decreasing climate change effects (Cobbinah et al., 2019). The promotion of climate agriculture has an important propensity to improve the adaptive capacity of smallholder crop farmers.

This paper aims to consider the effects of climate change on functional foods, functional health foods and medicinal plants. The screening of articles process was done in three stages, namely screening of title, abstract, and full text. The information in this article was provided from randomised control experiments, review articles, and analytical studies and observations which were gathered from numerous literature sources such as Scopus, Google Scholar, PubMed, and Science Direct.

## Functional health foods and medicinal plants

Many diseases can be prevented by appropriate functional health foods and diet which can optimize health improvement capabilities (Yeung et al., 2018). The body systems influenced by nutritionally related disorders are nervous, reproductive, musculoskeletal, respiratory, gastrointestinal, cardiovascular and endocrine systems, skin, mental health and special senses (Choudhary, Tandon, 2009). A suitable diet culminates in a healthy, properly functioning gastrointestinal (GI) tract, leading to the attainment of healthy living, and proper human physiology (Cencis, Chingwaru, 2010). A healthy and balanced diet is therefore a very good complement to the prevention and treatment of various diseases.

According to the classification of health foods, two main classes are food with specific health functions and nutritional supplements. Food with health functions is categorised into three groups, such as modern health food, traditional health food, and functional health food (Supachaturat et al., 2017). A functional health food can be a natural product that may have significant biological components, or a food achieved via a technological intervention that may boost its level of biologically active ingredients (Butnariu, Sarac, 2019). The different definitions of functional food categories are presented in table 1.

**Tab. 1.** Global definition of functional food groups (according to Del Castillo et al., 2018)

| Global definition for functional food category | Popular functional food ingredients worldwide |
|---|---|
| 1. Natural food with increased composition by employing particular agronomic conditions. | 1. Probiotics, prebiotics and synbiotics. |
| 2. Food including health-promoting constituents. | 2. Dietary fiber. |
| 3. Food from which a component has been removed to produce less negative impacts on health. | 3. Omega 3 fatty acids, oleic acids and phytosterols. |
| 4. Food in which the nature of one or more of its components has been chemically increased for obtaining health benefits. | 4. Phytoestrogens. |
| 5. Food in which the bioavailability of one or more of its components has been boosted to improve the assimilation of the health promoting components. | 5. Phenolic compounds. |

Some of the substantial functional food constituents of plants as a kind of nutraceutical are carotenoids, flavonoids, and dietary fibers (Shandilya, Sharma, 2017). Common carbohydrates, chlorophyll, and proteins are categorised as primary components whereas phenolics, terpenoids, and alkaloids are grouped into secondary components (Sharma et al., 2021) – Fig. 1.

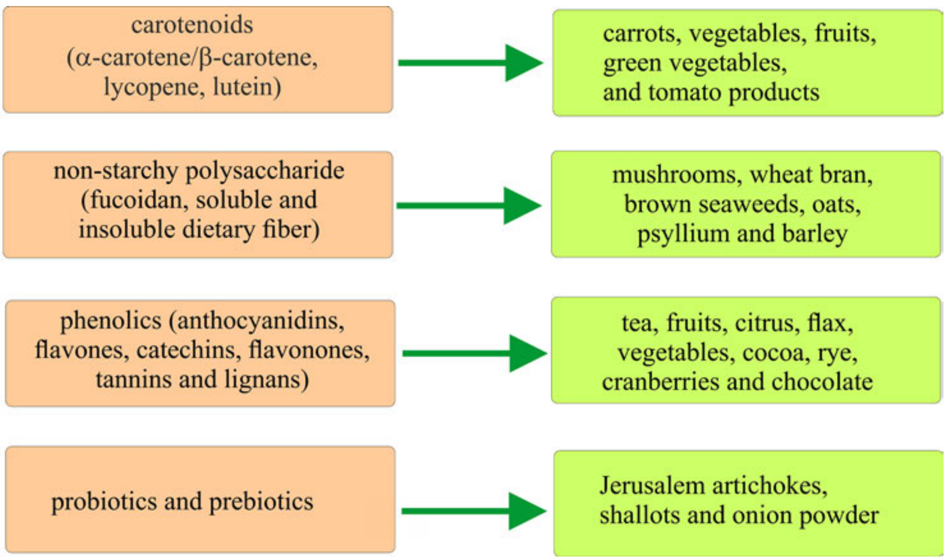


**Fig. 1.** The most significant sources of nutraceutical substances in functional foods (based on: Kotilainen et al., 2006; Ranga Rao, Ravishankar, 2018)

For example, Kotilainen et al. (2006) reported that different kinds of functional food were fortified products (like fruit juices fortified with vitamin C or margarine with plant sterol ester), probiotics and prebiotics, altered products (such as fibers as fat releasers in meat or ice cream products), and enhanced commodities (like eggs with increased omega-3 content obtained by altered chicken feed). On the other hand, Bayir et al. (2019) considered polyphenols as an essential functional food, due to their diverse chemical structure. The main classes of polyphenols are flavanoids, stilbenes, lignans, and phenolic acids.

It is often believed that healthy functional foods are a type of medicinal food (Das et al., 2016). This may be justified by the fact that some species of common vegetable plants have medicinal properties and their herbal raw materials are commonly used in herbal medicine. Good examples include onions, garlic, and various species of algae used as an addition to dishes. Of course, the amount of herbal raw material used and the method of its preparation plays a very important role in achieving a health-promoting effect. If we have isolated specific medicinal substances in high concentrations, it is difficult to talk about functional food in this case, but rather we are already dealing with a medicine. The method of application of this type of substance is also completely different. Medicines and functional or medicinal foods are taken differently prepared and eaten in various ways. For example, algal powders and extracts are used in the nutraceutical, food, and pharmaceutical industries as tablets, crystals, capsules, gels, and dietary supplements (Ranga Rao, Ravishankar, 2018) – Tab. 2.

**Tab. 2.** Utilisation of algae for food and health applications (according to Ranga Rao, Ravishankar, 2018)

| Algal species | Applications |
|---|---|
| *Spirulina platensis* (= *Arthrospira platensis* Gomont) | Phycocyanin, phycoerythrin, and biomass for health food, fee, pharmaceuticals, and cosmetics. |
| *Chlorella vulgaris* Beijerinck; *Chlorella* spp. | Polysaccharides for dietary supplements, extracts for cosmetics; Biomass for health food and feed. |
| *Dunaliella salina* (Dunal) Teodoresco | β-carotene for health food, feed, dietary supplements, and cosmetics. |
| *Haematococcus pluvialis* Flotow | Astaxanthin for health food, pharmaceuticals and feed additives. |
| *Chlamydomonas reinhardtii* P.A.Dangeard | Biomass for animal health and feed; environmental monitoring bioremediation, production of recombinant proteins. |
| *Isochrysis galbana* Parke | Fatty acids for animal nutrition |
| *Nannochloropsis oculata* (Droop) D.J.Hibberd | Lipids and fatty acids for animal nutrition; extracts for cosmetics |
| *Porphyra* spp. | Biomass for feed, food; extracts for cosmetics |
| *Porphyridium* spp. | Polysaccharides for nutrition, pharmaceuticals, and cosmetics, phycoerythrin and phycocyanin for pharmaceuticals, food, and cosmetics. |
| *Phaeodactylum tricornutum* Bohlin | Lipids and fatty acids for nutrition |

On the other hand, leafy thallus of species of the genus *Porphyra* is used for direct consumption in unprocessed form. Often, therapeutic treatment based on chemical drugs is supplemented with an appropriate functional or therapeutic diet, selected depending on the type of disease. Comparing functional foods with drugs and medicinal foods is shown in table 3.

**Tab. 3.** Comparing functional foods with medical foods and drugs (according to Das et al., 2016)

| Difference | Functional foods | Medical foods | Prescription drugs |
|---|---|---|---|
| Uses | Energy enhancement, bolster gut, disease risk reduction, weight management, bone or heart health, memory improvement. | Dietary management of a disease or condition with distinctive nutritional requirements. | Treatment of disease, symptom or condition |
| Method of obtainment | No prescription or supervision is needed, consumer selects | Used with medical supervision | Prescribed by health provider |
| Distribution channels | Supermarkets, drugstores, online, major retailers | Hospitals, drugstores, pharmacies, online | Hospitals, Pharmacies |
| Amount consumed | As desired | As needed | As prescribed |

However, it is worth being aware that combining medications, supplements, and a health-promoting diet should always be consulted with specialists in conventional medicine.

## Climate change and functional foods

### Symptoms and effects

The influences of climate on ecosystems are complex, complicated, and difficult to predict, and ecosystem responses to climate and other contemporary changes will reverberate through the whole biomes (Phillips, 2019). Climate-changing parameters such as the availability of ozone, heat stress, and high levels of atmospheric carbon dioxide perturb redox balance and have a significant impact on the photosynthetic metabolism of plants and environmental stress reactions (Kumar et al., 2021). Rhizosphere microbiome can stimulate root nutrient absorption, arranging crop immune response, and increasing stress resistance. However, climate changes have a very significant impact on these all parameters (Li et al., 2021).

There are several pathways through which climate-related characteristics may influence food safety (Tab. 4).

**Tab. 4.** Main effects of climate change on the reduction of agricultural food production, both plant and animal origin (according to Semba et al., 2022)

| | |
|---|---|
| Climate changes | 1) Extreme weather like drought, storms, heat waves;<br>2) Ocean hypoxia; variations in sea level (flooding);<br>3) Changes in temperature;<br>4) Increase atmospheric carbon dioxide;<br>5) Loss of coastal land, reefs, mangroves;<br>6) Increase land degradation;<br>7) Increase ground level ozone;<br>8) Increase level of biotic stressors, decrease numbers of pollinators, and increase pathogens, and others. |

These include, for example: increased repetition and intensity of extreme weather events, variations in temperature and precipitation patterns, acidification and ocean warming, and changes in the transport pathways of complicated contaminants, as already mentioned in the introduction (Ponce, 2020; Sun et al., 2023). Zhang and Liu (2022) discovered that climate changes prolonged the length of vegetative growth period, and they altered plant phenology. For example, alpine plants advances in the timing of first flowering alone will not necessarily translate to increases in flowering duration and enhanced reproductive effort. Instead, the findings demonstrate the importance of the date of last flowering in plant reproductive effort (Dorji et al., 2020). On the other hand, Wang et al. (2023) reported that the growth indicators of both C3 and C4 crops were more strongly associated with temperature and solar radiation, and variations in temperature and solar radiation had adverse effects on both C3 and C4 crops in different regions (Raes et al., 2021).

While warming can potentially reduce the crop growth period, water productivity and crop production are expected to decline because of higher water requirement and lower precipitation under higher temperature (Gohari et al., 2013). A marked increase in temperature since the middle of the last century most probably influenced the dynamics of P in the soil, having a significant impact on yields production (Seidel et al., 2021). According to many explorers, the leading cause of crop yield reductions is related to the soil water stress resulting from increased temperature and evapotranspiration during the growing season (Guo et al., 2021; Kang et al., 2022). The results of investigations show a frequent increase in the duration od dry season (an earlier onset of drought) and higher dependence on shallow precipitation water (Rolo, Moreno, 2019; Sun et al., 2024).

Important consequences of climate change are also worth mentioning seasonal distribution of rainfall erosivity, resulting from heavy rainfall (Auerswald, Menzel, 2021). These factors can e.g influenced cover crop performance and soil nitrogen leaching events concomitantly (Teixeira et al., 2021). It is changing also the distributions and effects of plant diseases and pests. Climate warming favors the emergence of fungal pathogens, which can pose a significant threat to agricultural crops. Such phenomena concern also crop pests, the ranges of which are subject to change as a result of warming. Both of these factors have a very significant impact on the yield of functional food crops (Dorji et al., 2020; Raza, Bebber, 2022).

In addition to all the important effects described above that affect the quantity of plant functional foods produced, it is also necessary to mention those factors resulting from climate change that affect the quality of the food produced. Several authors have noted that that in the case of climate changes, microorganisms in the food supply chain have numerous negative effects (e.g. Alvi et al., 2021; Weber et al., 2023; Zhang et al., 2023). An increase in average temperatures could induce an increased risk of the proliferation of microrganisms, like *Campylobacte*r sp. and *Salmonella* sp., that produce food-borne illnesses (Miron et al., 2023). They are most often the cause of food poisoning, which in extreme cases can lead to death.

## Remediation programs

Considering crop growth, and crop disease models to predict the effects of climate change we can promote climate change adaptation techniques to ensure future food security (Newbery et al., 2016) – Fig. 2.

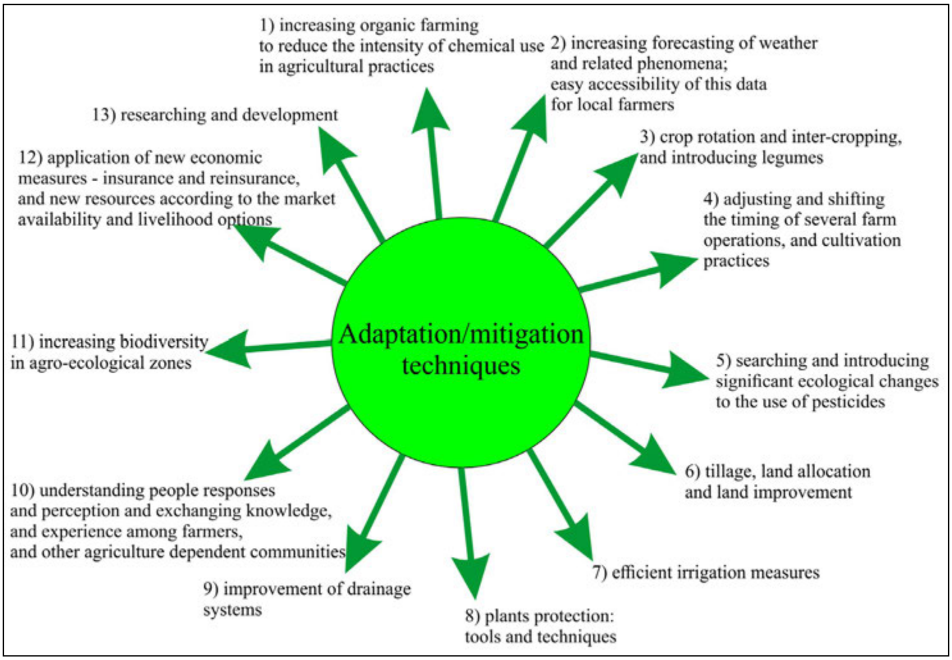


**Fig. 2.** Integration of various adaptation/mitigation techniques and their potential positive effects to cope up with future and current climate change effects to selected food sources (based on: Tripathi et al., 2016; Sulser et al., 2021)

Research on climate change mitigation techniques in the literature includes, among others: changes sowing dates, diversifying varieties to use less water and crops that are more heat-resistant (Kaushika et al., 2019). It is important to promote multiple cropping activities that include innovative water-saving methods and breeding approaches (Gao et al., 2019). According to the extent analysis of the correlation between grain yield and climate change, the relationship between the use of irrigation water and irrigation purposes, and human parameters such as agricultural technology innovation, policy mechanism increase and guarantee in farmland the financing of water conservancy construction can allevaite all types of negative effects of climate warming (Lu et al., 2019).

Many researchers even claim that warming caused by climate change may lead to: positive impact on plant production e.g. in China if concomitant alterations adopted in various cropping systems take place and positive effects of other socio-economic parameters co-occur (Wei et al., 2014; Yang et al., 2015). Drawing attention among farmers to the topic of the optimal application of agronomic inputs in changing climatic conditions could be an effective adaptation methodology that increases yields and can reduce yield instability (Mahmood et al., 2019). Massawe et al. (2015) concluded that the main adaptation technique to minimize the effect of climate change on crop production had to be through research and advancement of underutilised crops with proven potential to confront the negative effects of climate change. In such a case, the crop profile should be changed to one in which yields from other species will be satisfactory. For example, Liang et al. (2018) showed that climate change in northern China significantly affected wheat yield (+8.5% on average) but not maize yield and climate change reduced the annual nitrogen use efficiency (NUE) of maize and wheat by 15% on average.

Adaptation of crops to climate change positively and significantly influences net crop income and productivity, so indirectly promoting the local food security for farmers, their well-being, and more advantages for people, who utilise a combination of various adaptation techniques (Abid et al., 2016). Generally, improving sustainability results need multi-scale, multi-disciplinary, multi-taxon methods to quantify the capability of ecosystems to deal with existing and future climatic factors (Alonso-Ayuso et al., 2018; Toreti et al., 2019).

## Climate change and medicinal plants

Climate changes are an important parameter affecting the distribution, growth, and reproduction of different medicinal plants (Zhang et al., 2019). Based on the predicted consequences of climate changes for many medicinal plants, their proper range will limit or move essentially (Xia et al., 2022). Rawat et al. (2022) reported that climate change might alter environmental conditions in different localities and predicted the appropriate range for medicinal plants will narrow or move substantially from their original habitat. For example, *Saposhnikovia divaricata* (Turcz.) Schischk. is a notable economic medicinal plant in eastern Asia. It grows in grassy and stony slopes at 400–800 m (1,300–2,600 ft), and the margins of rice paddies, roadsides, and waste places. The range of occurrence of *S. divaricata* will increase under the influence of climate change, as the area of suitable habitats for its growth and development will increase (Chen et al., 2022). On the other hand, it was indicated that human modifications had significantly decreased the suitable distribution area of *Artemisia annua* Pall., in the current climate scenario (Wang et al., 2022).

Changes in the ranges of medicinal species concern both horizontal and vertical ranges. Climate change may not only lead to elevational shifts of mountain species but also a contraction of their elevational ranges, which may boost the risk of local extinctions of endemic species (Zu et al., 2021). *Gentiana rigescens* Franch. is an economically important medicinal plant in the subtropical zone in Asia. It grows on grassland slopes, in valleys, in scrub, and in forests from 1100 to 3000 m above sea level. It has responded negatively to climate change. Shen et al. (2021) concluded that the areas of the current highly suitable habitat of *G. rigescens* would be negatively influenced by climate change. It is assumed that medicinal plants of high value, such as *G. rigescens*, will face a great risk of total extinction as commercialization demands over-exploitation along with climate change (Applequist et al., 2020).

Extreme environmental conditions can lead to changes in the phytochemical characteristics (primary and secondary metabolites) of medicinal plants (Rawat et al., 2022). Climate change can influence the chemical composition of herbs and may induce quality changes in medicinal material (Applequist et al., 2020). Several studies indicated that in herbal medicines the synthesis and accumulation of efficient constituents had a connection with the particular climatic environment of their habitat (Mudge et al., 2016). For example, the appropriate occurence area of *Ziziphus jujuba* Mill. var. *spinosa* (Bunge) Hu ex H.F. Chou under the future climate scenario will be limited, as jujuboside A (triterpene saponin) and spinosin (flavone) – its active substances, are correlated with environmental parameters (Wu et al., 2022).

Climate change may boost local plant species richness, and climatic perturbation is recognised as a procedure driving biodiversity accrual. Feng et al. (2022) reported that endemic medicinal plant species richness was significantly connected with population size. Small populations are, according to them, the most threatened with extinction. Future climate change and human activity will therefore have a significant impact on the protection of endemic and endangered medicinal plants (Tab. 5).

**Tab. 5.** List of target species for highest conservation due to predicted climate changes effects (according to Cahyaningsih et al., 2021)

| No | Fammily | Species name |
|---|---|---|
| 1) | Araucariaceae | *Agathis borneensis* Warb. |
| 2) | Apocynaceae | *Alstonia iwahigensis* Elmer |
| 3) | Annonaceae | *Anaxagorea javanica* Blume |
| 4) | Dipterocarpaceae | *Anisoptera costata* Pierre |
| 5) | Thymelaeaceae | *Aquilaria malaccensis* Beneth. |
| 6) | Acanthaceae | *Barleria prionitis* L. |
| 7) | Fagaceae | *Castanopsis argentea* A.DC. |
| 8) | Diksoniaceae | *Dicksonia blumei* (Kunze) T.Moore |
| 9) | Dipterocarpaceae | *Dipterocarpus baudii* Korth. |
| 10) | Fabaceae | *Euchresta horsfieldii* (Lesch.) Benn. |
| 11) | Simaroubaceae | *Eurycoma longifolia* Jack |
| 12) | Lauraceae | *Eusideroxylon zwageri* Teijsm. & Binn. |
| 13) | Gentianaceae | *Gentiana quadrifaria* Blume |
| 14) | Euphorbiaceae | *Macaranga griffithiana* Müll.Arg. |
| 15) | Nepenthaceae | *Nepenthes reinwardtiana* Miq. |
| 16) | Pinaceae | *Pinus merkusii* Jungh. & de Vriese |
| 17) | Apocynaceae | *Rauvolfia serpentina* Benth. ex Kurz |
| 18) | Santalaceae | *Santalum album* L. |
| 19) | Lamiaceae | Scutellaria javanica Jungh. |
| 20) | Dipterocarpaceae | Shorea seminis (de Vriese) Slooten |

Besides, these changes could lead to modifications in plant community composition and the relative abundance of different species in the natural habitats (Getachew et al., 2021). Species with narrow ecological tolerance will be easily eliminated, and those with low habitat requirements, often with invasive features, will spread.

Probably in the future, climate changes will cause unpredictability for the reasonable introduction of medicinal plants in cultivation. It is a threat to the sustainable usage of medicinal plants. This may result in the need for greater exploitation of medicinal species from their natural habitats (Rana et al., 2020).

## Conclusions

The food system including agriculture is one of the main drivers of climate change, and climate change concurrently has significant effects on human health through the food system. An increase in temperature may lead to an increase in the chance of people being exposed to foodborne hazards, and multiple pathways are revealed to mediate climate change and increase negative health impacts through food safety. Studies on the possible impacts of climate change on healthy functional food and medicinal plants are particularly significant because of their value within traditional systems of medicine and as economically useful plants.

[1] In general, when plants are subjected to environmental stress, the production of secondary metabolites may increase because somatic growth is often inhibited more than photosynthesis, and growth-related carbon is instead transferred to secondary metabolites. Different plant species are supposed to react individually to climate change. Some species may remain in the region but adapt to new climatic conditions via selection, other species may shift to higher altitudes or latitudes, and some species of medicinal plants may become extinct.

[2] During the growing season, important phenological events for medicinal and healthy functional plants are adapted to the given climate. These include flowering and fruit setting, bud bursting and leaf development, and leaf fall in autumn or during the dry season. However, global warming processes have and will have an impact in the future on the timing of spring and the length of the growing season. This determines the course of plant phenological processes, affecting their productivity.

[3] The impact of climate change on overall global food production is likely to be devastating, especially in the later period per century, but these effects vary mainly by region. The most negative impacts are possibly to occur in the subtropical and tropical zones. These negative effects can be mitigated by implementing adaptation programs based on solid scientific principles and taking into account local biophysical and socio-economic conditions. In addition, further research and monitoring is necessary to assess the impact of climate change on the yields and chemical components of medicinal plants and health-promoting functional foods.

**Conflict of interest**

The author declare no conflict of interest related to this article.

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## Wpływ zmian klimatycznych na zdrową żywność funkcjonalną oraz rośliny lecznicze


### Streszczenie

Istnieje coraz większa potrzeba badań mających na celu określenie wpływu zmian klimatycznych na fenologię roślin leczniczych i prozdrowotnych, przemian ich siedlisk, zmian zasięgu oraz produkcję metabolitów wtórnych. Promowanie świadomości na temat potencjalnych skutków ocieplenia (m.in. podwyższonego stężenia $CO_2$ i zwiększonego promieniowania ultrafioletowego), wpływających na składniki wtórne roślin i metabolity, jest ważnym zadaniem na przyszłość. Istnieją dowody, że zmiany klimatyczne powodują następstwa objawiające się zmianami cykli życia i rozmieszczenia roślin, zarówno tych stanowiących żywność funkcjonalną, jak i dzikorosnących taksonów leczniczych. Zmuszają one rośliny do aklimatyzacji i zmian w fenologii oraz do rozwoju nowych cech fizycznych. Szybko zmieniający się klimat może być korzystny dla gatunków, które mogą szybko rozszerzyć swoje zasięgi lub które mogą tolerować szeroki zakres warunków klimatycznych, a obie te cechy są wspólne dla różnych gatunków roślin inwazyjnych. Niniejszy przegląd zawiera podsumowanie wpływu zmian klimatycznych na rośliny lecznicze, prozdrowotne i stanowiące żywność funkcjonalną.


**Słowa kluczowe:** czynniki klimatyczne, globalne ocieplenie, plony roślin, zasięgi gatunków

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