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PLANTS FOR THE FUTURE

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Summary: Plants have a unique role for the existence of all heterotrophic organisms including human population. For sustainable development it is indispensable to stop the loss of biodiversity connected with climate changes and anthropogenic activities. In this context changes of plant species strategy and risk of invasive plant and weed expansion are discussed. Utilization of plants as cover crops and green manure as well as use of allelopathy in the integrated plant protection is described. Perspectives of the use of phytoremediation (phytotechnology using plants for the removing of toxic metals and organic pollutants from contaminated environment) as well as agronomic and genetic biofortification (enrichment of crops with essential nutrients) are designed. Attention is also devoted to the traditional and non-traditional utilization of medicinal plants, plant-made pharmaceuticals, antioxidant activity of plants as well as to the interactions of herbal medicines with synthetic drugs. Cost and benefit of gene technology from the aspect of increased pest and herbicide resistance of genetically modified (GM) plants, co-existence of GM plants with non modified ones in the field conditions, potential effects of GM plants on soil microbial communities and non target organisms are analysed in detail also with respect to food sufficiency and food safety. Perspectives of plants as a raw material for production of biofuels are outlined, too. Requirement for acceptance of fundamental principles of bioethic aspects at exploitation of plant biotechnology, particularly in connection with the effects of GM plants on human health or with their potential environmental consequences are discussed.

Keywords: loss of biodiversity, climate changes, phytotechnologies, plant-made pharmaceuticals, genetically modified plants, food safety, biofuels

Introduction

World vegetation is an important component of our planet. Plants have a unique role for the existence of all heterotrophic organisms including human population. Therefore, it is indispensable to known the biology of the plants, to preserve plant biodiversity and to improve plant features for human prosperity. In this context European Union drafts out the outlines of the strategic agenda for the plant research. These are addressing to

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major socio-economic challenges: (a) to fulfil consumer demand for safe, sustainable and healthy food: novel plants aim at delivering non-allergic foods and foods with longer shelf- lives, better nutritional composition and more varied tastes; (b) to increase agricultural productivity while decreasing its environmental footprint: novel plants may need less input in terms of water, fertilizer or pesticides and will be more stress resistant, for instance against drought or seasonal instabilities caused by climate change; (c) to exploit the potential of biomass for the production of industrial materials. The above-mention conception was presented by Janez Potočnik (EU Commissioner responsible for Science and Research) in his press launch concerning the strategic research agenda for the "Plants for the Future" in Strasbourg on 5 July 2005. In this review the comprehensive appreciation of both actual and perspective usage of plants in the changing environmental conditions by continually developing human society is presented.

Sustainable development versus loss of biodiversity

At present, plant life strategy is appreciated in the sense of sustainable development, which could be defined as "development, which meets the needs of the present without compromising the ability of future generations to meet their own needs". In this concept as the most important topic appeared to avoid the loss of biodiversity [1]. Decline of biodiversity is not limited to increased rates of species extinction, but includes losses in genetic and functional diversity across population, community, ecosystem, landscape, and global scales. The term "biodiversity" refers collectively to all these aspects of biotic diversity.

Species diversity is unevenly distributed; the highest concentrations are in tropical ecosystems [2]. Tropical forests are global epicentres of biodiversity and important modulators of the rate of climate change. Recent research of deforestation rates and ecological changes within intact forests is focused on the implications for biodiversity (species loss) and climate change (*via* the global carbon cycle) [3]. Recent impacts have most likely been: (a) a large source of carbon to the atmosphere and major loss of species due to deforestation; (b) a large carbon sink within remaining intact forest, accompanied by accelerating forest dynamism and widespread biodiversity changes.

Our most obvious use of plants is for food. There are more than 20,000 known species of edible plants in the world and yet, over the centuries, we have become increasingly dependant upon fewer and fewer species to provide our food. Indeed, fewer than 20 species of plants now supply about 90 % of our plant foods. A changing world climate would also cause major disruptions in agriculture with many important food-growing regions. Clearly, a greater diversification is urgently required. Several considerations suggest that changing diversity in multi-level food webs can have important ecosystem effects that can be qualitatively different than those mediated by plants. Therefore, it is important to evaluate the trophic cascades specifically and understand the distribution of interaction strengths within natural communities as well as their change with community composition [4].

At the Johannesburg World Summit on Sustainable Development (in the year 2002), 190 countries endorsed a commitment to achieve, by 2010, a significant reduction of the current rate of biodiversity loss at the global, regional and national levels [5]. Governments have set the ambitious target of reducing biodiversity loss by the year 2010 [6]. Thuiller *et al.* [7] projected for late 21st century distributions for 1,350 European plants species under seven climate change scenarios and found that many European plant species could become severely threatened. More than half of the species they studied could be vulnerable or threatened about the year 2080. The greatest changes are expected in the transition between the Mediterranean and Euro-Siberian regions. These authors found that risks of extinction for European plants may be large, even in moderate scenarios of climate change and despite inter-model variability.

In general, the botanists of the most of EU countries classified plants of their territories into the special groups – endangered, threatened and endemic species, respectively. This material was summarized and published in so-called „Red Books“, *eg* „Red book 5 of endangered and rare species of plants and animals in Slovak Republic and Czech Republic. Vascular plants“ [8] or „Polish Red Data Book of Plants“ [9], List of threatened plants in Poland [10]. Special attention is also devoted to the flora and vegetation of individual regions, for example for Opole Province [11–13].

Nátr (2005) [14] published a very interesting but dilemmatic monograph entitled "Non-sustainable Development". In this book, the author stated that the term "sustainable development" became an absolutely spiritless expression of politicians and economists as well `as a not well-founded general hope for easy going perspectives promising trouble-free existence of human societies on our planet. On the other hand, the author emphasized that changes of human priorities and reconstructions of economic laws could result in dignified and harmonic life in consonance with the nature.

Risk of climate changes

Plants *vs.* climate changes

Global climate change caused mainly by increased emissions of greenhouse gases is likely to affect agroecosystems in many ways. However, the outcome, for instance, as a shift in productivity, depends on the combined effects of climate (temperature, precipitation) and other global change components [15]. Global climate changes, well known by their famous manifestation mentioned as the "greenhouse effects", represent still the main environmental problem of the biosphere which has already been stated by majority of states in the world in Kyoto protocol in 1997 [16].

With the rapid increase in human population, industrial development, fossil fuel dependence and changing land-use practices, doubling of atmospheric CO_2 concentration (currently over 370 ppm) is expected in raising extent within this century [17]. Doubling of CO_2 will lead to the increase of global temperature by 1.5 to 4.5 ^{o}C and consequently to the increase of global precipitation by 2 ± 0.5 % per 1 ^{o}C *via* the increased rates of evapotranspiration (taking into account also relationship between CO_2

concentration and stomata opening). Considering elevated CO_2 concentration both short-term and long-term effects on the plants have to be distinguished. Short-term effect (period of days to weeks) of elevated CO_2 concentration in C_3 plants is mediated by the increase in CO_2 concentration diffusion gradient (and thus increase of photosynthetic rate), reduction of the oxygenase component of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) (*ie* suppressed photorespiration), and insufficiency to saturate Rubisco activity by the current atmospheric CO_2 concentration [18, 19]. Indirect effect such as increase of water use efficiency can also increase photosynthetic rate [20]. After a long-term exposure to elevated CO_2 concentration (period of months to years) a reduction of the CO_2 concentration assimilation capacity is manifested as a result of assimilatory acclimation-photosynthetic adjustment to elevated CO_2 concentration [19]. Photosynthetic adjustment was discovered as a very specific response of carbon assimilation on the long term influence of elevated CO_2 concentration and is defined as any adjustment that may develop over time in plants grown continuously in elevated CO_2 concentration [21].

In general, in C_3 plants current atmospheric CO_2 concentration, O_2 and Rubisco specificity factors translate into photorespiratory losses by 20–60 %. Existing research data showed that a doubling of the atmospheric CO_2 concentration would increase CO_2 concentration exchange rates of C_3 crops up to 63 %, and their growth and yield up to 58 % [22]. However, long-term exposure of C_3 plants to elevated CO_2 concentration leads to a variety of acclimation effects, including changes in leaf photosynthetic physiology and biochemistry and alterations in plant growth and development [23]. Under long-term CO_2 concentration growth, many C_3 species show decreased leaf photosynthesis, and carbohydrate source-sink imbalance is believed to have a major role in the regulation of photosynthesis through feedback inhibition [24]. At present, this phenomenon is well known as acclimation depression of photosynthesis.

As we have already mentioned, the short-term exposure to elevated CO_2 concentration may have many positive effects on C_3 crops, *eg* (a) yield stimulation; (b) improved resource-use efficiency; (c) more successful competition with C_4 weeds; (d) reduced ozone toxicity; (e) in some cases better pest and disease resistance. However, many of these beneficial effects may be lost – at least to some extent – in a warmer climate. Warming accelerates plant development and reduces grain-fill and nutrient-use efficiency, increases crop water consumption, and favours C_4 plants (including weeds) over C_3 crops. It seems reasonable to assume that agroecosystem responses will be dominated by those caused directly or indirectly by shifts in climate, associated with altered weather patterns, and not by elevated CO_2 concentration, *per se*. Overall, intensive agriculture may have the potential to adapt to changing conditions, in contrast to extensive agricultural systems or low-input systems which may be affected more seriously [15].

Changes of plant species strategy

Climate change may affect food systems in several ways ranging from direct effects on crop production (*eg* changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), to changes in markets, food prices and supply chain infrastructure. The relative importance of climate change for food security differs between regions [25]. Global climatological changes (mainly "greenhouse effect") also induced water deficiency in the environment and thus "**blue revolution**" has been recently started with the slogan "**more crop for every drop"** after well-known "**green revolution**" which appeared in the beginning of 60′s years of the last century.

From the aspect of carbon metabolism the plants were divided into three groups: C_3, C_4 and CAM plants (in detail see in Handbook of photosynthesis 2005 [26]). The majority of cultural plants (crops) and wild species belong to the C_3 plants.

Plants with C_4 photosynthesis include some of the world's most important crops (maize, sugar cane) and noxious weeds (crabgrass, nut sedge, pigweed). Although C_4 plants only represent a small proportion of the world's plant species (5 %), they contribute to app. 18–21 % of global productivity because of the high productivity of C_4 grasslands. Based solely on the biochemistry of photosynthesis, it has been suggested that C_4 plants will not respond the ongoing increase in atmospheric CO_2 concentration. However, a number of recent studies have shown that the response of C_4 plants may have been underestimated. Due to the importance of C_4 grasslands in global carbon sequestration, recognition and understanding of the direct impact of rising atmospheric CO_2 concentration remains a crucial area of interest. The response of C_4 plants to the ongoing increase in atmospheric CO_2 concentration can directly and indirectly stimulate the growth of C_4 species.

The majority of weeds (as a negative component in agricultural management) belong to the C_4 plants, which respond directly to the increasing CO_2 concentration. It will stimulate photosynthesis and growth in C_3 weeds and reduce stomata aperture and increase water use efficiency in both C_3 and C_4 weeds [27]. C_4 plants are directly affected by all major global change parameters, often in a manner that is distinct from that of C_3 plants. Rising CO_2 concentration generally stimulates C_3 photosynthesis more than C_4, but C_4 species still exhibit positive responses, particularly at elevated temperature and arid conditions where they are currently common. C_4 photosynthesis is favoured by high temperature, but global warming will not necessarily favour C_4 over C_3 plants because the timing of warming could be more critical than the warming itself. C_3 species will likely be favoured where harsh winter climates are moderated, particularly where hot summers also become drier and less favourable to C_4 plant growth. Eutrophication of soils by nitrogen deposition generally favours C_3 species by offsetting the superior nitrogen use efficiency of C_4 species; this should allow C_3 species to expand at the expense of C_4 plants. It could be summarized that in the future, certain C_4 plants will prosper at the expense of C_3 species, and should be able to adjust to the changes the future brings [28].

Complex analysis of the climate changes in the relation to the photosynthetic productivity and nutrition of mankind as well as relationships between CO_2 concentration and plants was published by Nátr – nestor of Czech crop physiology, in three monographs (2000, 2002, 2006) [29–31]. The author presented critical review on direct and indirect effects of CO_2 concentration on plants and environment as well as on methodical approach for measurement of CO_2 exchange [29, 31]. Professor Nátr, as well known optimist, in his third book [30] presented sceptical vision on photosynthetic productivity and people nutrition: "*There are too many things to be changed in order to concentrate tools and knowledge of mankind on economical, political, social and moral conditions of human progress to its own advantage*". This statement should be warning not only for the scientists but also for the sociologists, economists and politician because insuring of sufficient amount of the food depends on the political and economical decisions.

Which plants will be green invaders?

Overall, recent data strongly suggest that rising carbon dioxide may directly influence the global primary productivity of C_4 grasslands with a subsequent increase in terrestrial carbon sequestration. It is important to stress that the above-mentioned changes of plant species strategy is closely connected with the changes of plant biodiversity and expansion of invasive plants (introduced plants, invasive alien species, green invaders). Recently appeared some negative experiences with the weeds (*eg Amaranthus palmeri*) [32, 33] or invasive species such as *Heracleum mantegazzianum* [34], *Impatiens parviflora* [35], *Datura stramonium* [36, 37] or *Robinia pseudacacia* [38] which intensively occupied large regions and caused many difficulties within biodiversity, soil erosion and human health. Newly Polish Ministry of Science financially supported a project „Plant and fungi invasions in Poland" the final result of which will be summarized in the publication entitled "Book of invasive species in Poland". In this book will be described approx. 170 species of plants and fungi established in the flora of Poland with the proposal of the comprehensive solutions to prevent invasions (law regulations, monitoring and others) [39].

Biological invasions are gaining attention as a major threat to biodiversity and an important element of global change. Increases in the prevalence of some of these biological invaders would alter basic ecosystem properties in ways that feed back to affect many components of global change [40]. The changes in atmospheric concentrations of CO_2 and subsequent climate change may facilitate biological invasions, both directly and indirectly [41]. The relevance of „green invaders" was also appreciated by EU strategy, which established Institute for European Environmental Policy. This institute coordinated many programmes including „Scope options for EU Action on invasive alien species (IAS) ENV. B. 2/SER/2005/0078r [42].

Use of plants as green manure and cover crops

A green manure is a crop used primarily as a soil amendment and a nutrient source for subsequent crops. Green manure approaches to crop production may improve economic viability, while reducing the environmental impacts of agriculture [43]. Typically, a green manure crop is grown for a specific period, and then plowed under and incorporated into the soil. Green manures usually perform multiple functions, that include soil improvement and soil protection: green manures increase the percentage of organic matter in the soil, thereby improving water retention (inhibition of soil erosion), aeration, and other physical soil characteristics. In agriculture, a green manure is a type of cover crops and therefore, it is suitable for suppression of the weeds. As green manure crops are usually used plant species such as oats, rye, mustard, clover, lupine, winter field beans, *etc.* [44]. The integration of cover crops into cropping systems brings costs (increased direct costs, potentially reduced income if cover crops interfere with other attractive crops, slow soil warming, difficulties in predicting N mineralization, and production expenses) and benefits (promoting pest-suppression, soil and water quality, nutrient cycling efficiency, and cash crop productivity) to the farm. For example, *Brassica* species produce glucosinolate-containing residues and suppress plant-parasitic nematodes and soil-borne diseases; cereal cover crops produce the largest amount of biomass and should be considered when the goal is to rapidly build soil organic matter [45]. As agroecosystems often interact with neighbouring natural ecosystems in agricultural landscapes, cover crops that improve the sustainability of agroecosystem attributes may also indirectly improve qualities of neighbouring natural ecosystems.

Recently it was found that waste biomass of medicinal plants (as a rest from pharmaceutical industry) could be used as a very effective green manure because of this material contains compounds specifically effective against weeds as well as different pests [46].

Allelopathy as a constituent of an integrated plant protection

Secondary metabolites are a measure of the fitness of the organisms to survive. The ability to synthesize an array of secondary products, which may repel other organisms, has evolved as a facet of the organism´s strategy for survival [47]. Allelopathy can be defined as an important mechanism of plant interference mediated by the addition of plant-produced secondary products to the soil rhizosphere or to the atmosphere. Allelochemicals are present in all types of plants and tissues and are released into the soil rhizosphere or atmosphere by a variety of mechanisms, including decomposition of residues, volatilization and root exudation. Allelochemical structures and modes of action are diverse, and may offer potential for development of future herbicides [48, 49]. The majority of allelochemicals are secondary metabolites and among others belong to terpenoids, phenolic compounds, organic cyanides and long chain fatty acids. The action of allelochemicals in target plant is diverse and affects a large number of biochemical reactions resulting in modifications of different physiological functions. Thus the results of allelochemical action can be detected at different levels of plant organization: molecular, structural, biochemical, physiological and ecological [50].

Allelopathy is related to the problems of chemical interference between crops and weeds as well as crops and crops. Allelopathy together with chemical ecology plays an important role in crop productivity, conservation of genetic diversity, and maintenance of ecosystems stability. It is strongly linked with other environmental stresses (*eg* extreme temperature and radiation, nutrient deficit, insects, diseases and herbicides). Such stress conditions often enhance allelochemical production and increase the potential for allelopathic interference. Allelopathy offers potential for weed control through the production and release of allelochemicals from plants. Allelochemicals may impact the availability of nutrients through effects on the symbiotic microbes [51].

Utilizing allelopathic plants to suppress the weed infestation is the most cost-effective and environment-friendly method of weed control. Activity of allelochemical compounds varies with several external factors (temperature, photoperiod, water and soils) as well as with their initial concentration, compound structure and operation processes [52]. To the plants producing allelochemicals belong *eg* garlic (*Allium sativum*), onion (*Allium cepa*) and some of medicinal (*eg Calendula*) and aromatic (*eg Vegeta*) plants. Recently was found [53] that wheat (*Triticum aestivum* L.) has allelopathic potential if used as a cover crop for weed control in various cropping systems. Many allelochemicals have been identified in wheat, mainly belonging to the categories of phenolic acids, hydroxamic acids and short-chain fatty acids. Some researchers conceived that wheat allelopathy is genetically controlled, but systematic research on gene behaviours is lacking.

Project FATEALLCHEM, financially supported by the European Commission in the 5th Framework Programme (involving agronomists, biologists, analytical chemists, organic chemists, environmental chemists, and ecotoxicologists) was focused on future assessments of an extensive use of allelopathic crops. This has to include the development of validated analytical methods, considerations of relevant concentrations, studies on soil transformation, ecotoxicological studies on individual compounds and mixtures, evaluation on human and mammal toxicity, and joint effect studies on weeds, insects, and pathogens. Results of this project clearly showed the relevance of optimizing the exploitation of cereal benzoxazinones: by the use of cereals as cover crops and green manure [54].

Recent research suggested that allelopathic properties can render one species more invasive to native species and thus potentially detrimental to both agricultural and naturalized settings. In contrast, allelopathic crops offer strong potential for the development of cultivars that are more highly weed suppressive in managed settings [49]. According to Peng *et al*. [52] in the future the research should be focused on the following topics: (a) identification and more effective purification of allelochemicals, especially for agriculture; (b) the functions of allelopathy at the molecular structure level; (c) using allelopathy to explain plant species interactions; (d) allelopathy as a driving force of succession; and (e) the significance of allelopathy in the evolutionary processes.

Phytoremediation – green technology for the removing of toxic metals and organic pollutants from the environment

Phytoremediation, the use of plants for environmental restoration, is an emerging cleanup technology belonging to the cost-effective and environment-friendly „new biotechnology“. Plants are especially useful in the process of bioremediation because they prevent erosion and leaching which can spread the toxic substances to surrounding areas. There are several types of phytoremediation technologies being used today.

These include (a) **phytoextraction**, which reduces soil metal concentrations by cultivating plants with a high capacity for metal accumulation in shoots; (b) **rhizofiltration** used for cleaning contaminated surface waters or wastewaters by adsorption or precipitation of metals onto roots or absorption by roots or other submerged organs of metal-tolerant aquatic plants; (c) **phytostabilization** using plants for immobilizing contaminant metals in soils or sediments by root uptake, adsorption onto roots or precipitation in the rhizosphere; (d) **phytodegradation,** a process in which elimination of organic pollutants by decomposition through plant enzymes or products occurs; (e) **rhizodegradation** – decomposition of organic pollutants by means of rhizosphere microorganisms; f) **phytovolatilization** – a process in which organic pollutants or certain metals (*eg* Hg or Se) absorbed by plants are released into the atmosphere by transpiration, either in their original form or after metabolic modification; (g) **hydraulic control –** use of plants that absorb large amounts of water and thus prevent the spread of contaminated wastewater into adjacent uncontaminated areas; (h) **phytorestauration**, *ie* revegetation of barren areas by fast-growing resistant species that efficiently cover the soil, thus preventing the migration of contaminated soil particles and soil erosion by wind and surface water runoff [55, 56].

Phytoremediation is a naturally occurring process that was recognized and documented by humans more than 300 years ago [57]. Since this time, humans have exploited certain plants' abilities to survive in contaminated areas and to assist in the removal of contaminants from soil. Some metal-tolerant plant species can accumulate high concentrations of specific metals in their aboveground biomass. These are the so-called metal hyperaccumulators (metal extractors) of which about 400 taxa have been described so far from 35 families of angiosperms [58]. Hyperaccumulators are conventionally defined as species capable of accumulating metals at levels 100-fold greater than those typically measured in common non accumulator plants. Thus, a hyperaccumulator will concentrate more than 10 ppm Hg, 100 ppm Cd, 1000 ppm Co, Cr, Cu and Pb and 10 000 ppm Ni and Zn in the shout [59].

As mentioned above, hyperaccumulators accumulate appreciable quantities of metal in their tissue regardless of the concentration of metal in the soil. Metal bioavailability could be improved by chelates or acidifying agents which enhance the phytoextraction of a number of metal contaminants including Cd, Cu, Ni, Pb, and Zn. From the aspect of practical application, besides hyperaccumulators the fast-growing (high-biomass-producing) plants are also important. In spite of lower shoot metal-bioaccumulating capacity of these species, the efficient phytoremediation is connected with their high biomass production [60].

Phytomining is the production of a 'crop' of a metal by growing high-biomass plants that accumulate high metal concentrations. Some of these plants are natural hyperaccumulators, and in others the property can be induced. Pioneering experiments in this field might lead to a 'green' alternative to existing, environmentally destructive, opencast mining practices. Phytomining for a range of metals is a real possibility, with the additional potential of the exploitation of ore bodies that it is uneconomic to mine by conventional methods [61, 62]. Gardea–Torresdey *et al.* [63] has shown that gold accumulated by alfalfa plants and stored in leaf and stem biomass can be present as discrete nanoparticles (2 to 20 nm) of pure metal. A similar study showed that also silver nanoparticles were formed in alfalfa plants [64].

Phytofortification

Phytofortification as a part of biofortification is the fortification of plants with essential nutrients, vitamins and metabolites during their growth and development, there by making these additives more readily available for human/animal consumption. The idea of fortifying food crops with the essential minerals required for a healthy diet is relatively new. For example, iron and zinc deficiencies result in nutritional disorders in the world today, whereby most of the world population getting both elements from edible plants. Therefore, increasing the iron and/or zinc content of crop plants could significantly improve human health. As many of the metals that can be hyperaccumulated are also essential nutrients, it is easy to see that food fortification and phytoremediation are two sides of the same coin [65]. Biofortification provides a truly feasible means of reaching malnourished populations in relatively remote rural areas, delivering naturally-fortified foods to population groups with limited access to commercially-marketed fortified foods that are more readily available in urban areas [66].

Recently phytofortification was divided into **agronomic** and **genetic phytofortification** [67]. The first one uses soil and spray fertilizers enriched by individual essential elements (*eg* Fe, Zn and Se). This approach has been adopted with success in Finland for enrichment of crops by Se. On the other hand, the genetic phytofortification present the possibility to enrich food crops by selecting or breeding crop varieties, which enhanced Se accumulation characteristics [67]. Agronomic biofortification could be used by food companies as a cost-effective method to produce high-Se wheat products that contain most Se in the desirable selenomethionine form. Increasing the Se content of wheat is a food systems strategy that could increase the Se intake of whole populations [68].

A strategy that exploits genetic variability to breed staple crops with enhanced ability to fortify themselves with micronutrients (**genetic biofortification** or **phytofortification**) offers a sustainable, cost-effective alternative to conventional supplementation and fortification programs. Genc *et al.* [69] suggested that a combined strategy utilising (a) plant breeding for higher micronutrient density, (b) maximising the effects of nutritional promoters (*eg* inulin, vitamin C) by promoting favourable dietary combinations, as well as by plant breeding; and (c) **agronomic biofortification** (*eg* adding iodide or iodate as fertiliser; applying selenate to cereal crops by spraying or adding to fertiliser) is likely to be the most effective way to improve the nutrition of populations.

Progress has been made in the accumulation of iron, zinc, and vitamins A and E in genetically modified plants. For future success in this area, many more studies will be required on the physiology of ion uptake and on the transport of vitamin precursors [70]. Biofortification of crops requires the identification of candidate genes involved in micronutrient accumulation. Scanning of available maize genome sequence resulted in the identification of 33 genes predicted to be involved in iron and zinc transport in maize. Candidate genes are expected to be of potential use in genetic and association mapping, molecular marker-assisted selection and development of **transgenic plants** for micronutrient enrichment traits in maize [71]. On the other hand, the latest information from the end of November 2006 outlined promising perspectives concerning approaches how to receive wheat enriched with protein, Fe and Zn using **non-transgenic plants**. The team of scientists supervised by Professor J. Dubcovsky used conventional methods at breading of wild and domesticated wheat to bring the gene into cultivated wheat varieties not genetically modified [72].

Plants as a source of antioxidants

Consumption of plant foods, mainly fruits, vegetables and cereal grains is encouraged because they render beneficial health effects. Phenolic and polyphenolic compounds are among the most desirable food bioactives because of their antioxidant activity [73]. To the extensively studied sources of natural antioxidants belong beside fruits, vegetables, seeds and cereals also berries, wine, tea, onion bulbs, olive oil and aromatic plants. Attempts are also made to identify and evaluate antioxidants in agricultural by-products, ethnic and traditional products, herbal teas, cold pressed seed oils, exudate resins, hydrolysis products, not evaluated fruits and edible leaves and other raw materials rich in antioxidant phenols that have nutritional importance and/or the potential for applications in the promotion of health and prevention against damages caused by radicals [74].

Tepe *et al.* [75] examined the *in vitro* antioxidant activities and rosmarinic acid levels of the methanol extracts of two cultivars of *Salvia verticillata* L. and found that rosmarinic acid and its derivatives are more likely to be responsible for most of the observed antioxidant activities of *Salvia* species. Recent studies have demonstrated that dietary plants are rich source of antioxidants and can contribute to the protection from age-related diseases. Žitňanová *et al.* [76] determined the total antioxidant capacity of extracts from different kinds of fruits and vegetables and examined their inhibitory effect on the oxidative damage to proteins *in vitro*. The highest antioxidant activity showed blueberries and red beet and the lowest one was determined in pears and green beans. Hinneburg *et al.* [77] investigated antioxidant activities of extracts from selected culinary herbs and spices (basil, laurel, parsley, juniper, aniseed, fennel, cumin, cardamom, and ginger). The extracts from basil and laurel possessed the highest antioxidant activities and both extracts are promising alternatives to synthetic substances as food ingredients with antioxidant activity. Yanishlieva *et al.* [78] in a review paper presented information about the antioxidative effects of rosemary, sage, oregano, thyme, ginger, summer savory, black pepper, red pepper, clove, marjoram, basil, peppermint, spearmint, common balm, fennel, parsley, cinnamon, cumin, nutmeg, garlic, coriander, etc. Sage and oregano, which belong to the same family, have gained the interest of many research groups as potential antioxidants.

Dietary carotenoids (plant pigments) also provide health benefits based on their antioxidant properties. New genetic and genomic approaches are now in progress to identify regulatory factors that might significantly contribute to improve the nutritional value of plant-derived foods by increasing their carotenoid levels [79]. At present, β-carotene (isolated from the carrot) is the most frequent applied carotenoid in pharmaceutical and food industry.

Tannins show strong antioxidative properties, too and some tannins in red wine or gallate esters were proved to have antioxidative effect *in vivo*. The number of hydroxy groups connected with the aromatic ring, in *ortho* or *para* position relative to each other, enhanced antioxidative and antiradical activity of phenolic acids. The substitution of a methoxy group in *ortho* position to the OH in monophenols seemed to favour the antioxidative activity of the former [80].

The pharmacological actions of phenolic antioxidants arise mainly from their free radical scavenging and metal chelating properties as well as their effects on cell signalling pathways and on gene expression [81]. The management of traditional risk factors such as hypertension and dyslipidaemia has been successful in reducing the development of cardiovascular disease. Flavonoids have been a major focus of attention since the days of the French paradox and the presence of high quantity of flavonoids in grapeseed extracts has prompted research looking at its effects on novel markers of vascular risk [82]. It is known that the consumption of red wine is high in Italy and France, approximately four times greater than that in the UK. This disparity in red wine consumption is thought to be the reason for the 'French paradox', where France was shown to have a coronary mortality rate close to that of China or Japan despite saturated fat intakes and cholesterol levels similar to those in the UK and USA. It was found that red wine polyphenols have little effect on plasma lipid concentrations but wine consumption appears to reduce the susceptibility of low density lipoproteins (LDL) to oxidation and increase serum antioxidant capacity. These evidences suggested that alcohol has a positive synergistic effect with wine polyphenols on some atherosclerotic risk factors. Thus evidence that wine drinking is beneficial for cardiac health continues to accumulate but more research is required to understand fully and exactly the functions of red wine polyphenols [83].

Traditional and non-traditional utilization of medicinal plants

According to World Health Organization (WHO) more than 80 % of the world's population in the developing countries depend on traditional medicine for their primary health care. Over 1.3 billion people in the world can hardly afford to spend any money on modern medicine and therefore have to resort to local medicinal plants for their health needs [84]. On the other hand, demand for medicinal plants use in phytomedicine increases also in developed countries because of many people prefer natural medicine in comparison with synthetic drugs.

Out of the 350,000 vascular plants identified so far about 35,000 (the estimates vary) species have at one time or other used by some people or cultures for medicinal purpose. Up to 90 % of species of medicinal and aromatic plants (MAPs) traded in Europe are still harvested from the wild, and a rapid growth in the market is now resulting in over-exploitation of wild stocks of some species [84]. Out of about 2,000 MAPs traded in Europe, 1,200–1,300 are native to the continent with only 130–140 species predominantly derived from cultivated stock. An estimated 70,000 hectares of land are devoted to the cultivation of MAPs in the European Union. Wild-harvesting of MAPs in Europe is still prominent in many former Eastern Bloc countries including Poland and Slovakia where the climate, soil and low levels of pollution in these countries are some of the best in middle Europe for the cultivation of medicinal plants. Between 20,000 and 30,000 Mg (ton or tonne) of wild-plant material are collected annually in Europe. For example, between 30 and 50 % of MAP material in trade in Hungary (probably also in Slovakia) is wild-collected [85]. Processing of medicinal plants cultivated under special environmental conditions is well developed in Poland where the area of herbal crops cultivation is up to 35,000 ha, while the area of medicinal plants is up to 20,000 ha. Details concerning the above-mentioned topic can be find in the project of Interactive European Network for Industrial Crops and their Applications, IENICA INFO*RRM* Project [86].

Medicinal plants could be regarded as potential plant factories for new natural drugs. There are many hundreds of medicinal plants that can be grown in temperate climates and there are probably a great deal more with properties as yet undiscovered. For example: thyme has been shown to slow down the ageing process by maintaining the vigour of our body cells; sage is an excellent antiseptic for treating mouth ulcers and sore throats; chamomile is a safe treatment for children's stomach upsets; various plants are currently being tested as possible treatments of diseases such as AIDS and cancer (*eg* St. John plant, *Hypericum preforatum* L.) [87]. Much more research needs to be carried out on a whole range of medicinal plants in order to find safer, more holistic alternatives to the synthetic drugs so often used nowadays. Additionally, medicinal plants have great potential for their exploitation in modern phytotechnologies, such are phytoremediation and phytofortification (in detail see corresponding chapters in this text). However, it could be stressed that it is necessary to check the herbs for the content of harmful substances (*eg* toxic metals). It was found that metal contamination could change the chemical composition of secondary metabolites in *H. perforatum* and thereby, seriously impact the quality, safety and efficacy of natural plant products produced by this medicinal plant [88]. On the other hand Falco *et al.* [89] performed risk assessment of trace elements (As, Cd, Hg, Pb, Fe, Zn, Mn and Cu) intake through natural remedies in Poland and found that according to the FAO/WHO provisional tolerable weekly intake (PTWI), the total daily intake of the toxic elements As, Cd, Hg and Ph should not mean potential adverse effects on the health of the consumers.

In general, important objectives for medicinal plants cultivation in the future are as follows:

- elaboration of novel cultivation technology helping the introduction of new herbal species, or modification of good agriculture practices for already cultivated species or cultivars with the new direction of application *eg* for the medicinal, nutrition and cosmetic needs,
- breeding new cultivars, which allows providing high quality raw material into medicinal, plants processing (increase of cultivation profitability),
- introduction of modern plant protection products,
- protection of natural resources of domestic medicinal plants,
- implementation of novel methods for the dissemination of research results.

Plant-made pharmaceuticals

Plant-made pharmaceuticals (phytopharmaceuticals) are natural pharmaceutically efficient substances (secondary metabolites) produced by the plants. Plants are a tremendous source for the discovery of new products of medicinal value for drug development. At present many chemicals derived from plants are important drugs currently used in the world. Recently, the increasing commercial importance of secondary metabolites resulted in a great interest in secondary metabolism, particularly in the possibility of altering the production of bioactive plant metabolites by means of tissue culture technology [90].

Production of medicinal plants under greenhouse conditions is a perspective method for controlling levels of phytochemicals through the changing environmental conditions, *eg* day length, irradiance, water or mineral nutrition supply, temperature, etc. However, it could be stressed, that better understanding of how the environment alter secondary metabolite levels is needed so that manipulating the environment to favour increased accumulation of one group of phytochemicals could not result in a decline of other key metabolites [91].

In the past, plants have been used as a source of medicinal compounds. At present, “molecular farming” represents a novel source of molecular medicines, such as plasma proteins, enzymes, growth factors, vaccines and recombinant antibodies, etc. Such pharmaceuticals are safer, easier to produce and less expensive than those produced in animals or microbial culture. From the agriculture aspects, molecular farming enables protein production on a massive scale using hectares of cultivated plants, which can then be harvested and transported using the agricultural infrastructure. Thus, molecular farming allows rapid progress from genetic engineering to crop production, and new cash crops producing recombinant proteins are already being commercially exploited [92].

Plant-made vaccines antibodies (plantibodies) are especially striking, as plants are free of human diseases, thus reducing screening costs for viruses and bacterial toxins. Plantibody is antibody expressed transgenically in an engineered plant [93, 94]. The most promising role for plantibodies is their potential for large-scale production in plants. Scientists hope that in the future cheaply produced plantibodies may be used as contraceptives, to treat cancer and as a tool against the spread of many infectious diseases. The expression of viral- or nematode-specific antibodies in planta (latin name for the plant and hence the term plantibody [95, 96]) is a promising new direction for controlling plant pathogens [97]. Edible vaccines that are heat stable, easy to administer and cheap to produce have the potential to redress many of the production, distribution and delivery limitations faced by traditional vaccines. Successful edible vaccines have the potential to transform health policy and practice in both developed and developing countries [98]. The production of vaccines in transgenic plants was first proposed in 1990 but no product has yet reached commercial use. However, there are several risks during the production and delivery stages of this technology, with potential impact on the environment (*eg* gene transfer and exposure to antigens or selectable marker proteins) and on human health (*eg* oral tolerance, allergenicity, inconsistent dosage, worker exposure and unintended exposure to antigens or selectable marker proteins in the food chain). Therefore, the value of vaccines produced in plant cells and delivered orally must be considered alongside the probability and severity of potential risks in their production and use, and the cost of not deploying this technology - the risk of continuing with the *status quo* alternative [99]. Hence, it is evident that the use of transgenic plants for human vaccines will require significant investment and developmental efforts that cannot be supported entirely by the academic sector and is not currently supported financially by industry [100].

Recombinant plant systems potentially offer economic alternatives to produce large amounts of pharmaceutical proteins, including those used in vaccines. Plant systems also provide a convenient oral delivery option, overcoming the cost and inconvenience of purification and injections. Current regulations for the production of plant-made pharmaceuticals are to prevent recombinant proteins from entering the food chain or from persisting in the environment, and to guard against recombinant nucleic acid sequences entering genomes of food or feed crops, or wild species [101].

It is evident that plants have provided many medicinal drugs in the past and remain as a potential source of novel therapeutic agents. Despite all of the powerful analytical techniques available, the majority of plant species has not been investigated chemically or biologically in any great detail and even well known medicinal plants require further clinical study [102]. Efficient biopharmaceutical production in plants involves the proper selection of host plant and gene expression system, including a decision as to whether a food crop or a non-food crop is more appropriate [103]. Recent advances in plant biotechnology have led to the successful commercialization of agricultural products for crop improvement and plant biotechnology is now being considered as a tool to produce non-food products such as biopharmaceuticals and bioindustrial products [104]. Moreover, the pharmaceutical industry is moving towards a profitability gap between increasing costs and decreasing prices. Therefore, classical approaches like the optimization of production technologies for drug substances, that might help to increase profitability, are receiving increasing attention. According to Behr *et al.* [105] the combination of innovative components (the design and manufacturing of production facilities as well as a process streamlining of the production process) will guide the way to very efficient and cost-effective production.

Interactions of herbal medicines with synthetic drugs

As it has already been mentioned, plant-made pharmaceuticals enable to produce great amounts of medicines cheaply using a range of different plant species. However, plant-made pharmaceuticals may present a risk to the public's health if they enter the food supply [106]. Plant-derived pharmaceuticals are designed to become the next major commercial development in biotechnology. They provide the most promising opportunity to supply low-cost drugs and vaccines to the developing world. However, despite the promised benefits, the commercialization of plant-derived pharmaceutical products is overshadowed by the uncertain regulatory terrain, particularly with regard to the adaptation of good manufacturing practice regulations to field-grown plants [107].

Recently, interactions of herbal medicines with synthetic drugs came into attention of particular interest and several review papers were published related to this topic [108–110]. Non-steroidal anti-inflammatory drugs, particularly aspirin, have the potential to interact with herbal supplements that are known to possess antiplatelet activity (ginkgo, garlic, ginger, bilberry, dong quai, feverfew, ginseng, turmeric, meadowsweet and willow), with those containing coumarin (chamomile, motherworth, horse chestnut, fenugreek and red clover) and with tamarind, enhancing the risk of bleeding [109]. The concomitant use of opioid analgesics with the sedative herbal supplements, valerian, kava and chamomile, may lead to increased central nervous system (CNS) depression. The analgesic effect of opioids may also be inhibited by ginseng [109]. In the past 3 years, more than 50 papers were published regarding interactions between *H. perforatum* L. and prescription drugs (111–115). Co-medication with *H. perforatum* resulted in decreased plasma concentrations of a number of drugs including amitriptyline, cyclosporine, digoxin, indinavir, irinotecan, warfarin, phenprocoumon, alprazolam, dextrometorphane, simvastatin, and oral contraceptives. Sufficient evidence from interaction studies and case reports indicate that *H. perforatum* is a potent inducer of cytochrome P450 enzymes (particularly CYP3A4) and/or P-glycoprotein [111, 112]. It could be concluded that interactions between herbal medicines and prescribed drugs can occur and may lead to serious clinical consequences. Both pharmacokinetic and/or pharmacodynamic mechanisms have been considered to play a role in these interactions, although the underlying mechanisms for the altered drug effects and/or concentrations by concomitant herbal medicines are yet to be determined [110]. The existence of drug-herb interactions could encourage physicians to "phytopharmacovigilance" [116].

Genetically modified plants – benefits and hazards of gene technology

The 20th century started vigorous development in biotechnology and genetic sciences. The changing of organism genomes *via* gene transfer opened up limitless research areas. Genetically modified foods, microorganisms, animals, plants, and cloned organisms present different products to society, but these technologies create suspicions among people [117]. Genetic engineering, as scientific discipline, appeared in the year 1973. The process involves transfer of DNA from one organism into another. Genetically engineered or genetically modified organisms (GEOs or GMOs) are the name given to such new species of plants created through this process [118]. Transgenic whole plants and plant cell culture systems have been developed that have the capacity to economically produce large-scale quantities of antibodies and antibody fragments, antigens and/or vaccine epitopes, metabolic enzymes, hormones, (neuro)peptides and a variety of biologically active complexes and secondary metabolites for direct use as therapeutic agents or diagnostic tools in the medical health care industry [119].

Plant biotechnology has made significant advancements during the past decade, and several crops are now grown commercially. Globally, the area covered by genetically modified (GM) crops increased from 1.7 million hectares to 90 million hectares between 1996 and 2005 (in 2004, it was estimated to cover a total of 81 million ha in 17 countries), with an increasing proportion grown in developing countries. At present, four plant species (soybean, maize, cotton and rapeseed) dominate with two traits (herbicide tolerance and insect resistance) [120, 121]. Increasing tendency of field cultivation of these GM plant species is reflected in Table 1 [122].

Table 1

Global area of genetically modified crops in the years 1996–2005

Crops	Million hectares				
	1996	1998	2000	2003	2005
Soybean	0.5	14.5	25.8	41.4	54.4
Maize	0.3	8.3	10.3	15.5	21.2
Cotton	0.8	2.5	5.3	7.2	9.8
Rapeseed	0.1	2.4	2.8	3.6	4.6

A crucial question facing the global agri-food system is whether GM crops can co-exist with traditional crops. The environmental hazard of gene flow leads to resistance evolution against herbicide, virus and insect/pest, movement of genes and non-target effects [123, 124]. The relative facility of system-wide cross-pollination of farmland by GM crops can cause genetic transfer between crops on an agricultural landscape and thus result in non-GM crop contamination [125]. One of the least understood areas in the environmental risk assessment of GM crops is their impact on soil- and plant-associated microbial communities. It was found that interactions between transgenic plants and plant residues and the soil microbial community could change microbial biodiversity and affect ecosystem functioning [126].

Transgenic insecticidal plants based on *Bacillus thuringiensis* (Bt) endotoxins, on proteinase inhibitors and on lectins, and transgenic herbicide tolerant plants are widely used in modern agriculture. Velkov *et al.* [127] analysed results of the studies on likelihood and non-likelihood of adverse effects of transgenic plants on the environment including: (a) effects on non-target species; (b) invasiveness; (c) potential for transgenes to „escape“ into the environment by horizontal gene transfer; and (d) adverse effects on soil biota and stated that large-scale implementation of transgenic insecticidal and herbicide tolerant plants do not display considerable negative effects on the environments. On the other hand, it was found that lignin content in *Bt* maize which has been genetically modified to express the Cry1Ab protein of *Bacillus thuringiensis* to kill lepidopteran pests was significantly (about 33–97 %) higher than that of their respective non-*Bt* isolines (in plants grown in a plant growth room as well as in the field) [128, 129]. As lignin is a major structural component of plant cells, modifications in lignin content may have ecological implications. The further ecological consequences could be connected with stronger binding and higher persistence of the Cry1Ab protein, as well as its remaining nearer the soil surface of the soil that contained the higher clay concentrations (and thus a higher cation-exchange capacity and specific surface area) indicating that it could be transported to surface waters *via* runoff and erosion [130]. Negative effects on non-target organism monarch butterfly (*Danaus plexippus* L).

suggested the need of non-target risk assessment for transgenic crops, which should be case specific, depending on the plant, the transgene, and the intended release environment [131]. Beside this, for non-target natural enemy species also evaluation both direct bitrophic impacts and indirect tritrophic impacts will be necessary [132]. Potential impacts on soil organisms will also depend on the persistence of the *Bt* toxin in *Bt* plant residues, which remain left in the field after harvest [133, 134].

Golden Rice is a new rice (*Oryza sativa* L.) variety that has been genetically modified to contain β-carotene as a precursor of vitamin A. In developing countries, where vitamin A deficiency prevails, grain from Golden Rice is expected to provide this important micronutrient permanently through agriculture [135, 136].

The ability of plants to tolerate drought conditions is crucial for agricultural production worldwide. Since water stress continues to be a major limiting factor hindering world wheat productivity under adverse hot and dry weather conditions the most promising recent progress is in the development of novel drought-tolerant wheat cultivars [137]. Thus, the molecular tailoring of genes has the potential to overcome a number of limitations in creating drought-tolerant transgenic plants [138].

While currently agronomic traits (herbicide resistance, insect resistance) dominate, traits conferring "quality" traits (altered oil compositions, protein and starch contents) will begin to dominate within the next years. However, economically the most promising future lies in the development and marketing of crop plants expressing pharmaceuticals or "nutraceuticals" (functional foods), and plants that express a number of different genes. But large-scale introduction of entirely novel genes and gene products in new combinations at high frequencies could have unknown impacts on non-target organisms, *ie* all organisms that are not targeted by the insecticidal protein [139].

Theoretical and methodical aspects of risk assessment procedure related to usage of genetically modified organisms in Slovakia were described in detail by Valková and Turňa [140].

Food sufficiency and food safety

Over the last 30 years great attention was devoted to the development of high-yielding varieties of wheat and rice, however in the 1990s, the rate of growth in food-grain production has been lower than the rate of growth in population. Therefore, it is necessary to develop strategies for integrated nutrient management, integrated pest management, and efficient utilization of water and soil resources [141]. The identification of the origin and authenticity of food, including ingredients and food sources is of prime importance for the protection of consumers. Traceability means the ability to trace the substances in food "through all stages of production, processing and distribution": primary production, storage, transport, sale, importation, manufacture, distribution, supply (Regulation EC/178/2002 – General Food Law) [142].

Agroenvironmental practices have direct and indirect effects on human health and thus "the quality of the environment influences the quality and safety of foods". The next generation of GM foods will not be limited to plants with agronomic advantages (*ie* increased yield due to herbicide-tolerance or insect-resistance) but will focus on improvements of the nutritional properties of a food crop [143]. Such GM crops with "added values" will cross the borderline between GM foods and "functional foods" or so-called "nutraceuticals" [144]. The World Health Organisation (WHO) has stated its commitment on food safety as an essential public health issue and jointly with the Food and Agriculture Organisation (FAO) sponsor the Codex Alimentarius Commission where international standards on guidance are prepared for member and non-member states [145, 146]. The European Food Safety Authority (EFSA) [147] was considered by the Commission the most appropriate response to the need to guarantee a high level of food safety. In the field of GMO Codex principles have been established for the assessment of GM food safety and the Cartagena Protocol on Biosafety (2000) outlines international principles for an environmental assessment of living modified organisms. The environment can act as a route of unintentional entry of GMOs into the food supply, such as in the case of gene flow *via* pollen or seeds from GM crops, but the environment can also be involved in changes of GMO-induced agricultural practices with relevance for health/ food safety. Examples for this approach include potential regional changes of pesticide uses and reduction in pesticide poisonings resulting from the use of Bt crops or influences on immune responses *via* cross-reactivity. The health/ food safety assessment of GM foods in cases when the environment is involved needs to be informed by data from environmental assessment [148].

The usage of GM foods for human consumption has raised a number of fundamental questions including the ability of GM foods to elicit potentially harmful immunological responses, including allergic hypersensitivity and therefore FAO, WHO, and the EU have developed approaches for evaluation assessment [149]. On the other hand, according to results of Ohya *et al.* [150], transgenic cytokine-expressing plants can be used prophylactically as edible pharmaceuticals to enhance systemic defence responses in humans and animals.

Means and opportunities by which to satisfy the health and nutritional needs (using also GM crops) of impoverished nations and communities differ significantly from those who enjoy greater affluence. It is distinctly unethical for Europeans and North Americans, whose food and health securities are not at risk, to impose their ethical predilections on poorer nations [151]. Enormous interest of developing countries concerning GMOs was also reflected in increased publication activity. Literature statistics covering the past 30 years reveal a dramatic increase in plant transgenic science in Asia during the past decade, a sustained expansion in North America and, recently, a slow down in the rest of the world. With the exception of the output of China and India, publications focusing on the development of transgenic technology have been slowing down, worldwide, since the early mid-1990s, a trend that contrasts with the increase in GM crop related studies [152].

Plants – source for biofuels

The energy sources have been divided into three categories: fossil fuels (oil-coal-natural gas), renewable sources, and nuclear sources. Oil and gas are expected to continue to be important sources of energy. New efficient and cost-effective small-scale renewable energy generation options are commercially available today. The share of renewable energy sources is expected to increase very significantly [153]. Bioenergy is one of the forms of renewable energy. Bioenergy, the energy from biomass, has been used for thousands of years, ever since people started burning wood to cook food, and today wood is still our largest biomass resource for bioenergy. The use of bioenergy has the potential to greatly reduce our greenhouse gas emissions [154]. Biomass, mainly in the form of wood, is the oldest form of energy used by humans. However, it represents only 3 % of primary energy consumption in industrialized countries. World production of biomass is estimated at 146 billion metric tons a year, mostly wild plant species [155]. Biomass can provide a sustainable and renewable source of transportation fuels and industrial chemicals that may significantly reduce our dependence upon petroleum. The agricultural sector has made significant progress in developing these bio-based fuels and chemicals. Technologies from the agricultural sector may be combined with recent technical improvements that have made wood-based bioconversion more feasible [156].

The most popular alternative motor fuels are bioethanol, biodiesel and hydrogen. Alternative engine fuels are fuels competitive to petroleum and these fuels are important because they replace petroleum fuels [157]. Ethanol is an attractive alternative fuel because it is a renewable bio-based resource and it is oxygenated, thereby providing the potential to reduce particulate emissions in compression-ignition engines [158]. Several renewable carbohydrate resources have been tested for the production of ethanol as a liquid fuel. Similar to ethanol production from sugar cane, the utilization of bio-waste as an alternate raw material can quench the demand for ethanol. By using biomass-derived ethanol, a net reduction in the levels of carbon dioxide (the main greenhouse gas) could range about 60–90 % relative to gasoline consuming vehicles [159]. The possibility of substitution of gasoline by sugar cane alcohol in automobile use appeared firstly in Brazilian National Bio-Fuel Program in the year 1975 [160]. Ethanol from sugar cane, either from final molasses and/or intermediate molasses (runoffs) or directly from cane juice, is used as gasoline additive ("gasohol") or fuel for alcohol engines [161]. Similar program of vegetable oils – OVEG, conceived in 1983, gave significant contribution to the automotive applications of vegetable oils (biodiesel) in vehicles [160].

Nishigami *et al.* [162] proposed a new synthesis method for methanol as a future alternative fuel, by the combination of carbon supplied from wood and hydrogen supplied from the electrolysis of water using a solar power generation system in the desert. In the developing countries, potential forest sites are expected to be available for wood production, even though they are presently grasslands or secondary forests, while natural tropical forests will not be allowed to be converted into artificial forests. Biofluel obtained from such biomass production could saturate approximately 34 % of the world's fuel consumption by vehicles.

Hydrogen is considered as a novel fuel for the twenty-first century, mainly due to its environmentally benign character. Production of hydrogen from renewable biomass has several advantages compared to that of fossil fuels. A number of processes are being practised for efficient and economic conversion and utilization of biomass to hydrogen [163]. Main studied non-conventional processes for hydrogen production from biomass are redox process for biomass derived syngas conversion, hydrogen from biomass *via* concentrated solar radiation, microbial fermentation of biomass and hydrogen from gasification of biomass *via* supercritical fluid extraction [164].

Vegetable oils (from *eg* rape and sunflower) are important not only for agriculture and food industry, but it seems that they could be used as an alternative fuel because of their properties similar to diesel fuel. For such renewable resources plants with fast CO_2-cycle and high biomass production could be exploited [165–167].

Biofuels in EU

According to the Directive 2003/30/EC of European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, the promoting the use of biofuels in transport will constitute a step towards a wider application of biomass which will enable biofuel to be more extensively developed in the future [168]. The most recent technological developments make it possible to use higher percentages of biofuel in the blend. Some countries are already using biofuel blends of 10 % and higher. The Commission Green Paper "Towards a European strategy for the security of energy supply" sets the objective of 20 % substitution of conventional fuels by alternative fuels in the road transport sector by the year 2020 [169].

Biofuels in Poland and Slovakia today

Poland and Slovakia as member countries of EU have being already devote great attention to the biofuels. In Poland in the year 2001, rapeseed, used to produce biofuels, was planted on 560,000 hectares of land. In this year the rapeseed yield was 1.03 million tons [170] whereas in the year 2005 this yield has already achieved 1.4 million tons. Thus, according to the FAO, Poland became seventh top rapeseed producer in the world [171]. In governmental simulations, Polish farmers could produce 2.5 million tons from 1 million hectares. According to the new law all fuels sold on the Polish market must contain the bio-component portion. The Polish market would need 260,000 Mg of dehydrated alcohol and 400,000 Mg of rapeseed oil annually staring from July 2003 [170]. According to the proposed legislation up to 5 percent of bio-components will be the norm in liquid fuels. Consumers will be able to choose traditional fuel or bio-fuel with a higher content of bio-components. The goal for 2010 is 5.75 % bio-fuel use (based on energy level), in accordance with the relevant EU directive [172].

Table 2

Potential and current usage of the biomass in Slovakia

Biomass type	Technically useful potential until 2010	Current usage	Unused potential	
	[TJ/year]	[TJ/year]	[%]	[TJ/year]
Forest biomass	10 180	1 778	13.4	8 402
Energy forest	1 635	372	2.8	1 263
Waste from the wood-processing industry	17 570	9 497	71.8	8 073
Agricultural biomass	32 708	216	1.6	32 492
Biofuels	9 000	1 188	8.9	7 812
Biomass	69 311	13 235	100	56 076

Slovnaft, Inc., refining and petrochemical company (Bratislava, Slovakia) is producer of rapeseed methyl ester (MERO or RME) which is blended into the motor fuel. Moreover, Slovnaft also produces ethyl-*tert*-butyl-ether (ETBE) as an additive for gasoline. Both, MERO and ETBE are bio-components of biofuels produced on the basis of renewable raw materials of plant origin (mainly rape, *Brassica napus* L.). Nowadays the exported diesel fuel for Austria have to contain 4.4 % of MERO and in the year 2010 – as mentioned above – this portion should be 5.75 % [172]. In the close future (end of the year 2007) a new factory will be built in the town Leopoldov (Slovakia) with annual MERO production 100 000 Mg requiring supply of approx. 300 000 Mg rapeseeds per year [173]. To realise above-mentioned objectives not only effective cooperation between chemical industry and botanical research in Slovakia will have to be started but also much more intensive fundamental and applied research in this topic will be needed.

Restrictions connected with waste disposal of forest, agricultural and garden biomass by burning (to limit the content of harmful substances in the atmosphere) resulted in the development of new approaches in waste usage. At present, straw, wood chips and wood briquets are more and more used in village landscapes for heating. Wood briquet is extremely environment-friendly and user-friendly biofuel, since it does not contain chemical substances, it has a very high heat value, it emits very little ash and it burns efficiently and at high temperature [174]. Potential and current usage of the biomass in Slovakia published by Kisely and Horbai [175] is presented in Table 2.

Requirement for acceptance of fundamental principles of bioethics

Bioethics could be defined as a discipline dealing with the ethical implications of biological research and applications, which studies ethical issues raised by the developments in the life science technologies. The aim of bioethics is to define a wise conduct for humans with regard to their environments whether living or inanimate.

However, owing to their diversity, bioethics can only deal with general problems such as biodiversity. For instance, the preservation of an apparently threatened biodiversity or the revival of a seriously damaged biodiversity must be the subject of a thorough preliminary scientific study and if legislative decisions are taken, a very careful scientific control of their consequences must be carried out [176]. It is necessary to consider the ethics as the basis of the constitutional mandate, with the role of FAO being to promote global food security, balanced conservation, management and utilization of natural resources, and sustainable rural development [177].

Nature may not be interested in the survival of humanity. *Homo sapiens* is the product of an adaptive evolution, but if the species continues to indulge in unlimited reproduction and undisciplined exploitation of the earth's resources, it may bring about its own destruction as well as the destruction of other species of animals and plants [178]. For millennia, plants have been selectively bred to develop varieties that are productive, or more suitable for human use. Recent decades have seen much progress in the use of plant biotechnology in food production, particularly in terms of gene transfer technology. This progress has been accompanied by changing public attitudes to plant biotechnology and increased ethical awareness, with concerns relating to the plant or gene itself or to health and environmental consequences [179]. A comprehensive report prepared by Darryl Macer for the Subcommittee on Food, Plant Biotechnology and Ethics, of the UNESCO International Bioethics Committee describes in detail roles of plant biotechnology in food production, ethical concerns about plant biotechnology, regulation of food safety and biotechnology and the role of UNESCO in this topic [180].

There is a new step in transforming life sciences (including biology) into technology through the "converging technologies". These represent a combination of **nano**-, **bio**-, **information**- and **cognition technologies** known as **NBIC technologies**. "Converging technologies" allow for totally new combinations of biological and non biological material. Converging technologies open totally new possibilities to interfere with living organisms. This concerns not only the beginning and the end of life, but also the whole duration of life. Likewise, intensive improvement of biological sciences accompanied with many novel technologies promote new substantial issues concerning ethics. **In the future, both scientists and politicians will have to accept fundamental bioethical principles to ensure the sustainable development of human society as well as essential protection of the nature.**

The importance of the above-mentioned "converging technologies" confirmed the foundation of Institute of Nanotechnology at University of Stirling, UK, in 1994, which was one of the world's first nanotechnology information providers [181]. This Institute cooperates closely with governments, universities, researchers, and companies worldwide on developing and promoting all aspects of nanotechnology and it also serves as a key organizer of international scientific events, conferences, and educational courses designed to encourage nanotechnology take up by industry. The last activity of this Institute was organization of the international conference entitled „Nano and microtechnologies in the food and healthfood industries" which was held in Amsterdam on October 25–26, 2006.

Conclusions

During the whole history plants provided not only food and natural medicines for human population but they also represented important energy sources for humans. For the future there are major challenges to prevent biodiversity, to exploit new phytotechnologies for remediation of contaminated environment, to use biofortification of plants with essential elements in the fight against malnutrition, to utilize healing potential of plants also by use of new biotechnologies, to secure sufficient and safe food for anybody as well as to focus increased attention on efficient exploitation of plants in production of environment-friendly biofuels. Thus, vigorous development and application of new biotechnologies in practice require more and more serious ethical appreciation. Moreover, it could not be omitted that plants are only living organisms that never disappoint us, their prettiness delight us every day, whether in happiness, gladness or sorrow.

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ROŚLINY DLA PRZYSZŁOŚCI

S t r e s z c z e n i e

Rośliny mają wyjątkowe znaczenie dla istnienia wszystkich organizmów heterotroficznych w tym i ludzi. Dla zrównoważonego rozwoju niezbędne jest powstrzymanie utraty bioróżnorodności związanej ze zmianami klimatycznymi i działalnością człowieka antropogenną W tym kontekście omawiano zmiany gatunkach roślin i ryzyko rozpowszechniania się inwazyjnych gatunków roślin. Opisano wykorzystanie roślin uprawnych i zielonego nawozu oraz wykorzystanie allelopatii w zintegrowanym systemie ochrony roślin w tym chwastów. W perspektywie zamierza się wykorzystywać rośliny do fitoremediacji (fitotechnologia polegająca na wykorzystaniu roślin do usuwania toksycznych metali i środków organicznych z zanieczyszczonego środowiska) oraz agronomicznej i genetycznej biofortyfikacji (wzbogacenie plonu w podstawie składniki odżywcze). Poświęcono także dużo uwagi tradycyjnemu i nie tradycyjnemu wykorzystywaniu roślin leczniczych, roślinnym środkom farmaceutycznym, antyutleniającym właściwościom roślin oraz interakcją pomiędzy preparatami ziołowymi a lekami syntetycznymi. Przeanalizowano szczegółowo koszty i zyski zastosowania technologii genowych w aspektach rosnącej odporności genetycznie modyfikowanych (GM) roślin na szkodniki i pestycydy, współistnienia w warunkach polowych roślin GM z nie modyfikowanymi, potencjalnego wpływu na mikrobiologię gleby, z uwzględnieniem jakości i bezpieczeństwa żywności. Wspomniano także o przyszłym wykorzystaniu roślin do produkcji biopaliw. Przedyskutowano podstawowe zasady bioetyczne, które muszą być spełnione podczas wykorzystywania biotechnologii roślin, zwłaszcza w powiązaniu z wpływem roślin GM na zdrowie człowieka lub potencjalnymi skutkami dla środowiska.

Słowa kluczowe: utrata bioróżnorodności, zmiany klimatyczne, fitotechnologie, roślinne środki farmaceutyczne, rośliny genetycznie zmodyfikowane, bezpieczna żywności, biopaliwa