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Agricultural practices, biology and quality of eggplant cultivated in Central Europe. A review

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Abstract

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The eggplant is a warm-climate crop of high economic importance. In many Asian and Mediterranean countries, eggplants are essential components of everyday dishes, while in Central Europe they have become popular only in recent years. Eggplants are harvested at an immature stage and have low storage value; therefore, the sale of fruits in local markets requires an appropriate production strategy. In Poland, consumer demand for eggplants is currently met by imports and domestic production, which, until recently, has been carried out only in greenhouses, ensuring the availability of fresh fruits but resulting in high selling prices. The demand for eggplants is growing among Polish consumers, and, accordingly, field production is expected to gradually gain in importance due to the fruit's profitability. Accordingly, the biology and farming practices of this warm-climate crop remain in the investigation phase in temperate climate. This review aims to report the status of current knowledge regarding the technologies affecting the biology, cultivation, and nutritional value of eggplant grown in temperate climatic zone.

Keywords: farming management; fruit quality; *Solanum melongena* L.; temperate climate

History and economic aspects of eggplant cultivation in Central Europe

The eggplant (*Solanum melongena* L.) is a fruit of major economic importance throughout the world, and is mainly grown in Asian subtropical regions (94% of world production), where its popularity has earned it the title of 'the king of vegetables'. According to the Food and Agriculture Organisation of the United Nations (FAO 2015), China and India are the world's largest eggplant producers (28 and 13 Mt per year, respectively). In Europe, the eggplant is cultivated mainly in Turkey (827,000 t), Italy (220,000 t), Spain (206,000 t) and Romania (123,000 t/year). Interestingly, eggplant cultivation has now also extended to more northern parts of Europe. The FAO (2015) has reported that both Ukraine (96,000 t in 2013) and Lithuania (2,000 t in 2013) now also grow this crop. However, there are still no data available for Poland and other neighbouring European countries, where this species is increasingly being grown in open fields and under unheated tunnels.

Eggplant is the most widely used English-language term for this species and dates from the time

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of British colonial rule in India, a period during which many eggplant varieties that give white egg-shaped fruits were imported into Europe. Interestingly, only in the United Kingdom did the name 'aubergine', derived from the French language, gain widespread use. The most popular name in India and Africa is 'brinjal', whose roots are in Sanskrit (Daunay, Janick 2007). The name 'eggplant' currently refers to three crops belonging to the genus *Solanum*, subgenus *Leptostemonum*, derived from the Old World: *Solanum melongena* L. (eggplant), *S. aethiopicum* L. (scarlet eggplant), and *S. macrocarpon* L. (Gboma eggplant). *Solanum aethiopicum* and *S. macrocarpon* are native to Africa, where they are grown locally for their edible fruits and young leaves (Lester 1998; Macha 2005; Sękara et al. 2007). The *S. melongena* complex exhibits a series of morphological intermediates, from small-fruited spiny plants to large-fruited non-spiny plants. Weese and Bohs (2010) used DNA sequence data to show that eggplants arose in Africa and were dispersed throughout the Middle East to other regions of Asia, where they have been cultivated and bred for 2,000 years (Wang et al. 2008). The long history of breeding resulted in a wide range of cultivars with edible fruits of different sizes, shapes and colours. The species was introduced to Europe during the twelfth century, when the Arabs initiated eggplant cultivation in the Iberian Peninsula (Daunay, Janick 2007). Later, this plant was introduced to Italy and France as well as to Poland during the fifteenth century, but it was initially grown for ornamental and medicinal purposes only. A number of ethnobotanical sources describe the first trials with eggplant cultivation and usage in Poland. Szymon Syrenius included this species in his well-known 'Zielnik Herbarzem Zwany' herbarium, printed in Krakow in 1613. Syrenius described this species using the name *Melongena* or *Mala insana*. He described the various methods of preparation of the eggplant (baked, fried in olive oil) but also attributed to it a long list of harmful effects (i.e., indigestion, ulcers, headache and bad mood) (Syrenius 1613). The horticultural and botanical literature from the eighteenth and nineteenth centuries mentions the eggplant as a fruit grown under an annual cycle for fruits that are either yellow or red at the stage of physiological ripeness. The Polish herbalist Krzysztof Kluk described the eggplant in his 'Dykcyonarz Roślinny' ('Plant Dictionary'), published in 1786. According to this author, the eggplant was grown in Poland as an annual crop from seed. The fruit was described to be egg-shaped, yellow or red, and intoxicating, but this was not confirmed by the author's own experience. Kluk noted that eggplant fruits were eaten as a salad component with vinaigrette or with vine and sugar (Kluk 1786). Until the end of the twentieth century, the eggplant did not enjoy popularity in Polish gardening and was described in the horticultural literature of that time as a warm-climate species with high temperature requirements.

In the 1960s, amateur Bulgarian cultivars of the eggplant were popularised in Poland by Doruchowski (1965), who recommended planting alternating fields of eggplant and corn as a windbreak in southern-facing locations. Research conducted on this species from the late 1980s onwards led to the development of cultivation guidelines for both cold greenhouses and heated tunnels, allowing consumers to benefit from the first-ever locally produced fruits. Technology that reduces the production costs of protected crops has increasingly been adapted to Polish horticulture in order to accelerate the production efficiency of, *inter alia*, nutrition, grafting methods and plant pruning systems. Currently in Poland, the eggplant is mostly grown under unheated plastic tunnels, which requires less energy in comparison to both greenhouses and heated tunnels. Increased interest in the cultivation and consumption of eggplants in Poland has led to studies on the farming practices of this species grown both in the greenhouse and under foil tunnels. Among recent reports, Kowalska (2003, 2008), Buczkowska (2010) and Michałojć and Buczkowska (2008, 2011, 2012) conducted comprehensive studies to develop farming technologies for growing eggplants under unheated tunnels and to expand the knowledge regarding the pollination biology of this species. Cebula (2003) and Ambroszczyk et al. (2007, 2008a, 2008b) developed optimal methods of eggplant pruning in greenhouse cultivation and specified the effects of pruning on vegetative plant growth as well as on fruit yield and quality. Markiewicz and Golcz (2007) and Markiewicz et al. (2008) evaluated the effects of thermal conditions, substrate type and plant nutritional status on eggplant yield. In recent years, breeding of hybrid cultivars resistant to environmental stresses in conjunction with air temperature increases have enabled field cultivation of eggplants in some regions of Poland

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and neighbouring countries and, accordingly, have lowered both production costs and fruit prices. Detailed recommendations for eggplant cultivation in the field are now available for the climatic conditions of Central Europe (Sękara 2010; Želísková, Jezdinský 2015).

Plant biology and environmental requirements

The eggplant (*S. melongena* L.) is a diploid species ($2n = 24$), and is cultivated as a vegetable that yields immature edible fruits. It is perennial but is typically grown as a frost-susceptible, warm-season annual. Plants are 0.4–1.5 m tall and branched, with large, broad leaves, and the stem is often spiny. The flowers are perfect, self-pollinating, purple or on rare occasion white, with a spiny calyx, five-lobed corolla and yellow stamens. Eggplant fruits are sometimes white or green in colour, but the most popular fruits exhibit different intensities of purple; fruits can be whitish to dark purple, even black or combinations of these colours in stripes. Physiologically ripe fruits are brown or yellow. The shape range includes spherical, oblong, ovoid, oval, long and many intermediate shapes. Fruits range from 4–45 cm in length, and 2–25 cm diameter. The mean fruit weight is in the range of 200–300 g. Newer Asian types have weights of 20–40 g (Swarup 1995; Hassan et al. 2015).

The eggplant is photoperiod neutral (Chen et al. 2002). Kürklü et al. (1998) recommended a temperature of 30°C for optimal vegetative growth and 22°C for reproductive phases based on the number and size of fruits produced. Pessarakli (1999) showed that damage caused by the 10–15°C temperature range may occur at any stage of eggplant growth and development. Eggplants can tolerate both slight drought and excessive rainfall, but high temperature and abundant rainfall promote the vegetative phase (Chen et al. 2002). Eggplants produce a strong root system in soil that is deep, fertile, well drained and high in organic matter with pH values of 5.5–6.8. High clay content and waterlogging should be avoided due to the build-up of root rot (Chen et al. 2002).

Climate and soil factors affect eggplant flowering and fruit set as well as the commercial production outcome. At the same time, flower morphology and functionality are dependent upon the ontogenetic development, which was described by Diggle (1997). Notably, the eggplant is characterised by flower heteromorphology, abundant flowering and frequent dropping of flowers or fruitlets. These phenomena are caused by different stresses, such as temperatures that are either excessive or too low, drought, light shortage or lack of pollination or fertilisation (Kikuchi et al. 2008). The heteromorphology of eggplant flowers which consists in pistil length diversity was described by Krishnamurthy and Subramaniam (1954), who distinguished long-style pistils with a large ovary, medium-styled pistils with a medium-sized ovary, and short-style pistils with a rudimentary ovary. Moreover, Chen (2001) reported that the short-style pistil flowers were not completely sterile, while in the medium- and long-pistil flowers the proximity of the stigma to anthers enhanced self-pollination; notably, pollen remained viable for 8–10 days at 20–22°C and a relative humidity of 50–55%. In hot and humid climates, fruits produced through cross-pollination can constitute up to 20% of yield (Chen 2001). The influence of genetic, agronomic, and environmental factors on phenotypic displays of heterostyly and flower fertility has been selectively reported in the literature. Passam and Khah (1992), Passam and Bolmatis (1997), and Kowalska (2003) stressed the genetic diversity of this phenomenon. According to Kowalska (2003), the flower set was more effective as a result of self-pollination and flower hormonisation as compared to pollination by bumble-bees. Regardless of the way of pollination and flower hormonisation, eggplants with long pistils yield the highest number of flowers, while those with medium and short pistils yield much fewer flowers. Based on experiments of eggplant cultivation under field conditions in southern Poland performed over a period of three years, Sękara (2010) suggested that heterostyly in this species represents a transition stage to andromonoecy, which physiologically prefers male flowers during periods when early-set fruits ripen. Sękara and Bieniasz (2008) investigated flower phenotype, fruit set, and seed number per fruit in the eggplant during the flowering period under field conditions in Poland. The authors did not observe any growth incompatibility in pollen tubes for any of the eggplant flower styles, though short-styled flowers were characterised by lower numbers of pollen tubes, fertilised ovules and seeds as a direct consequence of small-sized stigmas and spatial separation between

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anther pores and stigmas, which makes pollination difficult.

Genetic resources with emphasis on cultivation in temperate climatic zone

The number of eggplant cultivars has been expanded significantly as a result of intensive selection and breeding performed over the course of several hundred years. Cultivars with purple, oval fruits are commonly produced in Europe and the Americas, while in Southeast Asia there is a wide diversity of berry colours, shapes and sizes (Doganlar et al. 2002). Eggplant cultivars are conventionally grouped as 'Occidental', which are preferred in North Africa, Europe, and the Americas, and as 'Oriental' eggplants, which are grown in East and Southeast Asia (Cericola et al. 2013). Other desirable characteristics include high productivity, disease resistance, early maturity, fast growth habit and tolerance to environmental stresses (Chen et al. 2002). Global trade has focused on increasing the number of elite F_1 hybrids that are characterised by attractiveness for breeders, seed suppliers, and growers, owing to heterosis for fruit yield and quality (Ali et al. 2011; Cericola et al. 2013). Modern eggplant cultivars have been shown to have ecological plasticity, so it is possible to select the most favourable varieties of eggplant for growing in particular geographic areas. Poşta et al. (2012) successfully introduced four foreign genotypes to broaden the cultivation assortment in western Romania, and, according to them, the yield potential should be more than 30 t/ha for satisfactory economic profits. Notably, Sękara (2010) recommended the 'Epic' F_1 hybrid for field production in temperate climatic zone, as this cultivar achieved a mean marketable yield of 40 t/ha: the early production (first four harvests) accounted for 13.5% of the total yield and was represented by first- and second-class fruits (86% and 10%, respectively). Other authors (Markiewicz et al. 2008) had previously reported 40–50 t/ha average yield for 'Epic' F_1 and 'Solara' F_1 plants grown under unheated foil tunnels. Moreover, Adamczewska-Sowińska and Krygier (2013) showed that high temperature and sufficient rainfall significantly promoted eggplant development in field conditions in western Poland: 'Vernal' F_1, 'Epic' F_1, and 'Avan' F_1 plants yielded 19–24 t/ha, while 'Classic' F_1 and 'Black Beauty' plants yielded half as much. In other research (Adamczewska-Sowińska, Kołota 2010), marketable yields of field-cultivated eggplants fell within an 8–18 t/ha range. According to Donzella et al. (2000), the use of parthenocarpic eggplant cultivars (e.g., 'Talina', 'Galine') is a good cost-effective solution for improving fruit set and growth under environmental conditions not favourable for pollination. The advantages of parthenocarpy include efficient, marketable production of fruit under adverse temperatures; savings in energy, phytohormones, and labour costs during off-season and open-field cultivation; and enhancement of fruit quality (Acciarri et al. 2002). Moreover, seedless fruits have a consumable flesh which is larger in mass than that of seeded ones, so they are more attractive for consumers (Daunay 2008); however, the utility of natural parthenocarpic cultivars in cultivation in temperate climate needs further investigation.

Cultivation techniques and farming practices to improve eggplant yield and quality

Seedling production. An eggplant crop is usually started by growing seedlings in polystyrene alveolar containers in greenhouses filled with peat; these seedlings are then transplanted into the field (Sękara 2010). The optimum temperature for seed germination is 24–29°C (Chen et al. 2002), and the use of multi-pot alveolar containers allows for both nursery mechanisation and the maintenance of root integrity during transplantation of seedlings to the field. Seedling stage is a critical consideration in the vegetable production chain, and seedling quality and vigour are fundamental requisites for future plant performance in the field. Commercially produced eggplant seedlings should be genetically and morphologically uniform, visually attractive and healthy, with high physiological potential and resistance to stressful storage, transport and transplanting conditions (Costa et al. 2013). However, large-scale seedling production requires short-term storage to maintain the quality needed for supply continuity. Kubota et al. (2002) recommended a temperature of 9°C and 5 μmol/m^2/s photosynthetic photon flux for 24 h as the best storage conditions for eggplant seedlings. As for the best acclimatisation to stressful field conditions, De Grazia et al. (2008) proposed

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a reduction of nitrogen fertilisation, Bozokalfa (2008) proposed irrigation with low-temperature water, Faltenovich and Welbaum (2008) the use of mechanical stress, and Sękara et al. (2015) the treatment of germinated eggplant seedlings with various abiotic stressors in order to induce stress memory, improving the low temperature tolerance.

Production timing. Eggplants need a long growing season of about 120 days for successful production (Chen et al. 2002). As in temperate climatic zone, the favourable season for field-grown eggplant development is short; seedling production in greenhouse nurseries should start by the end of February/beginning of March in order to prolong the crop cycle. Advanced-age seedling plugs (9–10 weeks after sowing) should be set in the field after the last frost (about May 15) to minimise the risk of frost damage occurring below the –0.1°C critical temperature (Potop et al. 2014). Such production timing was described to contribute to significant yield increase, because plants entered the generative phase faster, and the fruiting period was long enough to obtain early and high yields (Sękara 2010). Standard acclimation to stressful external conditions, which is reached by subjecting seedlings to a hardening off process, is sufficient to mitigate the negative effects of low temperature after transplanting into the field. The length of the cultivation period is limited by the first autumn air frost, though the final fruits are collected in early October due to the ripeness delay caused by decreasing photoperiod and temperature. An analysis of field-grown eggplant production in Poland provides evidence that the above-mentioned timing of seedling production and transplanting guarantees stable yields, comparable to those obtained under unheated tunnels (Sękara 2010).

Microclimate modifications and mulching. Some common farming practices have been recommended to improve the microclimatic conditions for field-grown eggplants. Using sweet corn as a wind barrier to shelter eggplant fields led to temperature and humidity changes; although the mean temperature did not increase, the daily and night temperature fluctuations were reduced (Sękara 2010). Moreover, such climate modifications resulted in better prediction of either the flowering or the fruiting phase and, accordingly, of the berry harvest. Adamczewska-Sowińska and Kołota (2010) assessed the possibility of eggplant cultivation in field conditions in south-western Poland with the use of living and synthetic mulches: black foil provided the best results, but white clover intercropped with eggplant also resulted in significantly increased yield in comparison to the controls. Waterer (2010) evaluated biodegradable mulch applications in warm-season vegetable crops, including the eggplant. The clear and wavelength-selective mulch types typically produced beneficial effects on yield through enhancement of soil temperature, especially early in the growing season. Waterer (2010) also reported incomplete pollination in plants grown on biodegradable mulches, causing abnormalities in eggplant fruit shape. Moreover, the foil broke down too quickly, leaving the crop unprotected and requiring considerable amounts of additional hand weeding. The concept of degradable mulch is attractive, but some problems associated with its use in eggplant cultivation need further investigation and elucidation.

Plant density and pruning. Optimum spacing and proper pruning increase yield substantially and improve fruit quality in the eggplant (Pessarakli, Dris 2003). The eggplant is characterised by strong vegetative growth; thus, the recommended spacing in field cultivation is two plants per square metre for non-pruned plants. Pruning and staking are not applied for managing plant development in Poland, although they are typically applied for plants under tunnels and greenhouses. Pruning enhances either fruit colour or quality, and usually 3–4 branches per plant are maintained. Buczkowska (2010) demonstrated the positive effect of eggplant pruning that leaves 2–4 branches per plant on yield quantity and earliness; however, single topping performed after the first fruit harvest did not affect marketable yield under unheated tunnels. Additionally, Michałojć and Buczkowska (2012) reported that improving light conditions in the plant profile by pruning increased leaf phosphorus and calcium contents in eggplant. More research is needed to identify the proper balance between plant density range and pruning to allow for intensification of eggplant field production.

Fertilisation and plant protection. Eggplant development is affected by nutrient availability, especially that of nitrogen and phosphorus. Fertiliser rates depend mainly on soil fertility and texture as well as on plant requirements, and in this respect a soil analysis is strongly recommended. In sandy loam soils at the Asian Vegetable Research and Development Centre, typical fertiliser rates for

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eggplant are 170 kg/ha nitrogen, 70 kg/ha phosphorus pentoxide (P_2O_5) and 180 kg/ha potassium oxide (K_2O) (Chen et al. 2002). The crop showed different reactions to fertiliser applications of 75–300 kg/ha nitrogen, 30–224 kg/ha phosphorus, and up to 80 kg/ha potassium, depending on the agro-climatic conditions (Sharma, Brar 2008). Prabhu et al. (2006) studied the effects of different nitrogen and phosphorus application rates on eggplant cultivation and found that the crop yield per hectare was raised significantly by increasing nitrogen and phosphorus doses to 200 and 100 kg/ha of nitrogen and phosphorus, respectively. Adamczewska-Sowińska and Krygier (2008) found that eggplant fruit chemical composition did not depend on nitrogen fertilisation method; fruit nitrate accumulation was determined solely by nitrogen dose increases from 100 to 150 and to 200 kg/ha. Furthermore, extra nitrogen fertilisation caused shoot/root mineral ratio modifications, soil mycorrhizal induction disturbances, reductions in root activity, nutrient imbalances and delays in flowering (Aminifard et al. 2010). This study also showed that application of low amounts of nitrogen (50–100 kg/ha) is to be recommended for eggplant production and should be implemented by growers. According to Kamili et al. (2002), the application of *Azotobacter* and *Azospirillum* microbial inoculants can result in 25% chemical nitrogen savings without affecting eggplant yield. Moreover, the effectiveness of sulphur application in increasing macro- and micronutrient uptake, plant growth and total fruit yield was underlined by Abdel-Mouty et al. (2011). Based on the results of these investigations, and depending on the farming practices used and the environmental conditions, it is recommended to follow proper fertiliser guidelines with high-yielding F_1 hybrids.

Organic manures, biofertilisers, micronutrients and biostimulants have been reported to improved eggplant productivity. Notably, in recent years many assessments have been performed on crop development, yield and quality as affected by biostimulants, the latter exhibiting environmentally friendly features that fit well with sustainable and ecological agriculture. Majkowska-Gadomska and Wierzbicka (2013) reported that application of the synthetic biostimulant Asahi SL significantly decreased total nitrogen but increased potassium and copper contents in two eggplant cultivars grown under unheated tunnels in northern Poland. Because of the intensive development of the biostimulant market and of biostimulant utilisation in horticulture, such techniques can be applied successfully also to eggplants grown in the open field in order to improve plant viability and stress tolerance.

The eggplant grows slowly and cannot compete with aggressive weeds; it is also sensitive to damaging insects and diseases. In this respect, black plastic mulching effectively controls weeds and reduces the need for labour, and natural organic mulch is also recommended to preserve moisture and add organic matter to the soil. The effectiveness of chemical weed control varies, mainly depending on weed species present, soil type, and air and soil temperatures at time of application (Chen et al. 2002). Eggplant diseases and pests were described in detail by Daunay (2008). In temperate climatic zone, the eggplant is infected by several diseases, in particular, fusarium wilt and verticillium wilt. Szwejda and Rogowska (2011) described phytophagous entomofauna occurring on eggplant crops in Poland and noted *Thrips tabaci* Lind., *Myzus persicae* Sulz. and *Leptinotarsa decemlineata* Say as species spread throughout all regions that can potentially cause significant economic losses. There are many reports on modern, ecologically friendly techniques for disease and pest control, which can be recommended for eggplant cultivation in temperate climates as either alternative or supplementary to chemical control. The main recommended management methods against the wilts include crop rotation, resistant varieties, solarisation, soil chemical disinfection, and fungicides (Yucel et al. 2007). The application of select soil amendments (i.e., poultry waste, coco-dust, vermicompost, ash, sawdust, *Trichoderma harzianum* T22) could be an eco-friendly approach, and their use may be advised to farmers for both wilt disease prevention and to maximise the profitability of eggplant production (Faruq et al. 2014).

Increased eggplant resistance to pathogens is typically achieved by grafting, which was first performed commercially in the 1950s in Japan (Kubota et al. 2008). Currently, grafted transplants account for 65% and 75% of total eggplant production in France and the Netherlands, respectively (Lee et al. 2010). Moncada et al. (2013) reported that grafting onto *Solanum torvum* improved the fruit colour in four eggplant cultivars but decreased the total phenolic content. Grafting 'Tsakoniki' eggplant

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onto *S. torvum* and *S. sisymbriifolium* decreased flesh firmness and vitamin C content (Arvanitoyannis et al. 2005). Interspecific hybrids represent an alternative to the commonly used *S. torvum* Sw rootstock, which is a wild species with irregular germination. Gisbert et al. (2011) demonstrated that grafting eggplant onto interspecific hybrids, especially onto *S. incanum* × *S. melongena* hybrids, proved advantageous for eggplant production, as the high vigour and good compatibility of the rootstock with scion resulted in earlier and higher yield with no negative effects on fruit organoleptic qualities or composition. Grafting eggplant onto disease-resistant rootstocks, such as the 'Beaufort' interspecific tomato hybrid (*S. lycopersicum* × *S. habrochaites*), may be an effective strategy for managing verticillium wilt (Johnson et al. 2014). There are conflicting reports concerning the effect of grafting on different parameters associated with plant stress susceptibility, growth and yield. According to Fallik and Ilic (2014), rootstock/scion combinations need to be selected carefully for specific climatic and geographic conditions. Commercially available rootstocks have been selected especially for disease resistance and vigour, so breeding programmes are needed in order to identify suitable combinations that result in high fruit quality attributes under various growing conditions.

Fruit storability and browning. Eggplant fruits can be harvested at a range of immature stages before full seed development, depending on market requirements. In traditional distribution channels, fruits are harvested mostly at intermediate developmental phases, and 'baby' eggplants are increasingly in demand with consumers (Zaro et al. 2014). Regardless of developmental phase, eggplant fruits have a short shelf life; therefore, the development of production methods needs to be tailored to local markets.

The protopectin fraction is responsible for maintaining eggplant fruit texture, and its content increases until the physiological maturity stage, after which it drops, causing fruit softening. This occurs due to the hydrolytic decomposition of protopectin to soluble pectins, the latter being more representative in ripening fruits (Esteban et al. 1993); however, fruit quality and shelf life are also determined by the wax layer covering the skin (Bauer et al. 2005). With respect to fruiting management, late harvesting increases yield leading to soft fruits that exhibit lower respiration rates but which maintain quality for longer when stored at 10°C; in contrast, 'baby' eggplants performed better at a storage temperature of 0°C (Zaro et al. 2014). Short fruit shelf life and sensitivity to transport limit eggplant use for the processing industry and reduce fruit attractiveness to fresh vegetable markets. In fact, fruit enzymatic browning occurs following mechanical trauma or the temperature stress to which the berries are subjected at temperatures of below 10°C (Concellon et al. 2004; Zubini et al. 2005). This phenomenon is, in turn, caused by the enzymatic hydroxylation and oxidation of phenols to quinones, catalysed by polyphenol oxidase in the presence of molecular oxygen. In fresh eggplant fruits, browning was found to be dependent on both phenolic content and polyphenol oxidase-specific activity, whereas total phenolic content played a major role in stored fruit browning (Mishra et al. 2013). Gramazio et al. (2013) demonstrated that selection of eggplant varieties with high chlorogenic acid content and low browning is feasible. This enables evaluation of genetic eggplant resources with increased added value, i.e., those that harbour significant pro-health phenolic content and exhibit reduced browning susceptibility.

Eggplant as a functional food

Against the background of raw vegetables and their by-products, eggplant is distinguished by flavour, taste and dietary value as well as by fruit and plant decorativeness. Raigón et al. (2008) reported the quantities of phenolics and mineral salts that eggplant provides for the human diet. The global mean values were the following (in mg/100 g fresh weight (FW): 48.26 phenolics, 26.6 phosphorus, 198.5 potassium, and 0.062 copper. Moreover, landraces exhibited higher contents of phenolics (16.4%), phosphorus (34.6%) and zinc (30.0%) compared to commercial varieties. Eggplant field cultivation in temperate climatic zone makes it possible to obtain high biological fruit values, including 7.62 g/100 g FW dry weight (DW), high insoluble fibre content (0.97 g/100 g FW) and the following chemical element contents (in mg/100 g FW): 227.0 potassium, 20.2 phosphorus, 20.6 calcium, 12.1 magnesium, 0.44 iron, 0.11 manganese, 0.10 copper and 0.23 zinc (Sękara 2010). In this respect, Adamczewska-Sowińska and Krygier (2013) reported no significant differences in the chemical composition of five eggplant

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cultivars grown in open-field conditions in western Poland: 9.62 g/100 g FW DW, 2.51 mg/100 g FW reducing sugars, 5.54 mg/100 g FW L-ascorbic acid, and, in terms of mineral elements (in g/100 g DW), 0.28 phosphorus, 3.70 potassium, 0.18 magnesium, and 0.13 calcium. Želisková and Jezdinský (2015) determined the chemical composition of six eggplant cultivars in the Czech Republic and noted contents of 6.8–9.4 g/100 g FW DW, 0.5 to 3.7 mg/100 g FW L-ascorbic acid and 11.6 to 17.8 g/100 g DW insoluble fibre. These values are comparable to those of eggplants grown in warmer climates, in the open field or under heated greenhouses (Ambroszczyk et al. 2008b; Raigón et al. 2008).

The importance of eggplant as an antioxidant source lies in the fruit's relatively high content of these substances, which is comparable to that of many berry species consumed around the world. Delphinidin and nasunin were identified as the anthocyanins contained in eggplant skin with the greatest antioxidant potential (Sadilova et al. 2006). Anthocyanin content was found to decrease during fruit ripening and storage (Gajewski et al. 2006), and eggplant fruit antioxidant properties are also associated with high phenolic acid contents (Hanson et al. 2006; Prohens et al. 2008), especially N-caffeoylputrescine, 5-caffeoylquinic acid and 3-acetyl-5-caffeoylquinic acid (Kowalski, Kowalska 2005; Luthria et al. 2010). Luthria et al. (2010) evaluated the influence of organic and conventional farming practices on total phenolic contents in two eggplant cultivars, 'Blackbell' (American eggplant) and 'Millionaire' (Japanese eggplant). The authors showed plant-to-plant variation in phenolic content and concluded that multiple repetitive analyses of plant products collected from different cultivars, grown during various seasonal times at particular locations, should prove unambiguously the impact of growing conditions on phenolic content or antioxidant activity. Fruit colour and maturity stage at harvest also influence the bioactive compound contents: 'baby' eggplants exhibited higher antioxidant capacity and higher concentrations of chlorogenic acid, carotenoids and ascorbic acid than late-harvested fruits (Zaro et al. 2014). Moreover, Tateyama and Iragashi (2006) suggested that the antioxidant activity of fruit extracts collected from multi-coloured eggplant varieties depends mainly on the chlorogenic acid content. Several classes of bioactive eggplant compounds, including anthocyanidins, flavonoids, steroid saponosides (melongosides) and glyco-alkaloids (primarily solasonine and the main nitrogenic aglycone, solasodine) are responsible for the reported antioxidant, anti-carcinogenic, anti-inflammatory, anti-obesity, cardioprotective, neuroprotective and analgesic effects of the fruit (Daunay 2008; Friedman 2015). Moreover, solasonine and melongosides are the compounds responsible for the bitter taste of the fruits, the intensity of which depends mainly on cultivar, with important additional contributions from cultivation and harvest methods (Daunay 2008). Eggplant fruit crude extract may be effective for long-term treatment of asthma (Bello et al. 2005), atherosclerosis (Han et al. 2003) and hyperlipidaemia (Odetola et al. 2004), and for inhibition of the development of blood vessels that feed tumour tissue (Matsubara et al. 2005). Due to these health benefits, eggplant is considered a model for vegetable quality improvement (Gramazio et al. 2013; Plazas et al. 2013). The National Diabetes Education Programme, led by both the National Institutes of Health, USA, and the American Diabetes Association (ADA), recommend eggplant as a component of the diet for individuals with type 2 diabetes (NIH 2008; ADA, 2015).

CONCLUSION

The increase of vegetable species/cultivar biodiversity in the agroecosystems of Central Europe has the potential to lead to remarkable profits. The eggplant exhibits high biological plasticity, predisposing it for cultivation in the stressful conditions of temperate climatic zone. The introduction of this species into the spectrum of field-grown vegetables at high latitudes is made possible by the availability of F_1 hybrids that are tolerant to stress conditions and exhibit high yield potential as well as phenotypic stability. Many modern farming techniques can be applied to the eggplant in order to improve the final effects on both field production and biological value. In this review, we discussed the historical background of eggplant cultivation in Poland, and described the state of the art with respect to growing practices for field crop management. We also outlined those genetic resources and worldwide technological trends for the species which could potentially be applied for cultivation in temperate climatic zone. Currently, the main topic deserving further investigation is the detailed medium-term schedul-

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ing of each cropping aspect, such as fertilisation and plant protection. However, the growing practices used in unheated tunnels can be adapted for field cultivation of particular cultivars. The development of accurate guidelines for eggplant field cultivation in temperate climatic zone will be beneficial for both growers and consumers.

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