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REVIEW

The agricultural and therapeutic potential of *Lavatera thuringiaca* L. (Malvaceae)

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Abstract

One of the poorly recognized plant species well adapted to cultivation in temperate climate conditions is *Lavatera thuringiaca* L. It is a common species in Europe, but so far has not found much economic use. Few literature data report its high production potential, favorable chemical composition of biomass, resistance to adverse stress conditions, and medicinal properties. The biomass can be used for fodder and energy purposes and as forage for bees and other pollinators. *L. thuringiaca* can also be useful for the management of fallow soils or marginal land and for the reclamation of contaminated land. In turn, the presence of biologically active compounds offers opportunities for its use in medicine. Wider diversification of cultivated species is a key to ensuring food security and economic sustainability, especially in view of the observed climate change. In this context, an extensive review of literature dealing with taxonomic studies, morphological diversity and biological properties of *L. thuringiaca*, and the potential for multipurpose use of this species has been carried out.

Keywords

Thuringian mallow; Malvaceae family; energy biomass; fodder crop; phytochemical constituents

1. Introduction

Plant species that can be economically exploited and therefore have high productivity, make efficient use of solar radiation, have low habitat-agrotechnical requirements, and show high resistance to adverse environmental conditions deserve special attention (Sumi et al., 2022). Furthermore, a greater diversity of cultivated species is a key to ensuring food security and economic sustainability, especially in the face of the ongoing climate change (Dzida et al., 2023; Wongła et al., 2023). Increasing biodiversity prevents agroecological imbalances and reduces the spread of pests that move easily and are difficult to control, especially in large areas of agricultural monocultures (Tyburski & Kostrzewska, 2013). Increasing crop diversity is also important for the conservation of biodiversity in agricultural ecosystems and for the sustainable use of biological resources ensuring sustainable economic development. This indicates the need for research into the possibilities of introducing new or little-known plant species into cultivation (Tylkowski & Grupa, 2008).

Lavatera thuringiaca L. (Thuringian mallow) is a little-known endemic species, although it is commonly found in the wild in central European countries and southern Scandinavia (Celka et al., 2013; Ray, 1995; Szafer et al., 1996). So far, there

has been little interest in the cultivation of this species despite the possibility of its multi-directional use in many areas of economy and its capability of growing in adverse environmental conditions. This perennial plant adapts well to different environmental conditions, has low water demands, and is frost-resistant. According to different authors, it can be cultivated as a perennial plant suitable for production of high-performance energy biomass (Romanowska-Duda et al., 2014; Staszewski et al., 2008), a supplement for plant feed for ruminants (Staszewska, 1997), a raw material for the pharmaceutical industry (Matławska et al., 1999; Vadivel et al., 2016; Vysochina et al., 2011), a honey plant for bees to be cultivated on wastelands and uncultivated fields (Staszewski & Staszewski, 2014), an ecological plant to be sown on roadsides and used in recultivation of degraded land (Klimont et al., 2013), a high-value ornamental plant to be grown in gardens and parks on dry soils (Staszewska, 1997), and as a food crop, in the production of pigments, and raw material in the production of strings and ropes (Celka et al., 2013).

The literature on *L. thuringiaca* consists mainly of natural history publications on the botany and occurrence of the species in different regions and habitats, while reports on the economic use of the species are sporadic, scattered, and fragmentary. The collected material was organized and collated in the article to present the characterization of this species in terms of its biological, biochemical, and genetic properties and potential for economic use. The literature review was based on data collected mainly from Google Scholar, Web of Science, and ScienceDirect databases and older Polish research results. The gathered literature covered original research articles, reviews, book chapters and, in a few cases, conference proceedings.

2. Botanical characteristics

A total of 25 different species of *Lavatera* can be found in the *Malvaceae* family, with the majority of growing in Mediterranean climates (Zhandabayeva et al., 2021). *L. thuringiaca* is a species of the *Lavatera* family (*Malvaceae*) naturally occurring in the Adriatic Sea zone to central Siberia, through central Europe, and southern Scandinavia (Celka et al., 2013; Ray, 1995; Revenga et al., 2000).

L. thuringiaca plants generally reach a height of 80–150 cm but can grow up to 220 cm in favorable environmental conditions (Figure 1). The stems are thick, stiff, erect, and profusely leafy, protecting the canopy from lodging and guaranteeing a stable yield. After mowing, numerous new well-leaved stems emerge to enable the second crop to be harvested (Figure 2). In the second and subsequent growing years, the plants produce a massive short stem, from which thick, white, fleshy roots covered by a light grey skin emerge. A single crown can produce more than 20 main shoots (Figure 3), on which numerous 1st and 2nd order branches emerge. The intensity of tillering is negatively correlated with the density of plants per unit area (Staszewski & Staszewska,



Figure 1 *Lavatera thuringiaca* plantation in the flowering stage (photo: Z. Staszewski).



Figure 2 Single- and double-cut *Lavatera thuringiaca* harvest (photo: Z. Staszewski).



Figure 3 Branching of a single plant of *Lavatera thuringiaca* in the second year of vegetation (photo: Z. Staszewski).

1994). The taproot system is strongly developed and goes deep. The leaves are palmate and, like the stem, covered by hairs on the underside.

L. thuringiaca is a self-pollinating plant producing a large number of hermaphroditic pale pink flowers 5–8 cm in diameter with darker veins. They are borne singly at the angles of the leaves on the main stem and numerous branches, and each produces a fruit (schizocarp) containing about 20 seeds. The phenomenon of precociousness in flower development is characteristic here: the anthers, gathered in a whorl, are the first to mature, while the pistil grows among them a little later and is fertilized with its own pollen before the arrival of insects (Staszewska & Jabłoński, 1998). This phenomenon does not reduce insect abundance. The bud setting and flowering period in *L. thuringiaca* is relatively long, lasting from mid-June to early September, with most flowers produced in July. The seeds are kidney-shaped, smooth, grey to dark brown with an TSW of 3.6 g (Staszewski & Staszewska, 1994). Thanks to the self-pollination of the plants, the seed production of *L. thuringiaca* is very efficient. A single plant may produce up to 41,000 seeds per year (the individuals in question produced on average 3,200 seeds per year) (Celka et al., 2013). Depending on the planting density, 300 to even 600 kg of seeds can be obtained from 1 ha of plantation (Staszewski & Staszewska, 1994). The seeds contain about 18% of oil with dominant linolenic acid, which can be used in the production of medicines and cosmetics.

In the first year, the plants grow half the size but flower and set seed. In later years, shoot buds emerge at the beginning of spring; their vigorous growth begins in May



Figure 4 Germinated *Lavatera thuringiaca* seeds (photo: Z. Staszewski).

and continues until the end of flowering. In the second and third growing years, *L. thuringiaca* can yield 22.7–27.1 tonnes of dry matter per hectare. It yields better than e.g., *Helianthus annuus* L. (15.6–16.1 tonnes of dry matter per 1 ha) (Staszewski & Staszewska, 1994).

An advantage of this plant is the efficient production of seeds, which unfortunately have a low germination capacity in natural growing conditions caused by the high proportion of hard seeds that do not swell, because the seed coat does not allow water to pass through. The proportion of hard seeds in the total seed pool of *L. thuringiaca* harvested in different years can be up to 80–90% (Grzesik et al., 2015; Pawlat et al., 2017). A common treatment to facilitate hard seed germination is scarification, which involves damaging the seed coat and causing them to swell when water is available (Figure 4). A study conducted by Grzesik et al. (2015) indicated the possibility of increasing the germination of *L. thuringiaca* seeds up to over 40% with mechanical scarification (rubbing the seeds between sandpaper) and up to 85% after exposure to sulfuric acid. In order to improve the seed quality, physical factors such as electric, laser, and magnetic fields or plasma are also used. Studies found that the exposure of *L. thuringiaca* seeds to He-Ne laser light had a beneficial effect on field emergence capacity and biometric characteristics (Budzeń et al., 2015), seed germination (Budzeń et al., 2018), and the chemical composition of biomass ash (Budzeń et al., 2023). Pawlat et al. (2017) proved that pre-sowing plasma stimulation of seeds improved germination parameters, such as germination capacity and germination energy. In turn, Kornarzyński et al. (2015) showed a positive effect of an alternating electric field and magnetically treated water on the germination of parental and second-generation *Lavatera* seeds.

L. thuringiaca is adapted to grow on poor sites. It is characterized by high durability, frost hardiness, and competitiveness with other plant species. It tolerates drought conditions but does not tolerate excessive soil moisture and flooding (Vazquez-Thello et al., 1995). In the wild, it is often found on dry hillsides, scrub, and roadsides. According to the breeder (Staszewski & Staszewska, 1994), the cultivation technology of *L. thuringiaca* is easy and low-cost. Establishing a plantation requires careful cultivation because *L. thuringiaca* has small seeds and is exposed to competition from weeds during the initial growth period. It grows well on various types of soil. The best forecrops are fodder and root or industrial plants, but they can also be cereals. The seeds are sown with a grain seeder to a depth of 1–2 cm, and the sowing density and row spacing depend on the direction of use of the plantation. When growing for seeds and bee nectar, a population density of approx. 20 plants per 1 m² is used, maintaining a row spacing of 30–60 cm, for the production of energy biomass the recommended density is 30–40 plants per 1 m² with a row spacing of approx. 30 cm, and for the production of green fodder or for sowing fallow lands, it is recommended to have approximately 40 plants per 1 m² in rows every 20–40 cm. Sowing should be done in early spring, because the plant requires a lot of moisture for good germination.

L. thuringiaca requires protection against weeds in the initial period after sowing, but when the plants grow and develop well, their competitiveness in the field increases very quickly. It is quite resistant to diseases and pests and generally does not require protection. Its fertilizer needs are similar to those of *Althaea rosea* Cav. (kg ha⁻¹): N – 60–80, P – 60–90, K – 100–120. Harvesting should begin when the seeds grow to their maximum size and turn yellow and even slightly brown. Harvesting is carried out in one phase, using a combine harvester. Delaying the harvest too much causes large losses when the seeds scatter. The *Lavatera* plantation is used for approximately 5 years or longer (Staszewski & Staszewska, 1994).

3. Raw material for energy purposes

All EU member states are committed to reducing greenhouse gas emissions mainly by replacing traditional transport fuels with biofuels and coal with biomass (Hoogwijk et al., 2009). Every tonne of biomass used in energy production reduces air pollution by 1.5 t of carbon dioxide that was taken up in photosynthesis to produce it. This is because biomass is a renewable fuel, and this means that the CO₂ released during the biomass combustion process is taken up by other plants and converted into new biomass (Yemshanov & McKenney, 2008). Growing energy crops on agricultural land is seen as one of the most important potential sources of biomass (Rosenqvist & Dawson, 2005). In addition, compared to conventional agricultural crops, energy crop plantations have a better energy and carbon balance, higher soil carbon sequestration, less nitrogen leaching, better phytoremediation properties, and similar or higher plant, invertebrate, and bird biodiversity.

Plants used for energy crops should be characterized by efficient conversion of solar radiation into biomass and large annual growth under minimal habitat requirements and good adaptation to the climate conditions. As a perennial crop, *L. thuringiaca* can be cultivated for energy purposes, as it produces a relatively high biomass yield in different environmental conditions and affects the structure and fertility of the soil (Romanowska-Duda et al., 2014). Depending on the habitat conditions and the level of fertilization, *L. thuringiaca* harvested once a year yields 15–25 t ha⁻¹, and when harvested twice, the yield is higher at 23.0–27.0 t ha⁻¹ (Staszewski et al., 2008; Staszewski & Staszewski, 2014), which is a good result, compared to other popular energy crops such as (t ha⁻¹) *Salix* spp. (13.0–18.0 in an annual cycle, 19.0–22.8 in a 3-year cycle) (Matyka, 2013; Szczukowski, 2012), *Sida hermaphrodita* (L.) Rusby 8.2–18.5 (Majtkowski et al., 2010; Matyka, 2013), or *Miscanthus* ssp. 21.0–29.9 (Kotecki, 2010; Matyka, 2013). The biomass has comparable energy parameters (calorific value, C, H, N, S, fixed carbon, volatile matter and ash content) to typical energy crops, e.g., *S. hermaphrodita*, *Miscanthus*, *Helianthus tuberosus* L., or *Salix viminalis* L. (Budzeń et al., 2021). As shown by Budzeń et al. (2016, 2021), the application of pre-sowing He–Ne laser light stimulation influences the energy parameters of *L. thuringiaca* biomass, namely it increased the heat of combustion and the calorific value of the grown shoots. Besides, an innovative method for improvement of the chemical composition of *L. thuringiaca* biomass ash was presented by these authors (Budzeń et al., 2023). They determined the effect of pre-sowing seed stimulation with He–Ne laser light on the chemical composition (P, S, K, Ca, Mn, Fe, Ni, Cu, and Zn content) of ash. It was shown that the pre-sowing application of He–Ne laser light, depending on the stimulation time, intensified the content of preferred macro- and micronutrient groups in *L. thuringiaca* ash, allowing it to be used more effectively in agriculture as a substitute for commercial fertilizers.

The wood of *L. thuringiaca* is chemically similar to that of deciduous trees and the ash content (6.5–7.0%) is similar to that in cereal straw. The calorific value is 14,218 kJ/kg at moisture content of 8.33%, while the ash and sulfur contents are 3.90 and 0.28%, respectively, which qualifies this species as a valuable energy crop (Staszewski et al., 2008). The advantage of *L. thuringiaca* is the low cost of establishing a plantation, compared to other common crops, and the plantation establishment requirement is a few kg of seed per ha. For the cultivation of this species, machinery designed for cereals and oilseed rape is sufficient, so that the farmer does not have to incur costs associated with investing in additional equipment. A plantation of *L. thuringiaca* can be maintained for five years or even longer, given the easy seed dispersal and self-

Table 1 Chemical content of green fodder and silage (Staszewska, 1997).

Treatment	Dry mass [%]	Ash [%]	Crude protein [%]	NDF [%]	ADF [%]
Green mass of <i>L. thuringiaca</i>	20.6	18.8	20.7	19.3	13.0
Silage of <i>L. thuringiaca</i>	20.6	19.8	23.7	19.2	14.7
Silage of <i>L. thuringiaca</i> 50% + <i>Dactylis glomerata</i> 50%	22.2	17.6	24.8	32.8	19.8
Silage of <i>L. thuringiaca</i> 50% + <i>Medicago sativa</i> 50%	22.4	15.3	28.5	20.5	15.7
Silage of <i>L. thuringiaca</i> 50% + <i>Helianthus tuberosus</i> 50%	24.9	16.9	15.6	20.5	18.0

sowing of this plant, which renews the plantation. The *L. thuringiaca* biomass crop can be burned directly in a domestic furnace.

4. Fodder crop for livestock

Research conducted by Staszewska (1997) showed that *L. thuringiaca* can be used for fodder purposes. Biomass harvested several times (3–4) per year (except for the year of sowing) yielded 10.0–15.0 t of dry matter per hectare, providing forage with high content of protein and water-soluble sugars. The dry matter content of the crop was around 21–25%. The crude protein content in *L. thuringiaca* green forage and silage was 20.7 and 23.7%, respectively, and the NDF (neutral detergent fiber) and ADF (acid detergent fiber) fractions were 19.3, 19.2% and 13.0, 14.7%, respectively (Table 1). The silage was characterized by good indices of biological value and protein utilization by animals, and the nutrient digestibility coefficients (except for crude fiber) were similar to those of other forages of this type. This species can also be ensiled with other forage crops. The study showed that the addition of *Dactylis glomerata* L. slightly increased the protein value of the silage (by about 4%) and significantly increased the fiber fraction of NDF (by 41%). Ensiling with *Medicago sativa* L. increased the protein content (by 17%) and only slightly the NDF content (by 6%). In contrast, silage with *H. tuberosus* had significantly lower protein content (by 52%) and slightly higher NDF content (by 6%). All silages had adequate color, texture, odor, and biological value (Staszewska, 1997).

To date, there has been little interest in *L. thuringiaca* as a forage crop, but there is now more interest in introducing new crop species, in particular those with low soil and water requirements, especially on extensive farms with a high proportion of light soils.

5. Forage plant for honey bees

L. thuringiaca is a good melliferous plant, as it provides nectar to bees over a period of 4–6 weeks. Abundant flowering lasts for about 30 days and flowers persist for about 6 weeks on the tops of the stems (Staszewski & Staszewska, 1994). The flowers are visited mainly by honey bees and, to a lesser extent, by bumblebees. Pollinators only collect nectar, because they cannot form pollen baskets from very large pollen grains visible to the naked eye (Kołtowski, 2015). The frequency of honey bees visiting the flowers is very high because the nectar of *L. thuringiaca* is of good quality and contains a lot of sugar. During the day, it secretes up to 4.8 g of nectar per flower (Iriondo & Pérez, 1996). In terms of honey yield, it can be compared to buckwheat (150–200 kg of honey per hectare) but is more reliable than buckwheat because it produces nectar even in dry weather due to the fact that its nectaries are sheltered (Staszewska & Jabłoński, 1998). *L. thuringiaca* honey is characterized by its light color, pleasant aroma, and exquisite taste. It contains 82.0% of reducing sugars, 2.2% of sucrose, and 17.7% of water (Table 2). Besides biomass, honey harvesting is an additional benefit that can increase the value of *L. thuringiaca* production.

Jabłoński (2000) reports on the advisability of establishing the so-called bee pastures by sowing perennial species of melliferous plants that provide “bee nectars” on fallow

Table 2 Parameters of *Lavatera thuringiaca* honey (Staszewska, 1997).

Indicator	Unit	Content
Water	%	17.70
Carbohydrates	%	81.92
Saccharose	%	2.18
Acidity	ml 1 N NaOH 100 g ⁻¹	2.70
Conductivity	10 ⁻⁴ S cm ⁻¹	3.40
Diastase number		21.13
HMF*		0.05

* HMF – indicator of honey quality and durability.

and devastated lands. According to Klimont (2007), the following species are suitable for perennial bee pastures: *Solidago gigantea* Aiton, *Echinops exaltatus* Schrad., *L. thuringiaca*, *Agastache anethiodora* (Nutt.) Britton, and *Trifolium repens* L. The results of research conducted by Klimont et al. (2013) indicate that *L. thuringiaca* belongs to melliferous species characterized by high abundance and are additionally useful for biological reclamation of areas after sulfur exploitation. In addition to the utilization of post-industrial and domestic waste, thanks to such species it is possible to recreate the plant cover on devastated sites, obtain bee nectar (nectar, pollen), and additionally achieve an aesthetic effect for the surroundings.

6. Management of marginal soils and reclamation

Land devastated by human management requires reclamation, which helps to restart soil-forming processes, initiate biological life in the subsoil, and restore the vegetation cover. Plant species suitable for reclamation should be characterized by low sensitivity to soil compactness, pH, nutrient abundance, and content of harmful substances. According to Klimont et al. (2013), of the 45 perennial crop species studied, *L. thuringiaca* proved to be one of the most suitable plants for biological reclamation of land after sulfur mining due to its high plant vigor assessed by the density, uniformity, and abundance of the canopy overgrowing the substrate. *L. thuringiaca* spreads well, creates a dense, high canopy, and suppresses plants of other species (weeds). It has a deep pile root system strengthening the soil. In addition, the authors showed that the species had a beneficial effect on the chemical properties of the substrate by increasing the content of organic matter and available nutrients, serving as food for bees, and improving the aesthetics of the environment.

L. thuringiaca was also useful for the reclamation of nutrient-poor post-flood lime fertilized with sewage sludge (Klimont, 2007). The study showed that, of the 25 species of melliferous plants, *L. thuringiaca* had the highest exuberance on this substrate, along with *Solidago gigantea* Aiton, *Solidago canadensis* L., *Eryngium planum* L., *Anchusa officinalis* L., and *Agastache foeniculum* Kuntze. Cultivation of these plants had a beneficial effect on the chemical properties of the sludge-enriched lime, increasing the organic matter content in the forming humus layer from 0.86% in the control to 4.04%. In turn, the nutrient content in the sorption complex increased from 1.2 P₂O₅, 2.1 K₂O, and 1.2 Mg mg 100 g⁻¹ of soil in the control site to 7.2, 4.3, and 4.2 mg 100 g⁻¹ of soil, respectively (Klimont, 2007).

An additional possibility for the use of *L. thuringiaca* can be the management of wasteland, fallow land, and soils excluded from cultivation (Staszewski & Staszewski, 2014). The species is persistent, easily bushy, and has a dense canopy that successfully competes with weeds. In unmanaged plantations, mature seeds are easily self-sowing seeds providing regrowth, which can take decades. Thanks to this, the plantation reproduces itself. Its deep taproot system also makes the species suitable for strengthening slopes and embankments.

L. thuringiaca can act as a cover crop to help stop soil erosion in poor quality areas. In addition, its roots can improve soil structure by creating a root network, which is important especially in heavy soils. Its low water and soil requirements and good resis-

tance to cold help *Lavatera* adapt to diverse environmental conditions and contribute to a lower irrigation and fertilization effort (Vazquez-Thello et al., 1995).

The plant can be also used to create hedges, which can not only improve the aesthetics of the area, but can also serve a protective function. It is also an ornamental plant, often used on farms. Thanks to its beautiful flowers and green leaves, it can be an aesthetic element in areas that require visual improvement.

7. Phytochemical constituents

L. thuringiaca has pronounced antioxidant, antimicrobial (Kalayou et al., 2012), anti-inflammatory (Silva et al., 2014), antibacterial (Mašković et al., 2013), cytotoxic (Mašković et al., 2018), and antitussive (Tuzlaci et al., 2010) effects and other types of pharmaceutical activity (Mašković et al., 2018). Due to the high favorable content of phenolic compounds, it is applied in the pharmaceutical industry as a medicinal plant (Matławska et al., 1999). Zhandabayeva et al. (2021) present the composition of *L. thuringiaca* components that have a certain antibacterial effect. In the composition of thick CO₂ *L. thuringiaca* extract, the content of 31 components was proven: α-bisabolol oxide B (9.65%), linolenic acid (9.38%), bisabolol oxide A (8.26%), cis-β-farnesene (7.63%), spathulenol (6.97%), linoleic acid (6.95%), herniarin (5.61%), pulegone (5.08%), ethyl ether (3.15%), elaidic acid (2.57%), phytol (2.49%), myristic acid (2.33%), verbenone (1.93%), and α-bisabolol (1.36%). Antimicrobial activity studies have shown that the CO₂ extract of *L. thuringiaca* has a pronounced effect against clinically significant microorganisms: *Escherichia coli*, *Staphylococcus aureus*, *Candida albicans*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Streptococcus pneumoniae*, *Staphylococcus haemolyticus*, and *Staphylococcus saprophyticus*.

The presence of kaempferol 3-O-β-glucoside, kaempferol and quercetin 3-O-rutinosides, cis- and trans-tiliroside, and p-coumaric acid was identified in the flowers of *L. thuringiaca* (Matławska et al., 1999). Besides, the species contains 5 glycosides in flowers and 4 glycosides in leaves. The most common aglycones are quercetin, kaempferol, and apigenin (Matławska, 1990). This result fits well with the view that p-coumaric acid and kaempferol glucoside may occur regularly in the flowers of *Lavatera*. Fedoseeva and Myznikova (2017) identified derivatives of caffeic and chlorogenic acids and umbelliferone in the roots of *L. thuringiaca*, chlorogenic acid, flavonoids of the flavone and catechin groups, and coumarin compounds in the grass and stems, chlorogenic and ferulic acids and derivatives of quercetin (quercitrin, etc.), kaempferol, and flavone in the leaves, and phenologlycosides and kaempferol and flavone derivatives in the flowers.

L. thuringiaca plants have been analyzed by Vysochina et al. (2011) for the content of low-molecular biologically active compounds, such as flavonoids, phenolic acids, tannins, and coumarins. Their results showed that *L. thuringiaca* contains high amounts of coumarins and 1.3% of flavonoids. Coumarins are valuable natural products. The increased interest in these chemical compounds is related to the high physiological activity of many derivatives of coumarin and furocoumarins, which have antitumor activity. Natural coumarins and furocoumarins also have antibiotic, antifungal, anti-spasmodic, and insecticidal properties and exhibit anticoagulant, sedative, anticonvulsant, and vasodilating effects (Raters & Matissek, 2008). *Lavatera* species have been studied for their flavonoid content also by Skalicka-Wozniaka et al. (2007) and Razavi et al. (2011). Flavonoid compounds exhibit strong antioxidant activity (Rice-Evans et al., 1997). Many factors such as genotypes, organ, physiological stage, and growing conditions (soil, agronomy, and climate) have been reported to have a significant effect on phenolic acids and antioxidant properties of plants (Carbone et al., 2011). The phytochemical constituents of *L. thuringiaca* and its activities are presented in Table 3.

8. Molecular research on *Lavatera*

Genetic studies uncover the structure and biological function of the plant genome (i.e., all genes) and its regulatory parts. The molecular basis of genes is deoxyribonucleic acid (DNA). The function of particular genes or DNA segments can be inferred by making associations between varieties in the appearance of different plants

Table 3 Phytochemical constituents of *Lavatera thuringiaca* and their activities.

Phytochemical constituents	Class	Activities	References
Isopulegone, Piperitone, E-Nerolidol, Caryophyllene oxides and E-Nerolidol	Monoterpenoid	Anticonvulsant, anti-inflammatory, antioxidant, gastroprotective, anti-stress, antimicrobial, antiviral, and perfume compositions	(Shahverdi et al., 2004; Silva et al., 2007, 2009a, 2009b)
D-Menthol, Humulene, Caryophyllene oxide, α -Bisabolol, Phytol	Terpene	Pain-reliever, appetite suppressant, anti-irritant, anticancer, analgesic, antifungal, anti-inflammatory, sedative, anti-irritant, antimicrobial, and analgesic	(de Cássia Da Silveira e Sá et al., 2015; de Chavan et al., 2010; Kim et al., 2011; Laude et al., 1994; Nguyen et al., 2017; Santos et al., 2013; Willis et al., 2011; Zhandabayeva et al., 2021)
Alloaromadendrene, α -Bisabolol oxide A & B, Cis- β -farnesene, c-Muurolene, Isocaryophyllene, α -Curcumene	Sesquiterpene	Antifungal, anti-irritant, anti-inflammatory, antimicrobial, and antioxidant	(Darwish et al., 2020; Forrer et al., 2013; Kim et al., 2011; Nogueira et al., 2021; Yu et al., 2014)
Verbenone, Pulegone, Thymol	Monoterpene	Antinociceptive, antimicrobial, anticonvulsive, antiseptic, antibacterial, and antifungal	(de Melo et al., 2017; de Sousa et al., 2011; Hu et al., 2017; Santoyo et al., 2014)
Spathulenol	Sesquiterpenoid	Antimycobacterial, antiproliferative, anti-inflammatory, and antioxidant	(do Nascimento et al., 2018)
Palmitic acid, Ethyl ester, Linolenic acid, and Isovaleric acid	Fatty acid	Anti-inflammatory, promitogeic and, stimulating effects on HSC (hepatic stellate cells), anti-cancer, antibacterial and antifungal properties. Used to make validol, valocordins, and others	(Jalalvand et al., 2019; Kim et al., 2014; Kusumah et al., 2020; Li et al., 2003; Saeed et al., 2012; Tu et al., 2019; Zhandabayeva et al., 2021)
Myristic acid, Stearic acid, Elaidic acid	Saturated fatty acid	Antimicrobial, anti-cancer, and against herpes viruses	(Andrei et al., 2000; Chen et al., 2019; Habib et al., 1987)
Herniarin or 7-methoxycoumarin	Coumarin	Antigenotoxic, anti-inflammatory, and antinociceptive	(Andrei et al., 2000; Cheriyan et al., 2017; Nayeli et al., 2020)
Linoleic acid	Polyunsaturated fatty acid	Analgesic and bactericidal properties	(Kusumah et al., 2020; Tu et al., 2019; Zhandabayeva et al., 2021)
Cannabidiol	Phytocannabinoid	Anticonvulsant	(Frías-Soria et al., 2021)
Perhydrofarnesyl acetone	Diterpenoids	Perfume composition	(Zhandabayeva et al., 2021)
Geranyl linalpol	Diterpene	Antimicrobial and anti-inflammatory	(Zhandabayeva et al., 2021)

(for example, disease resistance) with their genetic differences. Genetic research also helps to analyze plant properties that are not based on individual genes but on gene networks. In this way, complex traits, such as yield and drought tolerance, can be tailored more precisely.

L. thuringiaca is able to survive at freezing temperatures. Its frost tolerant character may have potential use in the genetic improvement of other related plants for increased frost tolerance (Vazquez-Thello et al., 1995). The results reported by Vazquez-Thello et al. (1996) showed that the formation of somatic hybrids (fusion callus) between transgenic *Hibiscus rosa-sinensis* and transgenic *L. thuringiaca* (a cold-tolerant species) resulted in a significant improvement in cold tolerance over *H. rosa-sinensis*. The introduction by genetic transformation of chimeric marker genes encoding e.g., antibiotic or herbicide resistance enables the verification of hybrids at the

earliest stage. Selection based on resistance to two antibiotics has been used to verify somatic hybrids of *H. rosa-sinensis* + *L. thuringiaca* (Vazquez-Thello et al., 1996). Vazquez-Thello et al. (1996) produced transgenic *L. thuringiaca* plants by transformation of *Agrobacterium tumefaciens* LBA 4404 cell suspension carrying the binary vector pMM454 (Nos-Hpt). After 2 h co-culture, the cells were placed in solid media and the transformed loci were selected by somatic embryogenesis under selection control. A protoplast from a transgenic *L. thuringiaca* line was combined with protoplasts from a transgenic hibiscus in an attempt to transfer *Lavatera* cold tolerance to hibiscus. In addition, by selecting for resistance to kanamycin (from transgenic hibiscus protoplasts) and hygromycin (from transgenic *Lavatera*), somatic hybrids were isolated. In their study to identify intergeneric hybrids of *H. rosa-sinensis* and *L. thuringiaca*, Vazquez-Thello et al. (1996) used isoelectric focusing to distinguish allelic forms of the enzyme. Verification of the hybrids was performed based on the presence of marker genes introduced by genetic transformation. Inter- and intra-specific hybridization among different species and genera is one of the most important breeding methods for creating new and improved plants (Kuligowska et al., 2016).

Grant et al. (2001) and Grant and Culham (2001) carried out genetic analysis of perennial *Lavatera* cultivars, i.e., *L. thuringiaca* and *Lavatera olbia* (L.) Alef. The research involved investigating the parental origin of the cultivars and the role of hybridization in generation of *Lavatera* cultivars using artificial hybridization and randomly amplified polymorphic DNA (RAPD) markers. In addition, the ability of RAPD markers to distinguish cultivars with a narrow genetic base was also evaluated. Previous studies showed that RAPD were used widely to evaluate distinguishability and relatedness of genotypes in plants (Culham & Grant, 1999). The DNA extraction and RAPD polymerase chain reaction showed that species-specific molecular markers were identified from the RAPD profiles. Nine RAPD markers for *L. thuringiaca* were identified and showed that two bands (UBC 721 700 bp, UBC 792 900 bp) were unique only for *L. thuringiaca*. The identified molecular markers were used to determine the origin of the varieties. It was shown that 'Ice Cool' and 'Candy Floss' cultivars are derived from *L. thuringiaca* (Grant & Culham, 2001).

Tchórzewska et al. (2008) carried out analyses of karyokinesis, cytokinesis, and chondriokinesis occurring during meiosis in the process of microsporogenesis in dicotyledonous angiosperms, including *L. thuringiaca*. They demonstrated that, in *L. thuringiaca*, simultaneous cytokinesis occurs during microsporogenesis and organelles move in a characteristic manner, classified as envelope chondriokinesis (Tchórzewska, 2017; Tchórzewska et al., 2013). In this type of chondriokinesis, the autonomous organelles at the end of prophase I cluster around the nucleus and karyokinesis takes place in this confined space. Then, in telophase I, the envelopes of the organelles form around two nuclei, followed by four nuclei in telophase II. Such a position of the cell organelles is maintained not only until the end of meiosis, but also after this phase when the mononuclear pollen grains have already formed a sporoderm (Furness et al., 2002; Koç & De Storme, 2022). Subsequent analyses were focused on the configuration of the tubulin cytoskeleton in *L. thuringiaca* meiocytes. It turned out that the tubulin cytoskeleton in this species forms configurations differing not only from those observed in *Psilotum nudum* but also from those described in seed plants. The performed studies demonstrated new configurations of microtubules (MTs), which surrounded aggregates composed of organelles around the nucleus in the form of networks (in late prophase I and II). Moreover, an unusually strong perinuclear radial microtubule system occurring in telophase I and II in the species studied and the presence of a phragmoplast in a small space devoid of cell organelles between aggregates composed of cell organelles surrounding the progeny nuclei were observed. It was found that meiosis in *L. thuringiaca* microsporogenesis is similar to that occurring in most plants with simultaneous cytokinesis, but the movement of organelles during meiosis is very unique and specific (Brownfield et al., 2015; Marciniak et al., 2019). Microtubules were found to be closely associated with karyokinesis and chondriokinesis during microsporogenesis in *L. thuringiaca*, and thus determined the formation of functional pollen grains (Tchórzewska et al., 2008). Tchórzewska et al. (2008) described the role of both chondriokinesis and the tubulin cytoskeleton in meiotically dividing cells during microsporogenesis in species of the family *Malvaceae*. The research showed that the characteristic envelopes

of autonomous organelles in the species studied divide the space within which karyokinesis occurs, replacing the cell wall that is still absent. On the other hand, the analyses of the tubulin cytoskeleton showed that microtubules were responsible not only for segregation of chromosomes but also for the characteristic rearrangements of cell organelles during meiosis (chondriokinesis). In this study, colchicine was used, which is an alkaloid that binds specifically to microtubules causing inhibition of their polymerization. The destruction of the tubulin cytoskeleton resulted not only in the absence of normal chromosome segregation but also in the absence of the movement of cell autonomous organelles typical of envelope chondriokinesis (Tchórzewska et al., 2008). For *L. thuringiaca*, Markova and Goranova (1993) reported chromosome counts of $2n = 44$.

9. Conclusions

The review highlights the biological and biochemical properties of *L. thuringiaca* and the potential for multipurpose use of this species. Its high production potential and favorable chemical composition allow it to be used for fodder purposes, and its abundant and long flowering makes it an excellent forage for bees and other pollinators. The biomass can also be used for energy purposes, as it has similar energy parameters to those of typical energy crops (e.g., *Salix*, *Sida*, *Miscanthus*). In turn, its high resistance to unfavorable environmental conditions (drought, frost) and low habitat requirements (especially soil requirements) mean that it can be used for the development of marginal soils and for the reclamation of land contaminated by industry. At the same time, the cultivation of this plant is economically advantageous due to the low cost of establishing the crop and the easy dispersal of seeds that renew plantations despite the high proportion of hard seeds. *L. thuringiaca* contains numerous biologically active compounds (including phenolic compounds); hence, the plant exhibits antioxidant, antimicrobial, anti-inflammatory, and cytotoxic activities, which facilitate its use for medical and pharmaceutical purposes. Research has also been conducted on the use of *L. thuringiaca* genes in enhancing the frost resistance of crop plants.

The advantages of *L. thuringiaca* related to its potential use in various production directions and its resistance to unfavorable habitat conditions prompt wider interest in this species, especially in view of the observed climate change and increasing water problems in the world. Diversification of cultivated plant species will enhance food security and economic sustainability. However, the literature on this species is scarce and requires further research, especially in terms of the chemical composition and low-cost methods of seed extraction and scarification. A very important aspect of further research should also be the assessment of the threat of uncontrolled spread of a new alien species in the agroecological space of Poland.

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References

- Andrei, G., Snoeck, R., Neyts, J., Sandvold, M. L., Myhren, F., & de Clercq, E. (2000). Antiviral activity of ganciclovir elaidic acid ester against herpesviruses. *Antiviral Research*, 45(3), 157–167. [https://doi.org/10.1016/S0166-3542\(00\)00070-X](https://doi.org/10.1016/S0166-3542(00)00070-X)
- Brownfield, L., Yi, J., Jiang, H., Minina, E. A., Twell, D., & Köhler, C. (2015). Organelles maintain spindle position in plant meiosis. *Nature Communications*, 6, Article 6492. <https://doi.org/10.1038/ncomms7492>
- Budzeń, M., Hanusz, Z., & Sujak, A. (2015). Biometry of response of *Lavatera thuringiaca* L. energetic plant to pre-sowing electromagnetic seed treatment. *TEKA Commission of Motorization and Energetics in Agriculture*, 15(4), 25–30.
- Budzeń, M., Kornacki, A., Kornarzyński, K., & Sujak, A. (2018). Effect of laser light on germination of *Lavatera thuringiaca* L. seeds studied by binomial distribution. *Seed Science and Technology*, 46, 447–464. <https://doi.org/10.15258/sst.2018.46.3.02>

- Budzeń, M., Sujak, A., & Wiącek, D. (2016). Effect of pre-sowing treatment of seed on the biomass yield and energy value of *Lavatera thuringiaca* L. plant. *TEKA Commission of Motorization and Energetics in Agriculture*, 16(4), 3–6.
- Budzeń, M., Zajac, G., Sujak, A., & Szyszlak-Bargłowicz, J. (2021). Energetic and thermal characteristics of *Lavatera thuringiaca* L. biomass of different age produced from He–Ne laser light stimulated seeds. *Renewable Energy*, 178, 520–531. <https://doi.org/10.1016/j.renene.2021.06.007>
- Budzeń, M., Zajac, G., Sujak, A., Szyszlak-Bargłowicz, J., & Kafarski, M. (2023). Chemical composition of *Lavatera thuringiaca* L. biomass ash after pre-sowing stimulation of seeds with He–Ne laser light. *Scientific Reports*, 13, 528–538. <https://doi.org/10.1038/s41598-023-27836-5>
- Carbone, K., Giannini, B., Picchi, V., Lo Scalzo, R., & Cecchini, F. (2011). Phenolic composition and free radical scavenging activity of different apple varieties in relation to the cultivar, tissue type and storage. *Food Chemistry*, 127(2), 493–500. <https://doi.org/10.1016/j.foodchem.2011.01.030>
- Celka, Z., Drapikowska, M., Lembicz, M., Szkudlarz, P., Talaga, K., & Wydra, K. (2013). *Lavatera thuringiaca* L.: A relict of former cultivation on an historic earthwork in Poland-distribution and reproduction of individuals. *Ukrainian Botany Journal*, 70(2), 209–214.
- Chen, X., Zhao, X., Deng, Y., Bu, X., Ye, H., & Guo, N. (2019). Antimicrobial potential of myristic acid against *Listeria monocytogenes* in milk. *Journal of Antibiotics*, 72(5), 298–305. <https://doi.org/10.1038/s41429-019-0152-5>
- Cheriyian, B. V., Sr., Kadhivelu, P., Sr., Nadipelly, J., Jr., Shanmugasundaram, J., Sayeli, V., Sr., & Subramanian, V., Sr. (2017). An-ti-nociceptive effect of 7-methoxy coumarin from *Eupatorium Triplinerve* Vahl (Asteraceae). *Pharmacognosy Magazine*, 13(49), 81–84. <https://doi.org/10.4103/0973-1296.197650>
- Culham, A., & Grant, M. (1999). DNA markers for cultivar identification and classification. In S. Andrews, A. C. Leslie, & C. Alexander (Eds.), *Taxonomy of cultivated plants* (pp. 183–198). Royal Botanic Gardens.
- Darwish, R. S., Hammada, H. M., Ghareeb, D. A., Abdelhamid, A. S., Harraz, F. M., & Shawky, E. (2020). Efficacy directed discrimination of the essential oils of three *Juniperus* species based on their *in vitro* antimicrobial and anti-inflammatory activities. *Journal of Ethnopharmacology*, 259, Article 112971. <https://doi.org/10.1016/j.jep.2020.112971>
- de Cássia Da Silveira e Sá, R., Andrade, L. N., & de Sousa, D. P. (2015). Sesquiterpenes from essential oils and anti-inflammatory activity. *Natural Product Communications*, 10(10), Article 1934578X1501001033. <https://doi.org/10.1177/1934578X1501001033>
- de Chavan, M. J., Wakte, P. S., & Shinde, D. B. (2010). Analgesic and anti-inflammatory activity of Caryophyllene oxide from *Annona squamosa* L. Bark. *Phytomedicine*, 17(2), 149–151. <https://doi.org/10.1016/j.phymed.2009.05.016>
- de Melo, C. G. F., Salgado, P. R. R., da Fonsêca, D. V., Braga, R. M., Filho, M. R. D. C., de Farias, I. E. V., de Luna Freire Pessôa, H., Lima, E. M., do Amaral, I. P. G., de Sousa, D. P., & de Almeida, R. N. (2017). Anticonvulsive activity of (1S)-(-)-verbenone involving RNA expression of BDNF, COX-2, and c-fos. *Naunyn-Schmiedeberg's Archives of Pharmacology*, 390, 863–869. <https://doi.org/10.1007/s00210-017-1388-x>
- de Sousa, D. P., Nóbrega, F. F., De Lima, M. R., & Almeida, R. N. (2011). Pharmacological activity of (R)-(+)-pulegone, a chemical constituent of essential oils. *Zeitschrift für Naturforschung C.*, 66(7-8), 353–359. <https://doi.org/10.1515/znc-2011-7-806>
- do Nascimento, K. F., Moreira, F. M. F., Santos, J. A., Kassuya, C. A. L., Croda, J. H. R., Cardoso, C. A. L., do Carmo Vieira, M., Ruiz, A. L. T. G., Foglio, M. A., de Carvalho, J. E., & Formagio, A. S. N. (2018). Antioxidant, anti-inflammatory, antiproliferative and antimycobacterial activities of the essential oil of *Psidium guineense* Sw. and spathulenol. *Journal of Ethnopharmacology*, 210, 351–358. <https://doi.org/10.1016/j.jep.2017.08.030>
- Dzida, K., Zawislak, G., Jarosz, Z., Pitura, K., & Neugebauerova, J. (2023). Effect of natural fertilization on the yield, biological value, and qualitative and quantitative composition of essential oil in common basil (*Ocimum basilicum* L.). *Acta Agrobotanica*, 76, Article 173137. <https://doi.org/10.5586/aa/173137>
- Fedoseeva, L. M., & Myznikova, O. A. (2017). Study of qualitative composition of phenol compounds in various parts of garden tree-mallow which grows in the territory of the Altai Krai. *Almanac of Clinical Medicine*, 5(50), 167–174. <https://doi.org/10.21145/2499-9954-2017-5-167-174>
- Forrer, M., Kulik, E. M., Filippi, A., & Waltimo, T. (2013). The antimicrobial activity of alpha-bisabolol and tea tree oil against *Solo-bacterium moorei*, a Gram-positive bacterium associated with halitosis. *Archives of Oral Biology*, 58(1), 10–16. <https://doi.org/10.1016/j.archoralbio.2012.08.001>

- Frías-Soria, C. L., Pérez-Pérez, D., Orozco-Suárez, S., & Rocha, L. (2021). Cannabidiol modifies the seizure expression and effects of antiseizure drugs in a rat model of recurrent severe seizures. *Seizure*, 90, 67–73. <https://doi.org/10.1016/j.seizure.2021.04.008>
- Furness, C. A., Rudall, P. J., & Sampson, F. B. (2002). Evolution of microsporogenesis in angiosperms. *International Journal of Plant Sciences*, 163(2), 235–260. <https://doi.org/10.1086/338322>
- Grant, M. L., & Culham, A. (2001). An investigation into the identity of the perennial cultivars of *Lavatera* L. using morphology and RAPD markers. *Acta Horticulturae*, 546, 407–411. <https://doi.org/10.17660/ActaHortic.2001.546.52>
- Grant, M. L., Miller, D. M., & Culham, A. (2001). Genetic and morphological analysis of the origin and identity of perennial *Lavatera* (Malvaceae) cultivars. *Journal of the American Society for Horticultural Science*, 125(5), 593–598. <https://doi.org/10.21273/JASHS.126.5.593>
- Grzesik, M., Romanowska-Duda, Z., & Janas, R. (2015). Jakość nasion jako klucz do powszechnej uprawy szałwówki turyngskiej - rośliny o dużym potencjalnym wielokierunkowym wykorzystaniu [Quality of seeds as a key to commodity cultivation of *Lavatera thuringiaca* L. – Plants with high potential for multi directional use]. *Acta Innovations*, 15, 5–12.
- Habib, N. A., Wood, C. B., Apostolov, K., Barker, W., Hershman, M. J., Aslam, M., Heinemann, D., Fermor, B., Williamson, R., & Jenkins, W. E. (1987). Stearic acid and carcinogenesis. *British Journal of Cancer*, 56(4), 455–458. <https://doi.org/10.1038/bjc.1987.223>
- Hoogwijk, M., Faaij, A., De Vries, B., & Turkenburg, W. (2009). Exploration of regional and global cost-supply curves of biomass energy from short-rotation crops and abandoned cropland and rest land under four IPCC SRES land-use scenarios. *Biomass & Bioenergy*, 33(1), 26–43. <https://doi.org/10.1016/j.biombioe.2008.04.005>
- Hu, Q., Lin, G. S., Duan, W. G., Huang, M., & Lei, F. H. (2017). Synthesis and biological activity of novel (Z) and (E)-verbenone oxime esters. *Molecules*, 22(10), Article 1678. <https://doi.org/10.3390/molecules22101678>
- Iriondo, J. M., & Pérez, C. (1996). Somaclonal variation in *Lavatera* species. In Y. P. S. Bajaj (Ed.), *Somaclonal variation in crop improvement II. Biotechnology in agriculture and forestry* (Vol. 36, pp. 280–195). Springer. https://doi.org/10.1007/978-3-642-61081-3_19
- Jabłoński, B. (2000). Krótka charakterystyka roślin wybranych do uprawy pożytków pszczelich [Brief description of plants selected for growing bee nectar]. In *O potrzebie i możliwościach poprawy pożytków pszczelich* (pp. 24–71). Branch of Apiology IPF.
- Jalalvand, A. R., Zhaleh, M., Goorani, S., Zangeneh, M. M., Seydi, N., Zangeneh, A., & Moradi, R. (2019). Chemical characterization and antioxidant, cytotoxic, antibacterial, and antifungal properties of ethanolic extract of *Allium Saralicum* RM Fritsch leaves rich in linolenic acid, methyl ester. *Journal of Photochemistry and Photobiology B: Biology*, 192, 103–112. <https://doi.org/10.1016/j.jphotobiol.2019.01.017>
- Kalayou, S., Haileselassie, M., Gebre-Egziabher, G., Tikue, T., Sahle, S., Taddele, H., & Ghezu, M. (2012). *In vitro* antimicrobial activity screening of some ethnoveterinary medicinal plants traditionally used against mastitis, wound and gastrointestinal tract complication in Tigray region, Ethiopia. *Asian Pacific Journal of Tropical Biomedicine*, 2(7), 516–522. [https://doi.org/10.1016/S2221-1691\(12\)60088-4](https://doi.org/10.1016/S2221-1691(12)60088-4)
- Kim, S., Jung, E., Kim, J. H., Park, Y. H., Lee, J., & Park, D. (2011). Inhibitory effects of (–)- α -bisabolol on LPS-induced inflammatory response in RAW264.7 macrophages. *Food and Chemical Toxicology*, 49(10), 2580–2585. <https://doi.org/10.1016/j.fct.2011.06.076>
- Kim, K. B., Nam, Y. A., Kim, H. S., Hayes, A. W., & Lee, B. M. (2014). α -Linolenic acid: Nutraceutical, pharmacological and toxicological evaluation. *Food and Chemical Toxicology*, 70, 163–178. <https://doi.org/10.1016/j.fct.2014.05.009>
- Klimont, K. (2007). Przydatność wybranych gatunków roślin miododajnych do rekultywacji osadników wapna poflotacyjnego wzbogaconego osadami ścieków komunalnych [The application of some species of honey plants in reclamation of tanks of flotation lime enriched with municipal sewage]. *Bulletin of Plant Breeding and Acclimatization Institute*, 244, 249–257.
- Klimont, K., Bulińska-Radowska, Z., & Górka, J. (2013). Utilization possibility of selected honey-yielding plants for reclamation of abandoned sulfur mining sites. *Polish Journal of Agronomy*, 12, 17–25.
- Koç, A., & De Storme, N. (2022). Structural regulation and dynamic behaviour of organelles during plant meiosis. *Frontiers in Cell and Developmental Biology*, 10, Article 925789.
- Kołtowski, Z. (2015). *Przewodnik po roślinach miododajnych* [A guide to melliferous plants]. Agencja Fotograficzno-Wydawnicza Mazury.

- Kornarzyński, K., Budzeń, M., & Sujak, A. (2015). Estimation of the effect of magnetic and electric field and magnetically treated water on the course of germination of seeds of Thuringian Mallow (*Lavatera thuringiaca* L.). *Acta Scientiarum Polonorum Technica Agraria*, 14(1-2), 23–33.
- Kotecki, A. (2010). *Uprawa miskanta olbrzymiego. Energetyczne i pozaenergetyczne możliwości wykorzystania słomy* [Growing Miscanthus giant. Energy and non-energy possibilities of using straw]. UP.
- Kuligowska, K., Lutken, H., Christensen, B., & Muller, R. (2016). Interspecific hybridization among cultivars of hardy *Hibiscus* species section Muenchhusia. *Breeding Science*, 66, 300–308. <https://doi.org/10.1270/jsbbs.66.300>
- Kusumah, D., Wakui, M., Murakami, M., Xie, X., Yukihito, K., & Maeda, I. (2020). Linoleic acid, α -linolenic acid, and monolinolenins as antibacterial substances in the heat-processed soybean fermented with *Rhizopus oligosporus*. *Bioscience, Biotechnology, and Biochemistry*, 84(6), 1285–1290. <https://doi.org/10.1080/09168451.2020.1731299>
- Laude, E., Morice, A., & Grattan, T. (1994). The antitussive effects of menthol, camphor and cineole in conscious guinea-pigs. *Pulmonary Pharmacology and Therapeutics*, 7(3), 179–184. <https://doi.org/10.1006/pulp.1994.1021>
- Li, J., Hu, W., Baldassare, J. J., Bora, P. S., Chen, S., Poulos, J. E., O'Neill, R., Britton, R. S., & Bacon, B. R. (2003). The ethanol metabolite, linolenic acid ethyl ester, stimulates mitogen-activated protein kinase and cyclin signaling in hepatic stellate cells. *Life Science Journal*, 73(9), 1083–1096. [https://doi.org/10.1016/S0024-3205\(03\)00383-7](https://doi.org/10.1016/S0024-3205(03)00383-7)
- Majtkowski, W., Majtkowska, G., & Tomaszewski, B. (2010). Dynamika wzrostu roślin energetycznych oraz potencjalnej biomasy [Growth dynamics of energy plants and potential biomass]. In A. Grzybek (Ed.), *Modelowanie energetycznego wykorzystania biomasy* (pp. 114–126). ITP.
- Marciniak, R., Zięba, E., & Winiarczyk, K. (2019). Distribution of plastids and mitochondria during male gametophyte formation in *Tinantia erecta* (Jacq.) Fenzl. *Protoplasma*, 256, 1051–1063. <https://doi.org/10.1007/s00709-019-01363-5>
- Markova, M. L., & Goranova, V. Y. (1993). Karyological study of representatives of family *Malvaceae* in Bulgaria. *Fitologija*, 46, 12–32.
- Mašković, P., Radojković, M., Ristić, M., & Solujić, S. (2013). Studies on the antimicrobial and antioxidant activity and chemical composition of the essential oils of *Kitabelia vitifolia*. *Natural Product Communications*, 8(5), 667–670. <https://doi.org/10.1177/1934578X1300800530>
- Mašković, P. Z., Veličković, V., Durović, S., Zeković, Z., Radojković, M., Cvetanović, A., Švarc-Gajić, J., Mitić, M., & Vujić, J. (2018). Biological activity and chemical profile of *Lavatera thuringiaca* L. extracts obtained by different extraction approaches. *Phytomedicine*, 38, 118–124. <https://doi.org/10.1016/j.phymed.2017.11.010>
- Matławska, I. (1990). Poszukiwanie związków flawonoidowych w wybranych gatunkach rodziny *Malvaceae* [Investigation of flavonoid compounds of selected species from *Malvaceae* family]. *Herba Polonica*, 36(3), 65–69.
- Matławska, I., Sikorska, M., & Bylka, W. (1999). Flavonoid compounds in *Lavatera thuringiaca* L. (*Malvaceae*) flowers. *Acta Poloniae Pharmaceutica - Drug Research*, 56(6), 453–458.
- Matyka, M. (2013). Produkcyjne i ekonomiczne aspekty uprawy roślin wieloletnich na cele energetyczne [Production and economic aspects of growing perennial plants for energy purposes]. *Monografie i Rozprawy Naukowe*, 35, 1–98.
- Nayeli, M. B., Maribel, H. R., Enrique, J. F., Rafael, B. P., Margarita, A. F., Macrina, F. M., Ivan, M. D., & Manasés, G. C. (2020). Anti-inflammatory activity of coumarins isolated from *Tagetes lucida* Cav. *Natural Product Research*, 34(22), 3244–3248. <https://doi.org/10.1080/14786419.2018.1553172>
- Nguyen, L. T., Myslivečková, Z., Szotáková, B., Špičáková, A., Lněničková, K., Ambrož, M., Kubíček, V., Krasulová, K., Anzenbacher, P., & Skálová, L. (2017). The inhibitory effects of β -caryophyllene, β -caryophyllene oxide and α -humulene on the activities of the main drug-metabolizing enzymes in rat and human liver *in vitro*. *Chemico-Biological Interactions*, 278, 123–128. <https://doi.org/10.1016/j.cbi.2017.10.021>
- Nogueira, C. R., Carbonezi, L. H., de Oliveira, C. T. F., Garcez, W. S., & Garcez, F. R. (2021). Sesquiterpene derivatives from *Ocotea minarum* leaves. *Phytochemistry Letters*, 42, 8–14. <https://doi.org/10.1016/j.phytol.2021.01.004>
- Pawlat, J., Starek, A., Sujak, A., Kwiatkowski, M., Terebun, P., & Budzeń, M. (2017). Effects of atmospheric pressure plasma generated in GlidArc reactor on *Lavatera thuringiaca* L. seeds' germination. *Plasma Processes and Polymers*, 15, Article e1700064. <https://doi.org/10.1002/ppap.201700064>
- Raters, M., & Matissek, R. (2008). Analysis of coumarin in various foods using liquid chromatography with tandem mass spectrometric detection. *European Food Research and Technology*, 227(2), 637–642.

- Ray, M. F. (1995). Systematics of *Lavatera* and *Malva* (*Malvaceae*, *Malvae*) – A new perspective. *Plant Systematics and Evolution*, 198, 29–53. <https://doi.org/10.1007/BF00985106>
- Razavi, S. M., Zarrini, G., Molavi, G., & Ghasemi, G. (2011). Bioactivity of *Malva sylvestris* L., a medicinal plant from Iran. *Iranian Journal of Basic Medical Sciences*, 14(6), 574–579.
- Revenga, C., Brunner, J., Henninger, N., Kassem, K., & Payne, R. (2000). *Pilot analysis of global ecosystems: Freshwater systems* (pp. 1–78). World Resources Institute.
- Rice-Evans, C. A., Miller, N. J., & Paganga, G. (1997). Antioxidant properties of phenolic compounds. *Trends in Plant Science*, 2(4), 152–159. [https://doi.org/10.1016/S1360-1385\(97\)01018-2](https://doi.org/10.1016/S1360-1385(97)01018-2)
- Romanowska-Duda, Z., Grzesik, M., Pszczółkowski, W., Piotrowski, K., & Pszczółkowska, A. (2014). Dydaktyczne i środowiskowe funkcje kolekcji roślin energetycznych w centrum transferu technologii OZE w Konstantynowie Łódzkim [Didactic and environmental functions of the collection of energy plants in the RES technology transfer center in Konstantynów Łódzki]. *Acta Innovations*, 13, 41–52.
- Rosenqvist, H., & Dawson, M. (2005). Economics of willow growing in Northern Ireland. *Biomass & Bioenergy*, 28(1), 7–14. <https://doi.org/10.1016/j.biombioe.2004.06.001>
- Saeed, N. M., El-Demerdash, E., Abdel-Rahman, H. M., Algandaby, M. M., Al-Abbasi, F. A., & Abdel-Naim, A. B. (2012). Anti-inflammatory activity of methyl palmitate and ethyl palmitate in different experimental rat models. *Toxicology and Applied Pharmacology*, 264(1), 84–93. <https://doi.org/10.1016/j.taap.2012.07.020>
- Santos, C. C. D. M. P., Salvadori, M. S., Mota, V. G., Costa, L. M., de Almeida, A. A. C., de Oliveira, G. A. L., Costa, J. P., de Sousa, D. P., de Freitas, R. M., & de Almeida, R. N. (2013). Antinociceptive and antioxidant activities of phytol *in vivo* and *in vitro* models. *Journal of Neuroscience*, 2013, Article 949452. <https://doi.org/10.1155/2013/949452>
- Santoyo, S., Jaime, L., García-Risco, M. R., Ruiz-Rodríguez, A., & Reglero, G. (2014). Antiviral properties of supercritical CO₂ extracts from oregano and sage. *International Journal of Food Properties*, 17(5), 1150–1161. <https://doi.org/10.1080/10942912.2012.700539>
- Shahverdi, A., Rafii, F., Fazeli, M., & Jamalifar, H. (2004). Enhancement of antimicrobial activity of furazolidone and nitrofurantoin against clinical isolates of *Enterobacteriaceae* by piperitone. *International Journal of Aromatherapy*, 14(2), 77–80. <https://doi.org/10.1016/j.ijat.2004.04.007>
- Silva, M. I. G., de Aquino Neto, M. R., Neto, P. F. T., Moura, B. A., do Amaral, J. F., de Sousa, D. P., Vasconcelos, S. M. M., & de Sousa, F. C. F. (2007). Central nervous system activity of acute administration of isopulegol in mice. *Pharmacology Biochemistry and Behavior*, 88(2), 141–147. <https://doi.org/10.1016/j.pbb.2007.07.015>
- Silva, M. I. G., Moura, B. A., de Aquino Neto, M. R., da Rocha Tomé, A., Rocha, N. F. M., de Carvalho, A. M. R., Macêdo, D. S., Vasconcelos, S. M. M., de Sousa, D. P., & de Barros Viana, G. S. (2009a). Gastroprotective activity of isopulegol on experimentally induced gastric lesions in mice: Investigation of possible mechanisms of action. *Naunyn-Schmiedeberg's Archives of Pharmacology*, 380(3), 233–245. <https://doi.org/10.1007/s00210-009-0429-5>
- Silva, M. I. G., Silva, M. A. G., de Aquino Neto, M. R., Moura, B. A., de Sousa, H. L., de Lavor, E. P. H., de Vasconcelos, P. F., Macêdo, D. S., de Sousa, D. P., & Vasconcelos, S. M. M. (2009b). Effects of isopulegol on pentylenetetrazol-induced convulsions in mice: Possible involvement of GABAergic system and antioxidant activity. *Fitoterapia*, 80(8), 506–513. <https://doi.org/10.1016/j.fitote.2009.06.011>
- Silva, R. O., Sousa, F. B. M., Damasceno, S. R. B., Carvalho, N. S., Silva, V. G., Oliveira, F. R., Sousa, D. P., Aragão, K. S., Barbosa, A. L., Freitas, R. M., & Medeiros, J. V. (2014). Phytol, a diterpene alcohol, inhibits the inflammatory response by reducing cytokine production and oxidative stress. *Fundamental & Clinical Pharmacology*, 28(4), 455–464. <https://doi.org/10.1111/fcp.12049>
- Skalicka-Wozniaka, K., Mellioub, E., Gortzic, O., Glowniaka, K., & Chinoub, I. B. (2007). Chemical constituents of *Lavatera trimestris* L.- Antioxidant and antimicrobial activities. *Journal of Biosciences: Zeitschrift für Naturforschung*, 62(11/12), 797–800.
- Staszewska, U. (1997). Thuringian Mallow – A crop for protection of set aside soils. In *Ecological aspects of breeding fodder crops and amenity grasses*. Proceedings of 20th EUCARPIA Meeting (pp. 190–192). IHAR.
- Staszewska, U., & Jabłoński, B. (1998). Wartość pszczelarska ślázowki turyngskiej [The beekeeping value of Thuringian Mallow]. *Pszczelarstwo*, 49(11), 10–11.
- Staszewski, Z., & Staszewska, U. (1994). Thuringian Mallow (*Lavatera thuringiaca* L.) - An alternative crop of marginal conditions and wasted lands. In O. A. Rognli, E. Solberg, & I. Schjelderup (Eds.), *Breeding fodder crops for marginal conditions* (pp. 93–94). Kluwer Academic Publishers.
- Staszewski, Z., Staszewska, U., & Staszewski, L. (2008). Ślázówka – alternatywna roślina energetyczna [Mallow - An alternative energy plant]. In *Uwarunkowania Ekorozwoju*

- Turystyki i Rekreacji*. Proceedings of IV Forum Inżynierii Ekologicznej, Nałęczów (pp. 75–80). Lubelski Oddział Polskiego Towarzystwa Inżynierii Ekologicznej.
- Staszewski, Z., & Staszewski, L. (2014). Przydatność ślázówki w gospodarstwie pszczelarstwie o poszerzonym profilu produkcji [The usefulness of mallow in a beekeeping farm with an extended production profile]. *Pszczelarstwo*, 1, 14–16.
- Sumi, A. A., Khayer, A., Jhan, P. K., & Rubel, M. H. (2022). Medicinal plants as biocontrol agents: An *in vitro* study on black rot pathogen of cabbage (*Xanthomonas campestris* pv. *campestris*). *Acta Agrobotanica*, 75, Article 759.
- Szafer, W., Kulczyński, S., & Pawłowski, B. (1996). *Rośliny Polskie cz. I* [Polish plants/Plants of Poland part I]. PWN.
- Szczukowski, S. (2012). Wierzba *Salix* L. [Willow *Salix* L.]. In B. Kołodziej & M. Matyka (Eds.), *Odnawialne źródła energii. Rolnicze surowce energetyczne* (pp. 243–253). PWRiL.
- Tchórzewska, D. (2017). Chondriokinesis during microsporogenesis in plants. *Planta*, 246, 1–18. <https://doi.org/10.1007/s00425-017-2706-8>
- Tchórzewska, D., Pietrusiewicz, J., & Winiarczyk, K. (2013). Organelle aggregations during microsporogenesis with simultaneous cytokinesis in species from the family *Malvaceae* (*Gossypium arboreum*, *Alcea rosea*, *Lavatera thuringiaca*). *Annales UMCS Lublin, Sectio C*, 68(2), 35–44. <https://doi.org/10.2478/v10067-012-0032-x>
- Tchórzewska, D., Winiarczyk, K., Pietrusiewicz, J., & Bednara, J. (2008). A new type of microtubular cytoskeleton in microsporo-genesis of *Lavatera thuringiaca* L. *Protoplasma*, 232, 223–231. <https://doi.org/10.1007/s00709-007-0281-8>
- Tu, T. H., Kim, H., Yang, S., Kim, J. K., & Kim, J. G. (2019). Linoleic acid rescues microglia inflammation triggered by saturated fatty acid. *Biochemical and Biophysical Research Communications*, 513(1), 201–206. <https://doi.org/10.1016/j.bbrc.2019.03.047>
- Tuzlaci, E., Isbilen, D. F. A., & Bulut, G. (2010). Turkish folk medicinal plants, VIII: Lalapasa (Edirne). *Marmara Pharmaceutical Journal*, 14, 47–52. <https://doi.org/10.12991/201014463>
- Tyburski, J., & Kostrzewska, M. (2013). *Biologiczna różnorodność ekosystemów rolnych oraz możliwości jej ochrony w gospodarstwach ekologicznych* [Biological diversity of agricultural ecosystems and possibilities of its protection on organic farms]. UWM.
- Tylkowski, T., & Grupa, R. (2008). Efektywne metody skaryfikacji nasion robinii akacjowej [Effective methods of scarifying black locust seeds]. *Przegląd Leśniczy*, 18(8), 4–5.
- Vadivel, V., Sriram, S., & Brindha, P. (2016). Distribution of flavonoids among *Malvaceae* family members – A review. *International Journal of Green Pharmacy*, 10(1), 33–45.
- Vazquez-Thello, A., Hidaka, M., & Uozumi, T. (1995). Somatic embryogenesis and plant regeneration from isolated protoplasts of *Lavatera thuringiaca*. *Plant Cell, Tissue and Organ Culture*, 40, 169–177. <https://doi.org/10.1007/BF00037671>
- Vazquez-Thello, A., Yang, L. J., Hidaka, M., & Uozumi, T. (1996). Inherited chilling tolerance in somatic hybrids of transgenic *Hibiscus rosa-sinensis* × transgenic *Lavatera thuringiaca* selected by double-antibiotic resistance. *Plant Cell Reports*, 15, 506–511. <https://doi.org/10.1007/BF00232983>
- Vysochina, G. I., Kukushkina, T. A., Kotsupii, O. V., Zagurskaya, Y., & Bayandina, I. I. (2011). Flora of the forest-steppe zone of west Siberia as a source of biologically active compounds. *Contemporary Problems of Ecology*, 4(2), 202–211. <https://doi.org/10.1134/S1995425511020123>
- Willis, D. N., Liu, B., Ha, M. A., Jordt, S. E., & Morris, J. B. (2011). Menthol attenuates respiratory irritation responses to multiple cigarette smoke irritants. *FASEB Journal*, 25(11), 4434–4444. <https://doi.org/10.1096/fj.11-188383>
- Wongla, W., Theerakulpisut, P., & Lontom, W. (2023). Exogenous silicon application promotes growth and alleviates drought and salt stresses of rice plants. *Acta Agrobotanica*, 76, Article 172075. <https://doi.org/10.5586/aa/172075>
- Yemshanov, D., & McKenney, D. (2008). Fast-growing poplar plantations as a bioenergy supply source for Canada. *Biomass & Bioenergy*, 32(3), 185–197. <https://doi.org/10.1016/j.biombioe.2007.09.010>
- Yu, C. W., Li, W. H., Hsu, F. L., Yen, P. L., Chang, S. T., & Liao, V. H. C. (2014). Essential oil alloaromadendrene from mixed-type *Cinnamomum osmophloeum* leaves prolongs the lifespan in *Caenorhabditis elegans*. *Journal of Agricultural and Food Chemistry*, 62(26), 6159–6165. <https://doi.org/10.1021/jf500417y>
- Zhandabayeva, M. A., Kozhanova, K. K., Boshkayeva, A. K., Kataev, V. A., Ustenova, G. O., Gemejiyeva, N. G., & Iskakbayeva, Z. A. (2021). Determination of the chemical composition and antimicrobial activity of *Lavatera thuringiaca* L. medicinal herb material extracted under subcritical conditions by the liquid carbon dioxide method. *International Journal of Biomaterials*, 2021, Article 7541555. <https://doi.org/10.1155/2021/7541555>