Biomass Analysis of Industrial Hemp "Felina 32" and the Influence of Plant Height on its Quality

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The "Felina 32" variety of industrial hemp (*Cannabis sativa* L.) is among the most popular cultivated varieties in Lithuania. In 2020 to 2021, the height of the above-ground portion of "Felina 32" ranged from about 1.37 to 2.52 m. In the less favorable year of 2021, 9.8% lower height and 28.5% lower mass plants grew. However, the impact of meteorological conditions on their comparative indicators was not confirmed. Two critical intervals were distinguished, which essentially influence the dynamics of plant growth: crop density of 90 to 150 plants·m^2 and plant height of 1.9 m to 1.99 m. Lower crop density results in larger plants, and plants taller than 1.9 m gain mass 2.58 times faster than shorter plants. In addition, industrial hemp of different heights is characterized by differences in the development of morphological parts. This directly affects the physical and chemical properties of biomass. It was determined that when the height of "Felina 32" variety changes, the heat value of biomass increases 0.342 MJ/kg, carbon concentration increases 0.70%, and ash content, sulfur, nitrogen, and chlorine concentrations decreased.

DOI: 10.15376/biores.19.3.6380-6402

Keywords: Industrial hemp; "Felina 32"; Biomass; Crop density; Physical properties; Chemical properties; Cannabis sativa L.

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INTRODUCTION

Industrial hemp (*Cannabis sativa* L.) is an herbaceous annual plant with a height of up to 4 m, rarely up to 6 m. It has branched stems, is slightly woody in the lower part, and has finger-like pointed leaves. It is believed that the plant originated from central Asia, from the semi-arid climate zone. Hemp plants like sunlight but are easily adaptable and able to grow in different climatic conditions (Aleksynas 2007; Amaducci *et al*. 2015; Husain *et al*. 2019; Kołodziej *et al*. 2023). Therefore, industrial hemp has spread widely and is considered one of the oldest cultivated plants. Varieties of hemp are cultivated for seeds, fiber, and biologically active substances (Yang *et al*. 1991; Datwyler and Weiblen 2006; Fike 2016; Campiglia *et al*. 2017; Gudžinskas and Petrulis 2020). Industrial hemp spread especially widely in Europe in the 16th century. However, in 1924 they were classified as narcotic plants. Their cultivation and use subsequently have been restricted. In the recent period, the restrictions are being eased little by little, and the business of growing and processing hemp fiber is recovering (Gudžinskas and Petrulis 2020). From

2016 to 2021, the global industrial hemp market increased from 2760.00 million USD to 6226.85 million USD, *i.e*. 2.26 times (Verified Market Research 2022).

The renaissance of industrial hemp is also benefiting from the "green policy" and the development of the bioeconomy, which promotes the development of technologies for the production and conversion of biomass resources, the use of bio-raw materials in industry, and the processing of waste and secondary products into higher-value products (Vitunskienė 2019; Nordic Co-operation 2020).

The use of industrial hemp in the world is very wide. Hemp is grown both for seed and for plant biomass (Ahmed *et al*. 2022; Kołodziej *et al*. 2023). All parts of the plant are usefully employed, and products from various fields are produced. Due to its nutritional and medicinal properties, industrial hemp seeds are used in the food industry and medicine (Kołodziej *et al*. 2023). They contain a lot of protein (14 to 27%) and valuable amino acids, so they are suitable for dietary nutrition (Hadnađev *et al*. 2018; Crini *et al*. 2020; Kołodziej *et al*. 2023). They are also used in making butter (Crini *et al*. 2020), press oil of exceptional nutritional value, and pomace to make food products and feed. Hemp seed oil has exceptional nutritional value. Its properties are close to the best edible oils (olive, sesame) (Montserrat-de la Paz *et al*. 2014; Liang *et al*. 2015). Hemp seed oil in cosmetics is often included in the composition of moisturizing creams. It is also an excellent base for paints, varnishes, detergents, and soaps (Tutek *et al*. 2022). The essential oils, resins, and other biologically active substances accumulated in the inflorescences give industrial hemp specific properties, which allow the plants to be grown and used for the preparation of medicinal-plant raw materials (Campiglia *et al*. 2017; Hayley *et al*. 2018; Barčauskaitė *et al*. 2022). Industrial hemp has been used to make ropes, steel flax cores, and fabrics since ancient times. It is warm, has antibacterial properties and poor sweat odor sorption properties. However, it is strong and water-resistant, which is why it is especially loved by sailors (Ranalli *et al*. 2004; Jankauskienė and Gruzdevienė 2013). Hurds, which is rich in cellulose, is an excellent raw material to produce pulp, paper, construction and thermal insulation materials, and biodegradable packaging. Thus, industrial hemp biomass is an alternative to wood and plastic traditionally used in production; it can partially replace them, for example by replacing wood-plastic composites with hemp composites, replacing wood panels with hemp panels or conventional plastics in the food industry with 100% biodegradable hemp bioplastic (Lühr *et al*. 2018; Ahmed *et al*. 2022; Modi *et al*. 2022; Talcott *et al*. 2023).

Industrial hemp (*Cannabis sativa* L.) is characterized by a low investment requirement for cultivation, a short production cycle (Amaducci *et al*. 2015; Ahmed *et al*. 2022), as well as high versatility and productivity (Tang *et al*. 2016; Dimitriev *et al*. 2021; Kołodziej *et al*. 2023). It is claimed that the biomass yield of industrial hemp grown in Lithuania is about 10 t/ha DM (Žiura *et al*. 2023). However, researchers present very different biomass yield results: from 6.07 t/ha DM (variety "Felina 32") (Barčauskaitė *et al*. 2022), to 9.27 t/ha DM (variety "Fedora 17") (Černiauskienė *et al*. 2017), 11.85 t/ha DM (variety "Beniko") (Butkutė *et al*. 2015), 13.31 t/ha DM (variety "Wojko") (Černiauskienė *et al*. 2017), 15.53 t/ha DM (variety "Felina 32") (Žydelis *et al*. 2022) in Lithuania, from 9.9 t/ha DM to 14.4 t/ha DM (variety "Futura 75") in Sweden (Prade *et al*. 2011), from 10.4 t/ha DM (variety "Fasamo") to 12.0 t/ha DM (variety "Ferimon") (Kołodziej *et al*. 2023) in Poland, from 10.6 t/ha DM (variety "Fasamo") to 34.5 t/ha DM (variety "Ferimon") (Swanepoel *et al*. 2018) in New Zealand, from 9.4 t/ha DM to 13.6

t/ha DM (variety “Futura 75”) (Tang *et al*. 2017) in France, Italy, Latvia, and the Czech Republic on average.

Hydrometeorological conditions during the growing year, fertilization, soil quality, and other conditions are the main factors that determine the biomass yield of industrial hemp (Campiglia *et al*. 2017; Černiauskienė *et al*. 2017; Flajšman and Kocjan Ačko 2020). Studies also emphasize the effect of plant genotype, citing it as one of the most important types (Campiglia *et al*. 2017; Swanepoel *et al*. 2018). Contrary to other reports that single out the significant influence of crop density in the formation of hemp yield (Amaducci *et al*. 2015; Tang *et al*. 2017; Swanepoel *et al*. 2018; Dimitriev *et al*. 2021). This idea is also confirmed by Barčauskaitė *et al*. (2022), but she did not emphasize the significance of the effect of fertilization on the above-ground biomass yield. Additionally, moisture balance disturbances in the early stages of plant development, weeds (Flajšman and Kocjan Ačko 2020), sowing density (cropping density), and harvest time (Kołodziej *et al*. 2023) have a significant negative impact on the performance of industrial hemp.

The impact of agrotechnological measures on the hemp biomass has been studied and is being studied by many scientists. The abundance of factors, their diversity, and complex effects do not reduce the relevance of analogous studies. However, it is also necessary to consider that factors can have different effects on a plant crop, individual plant, or its parts. When evaluating the cultivation technology, it is important to pay more attention to the specific morphological parts of the plants that are intended for further processing or use. For example, Campiglia *et al*. (2017) found that increasing the rate of nitrogen fertilizer from 50 kg·ha^{-1} to 100 kg·ha^{-1} increased the biomass yield of stems 28% and inflorescences by 17%. However, only a 4% positive effect was recorded on seed yield. Analogous trends were recorded by other researchers (Tang *et al*. 2017). The effect of nitrogen fertilization on seed yield was not statistically reliable, in contrast to the yield of stems and aerial plant mass. In addition, it was found that the influence of seeding density on yield increase is limited compared to its effect on stem biometric indicators (Struik *et al*. 2000; Amudacci *et al*. 2015). Thus, plant cultivating strategy and agronomic practices must be flexible and selected based on crop objectives (Campiglia *et al*. 2017; Livingstone *et al*. 2022), cultivated plants, their specific morphological parts, and purpose.

When developing such a cultivation strategy and agronomic practice, there has been a lack of greater attention to such studies that would analyze the influence of morphological parts on the quantitative-qualitative value of plant biomass. Different morphological parts of the plant have specific physical and chemical properties. Thus, as the height of the plant changes, and at the same time the development of the morphological parts and their relationship, the general physical and chemical properties of the whole plant also change. This is especially true for industrial hemp and other plants that have a distinct morphological structure and do not have a single dominant morphological part, and the cultivation target is the whole plant biomass rather than a specific plant morphological part such as seed or fiber. In this case, plant height and its influence on plant morphology can be used to control the physical and chemical properties of the harvested biomass (the aerial part of industrial hemp).

The aim of the study was to evaluate the biometric indicators (plant height, stem diameter, chemical composition) of “Felina 32” industrial hemp (*Cannabis sativa* L.) grown in the cool temperate climate zone (Lithuania). The plant mass, height, and stem diameter were tested to perform an analysis of their dispersion, and also to determine the effect of plant height on above-ground vegetation as a potential predictor of the morphological composition, physical-chemical properties, and quantitative-qualitative value of biomass.

EXPERIMENTAL

Materials

The research was carried out for two years (2020 to 2021), in collaboration with the Laboratory of Biomass Preparation, Logistics and Solid Fuel Processes of the VMU Agricultural Academy, and the LAMMC Institute of Agriculture at Lithuania.

Research Object and Cultivation Conditions

The object of the research is the above-ground plant material of industrial hemp (*Cannabis sativa* L.) variety "Felina 32". Industrial hemp was grown at LAMMC Institute of Agriculture, Dotnuva, Lithuania. In the field of the Department of Plant Nutrition and Agroecology, industrial hemp experimental fields were set up for research conducted at the institute. Raw material used for this study was used from the control-protective strips, which were 3 m wide and were used for the control variants of the research, as well as for separating the test fields from each other. In the control-protective strips, industrial hemp was grown without fertilization by sowing into prepared soil, which was plowed to a depth of 25 cm and cultivated in the autumn and germinated and cultivated in spring. The granulometric composition of the field soil is Endogleyic Endostagnic Endocalcaric Luvisol (Loamic) soil according to WRB IUSS Working Group, the amount of mobile potassium in the soil was 260 mg/kg, mobile phosphorus – 110 mg/kg, and nitrogen - 144 mg/kg. Depending on the meteorological conditions, industrial hemp was sown on May 8, 2020 and May 21, 2021. The seed rate was 15 kg/ha, the seeds were not sprayed, pesticides were not used, and weed control was carried out manually at the beginning of the growing season. The used hemp plants were cut randomly from the control-protective strips in the second half of August, when the plants were flowering.

Crop density studies were carried out in parallel in the hemp plant field; after randomly selecting a research plot of 0.25 m^2 area, all hemp plants that fell into the selected area were cut. Then, the number of cut plants, their weight, the average weight of one plant, and the yield of the crop were calculated. This study was carried out in the entire industrial hemp field, regardless of the purpose of the experimental field and the agrotechnological conditions used. In total, the study was repeated 32 times, 16 times each year.

Methods

Determination of biometric indicators of hemp plant biomass

Research in the Biomass Preparation, Logistics and Solid Fuel Process Laboratory was conducted using 90 plants each year. The aerial parts of hemp plant were randomly selected from the control-protection strips in the experimental field. In the laboratory, industrial hemp plants were first measured by determining total plant height, inflorescence length, and stem diameter at the base of each plant individually. Then, the leaves and inflorescence were separated from the stem of the plant. The above-ground part of plant was divided into separate morphological parts: stem, leaves, and inflorescence. All morphological parts were weighed with a Scaltec SPO 62 scale. This was done with each plant brought from the field to the laboratory for testing separately. The moisture content of the stem, leaves, and inflorescence was determined by drying their samples (at least 8 units each) at a temperature of 105 ± 0.5 °C in a drying cabinet Memmer UF 450 Plus to a constant mass. Samples for moisture tests are prepared by randomly selecting raw material from different plants and chopping it into 1 to 3 cm-long pieces with a secateur. The remaining raw material was dried to a safe moisture content and crushed to 1-mm particles with a Retsch SM 300 rotary chopper.

According to the obtained research results, the average moisture content of all morphological parts of the plant, their mass (wet and dry raw material), dimensions (plant height, stem and inflorescence lengths, and stem diameter at the base) were determined, and their percentages in the total mass of the above-ground part of the plant were also estimated. The average mass and moisture content of the whole plant were calculated using Eqs. 1 and 2,

$$\omega = \frac{\omega_s \times m_s + \omega_z \times m_z + \omega_l \times m_l}{m_s + m_z + m_l} \tag{1}$$

$$M_{d.m.} = m_s + m_z + m_l \tag{2}$$

where ω is the average moisture content of the entire above-ground part of hemp plant, %;ω_s, ω_z, and ω_l are the average moisture contents of stem, inflorescence, and leaves of hemp, respectively (%); m_s, m_z, m_l are the average mass of stem, inflorescence, and leaves (wet raw material) in the above-ground part of hemp, respectively (g); and $M_{d.m.}$ is the average mass of the above-ground part (primary raw material) of cut industrial hemp (g).

To compare plants harvested in different years, comparative indicators were additionally calculated: comparative plant mass and comparative stem diameter:

$$M_{lyg} = \frac{M_{w.m.} \times (100 - \omega)}{100 \times L} = \frac{M_{d.m.}}{L} \tag{3}$$

$$d_{lyg} = \frac{d}{L} \tag{4}$$

where M_{lyg} is the comparative dry weight of the above-ground part (plant) (g DM/m); d_{lyg} is the comparative diameter of the stem (mm/m); $M_{w.m.}$ is the average mass of the above-ground part (primary raw material) (g); $M_{d.m.}$ is the average dry weight of the above-ground part (primary raw material) of cut hemp (g DM); ω is the average moisture content of the above-ground part of all industrial hemp (%); d is the average diameter of the stem, mm.; L is the average height of the above-ground part (plant) of the cut industrial hemp (m).

Determination of chemical properties

The ECS 4010 combustion system was used in the study to determine the composition of chemical elements in the raw material. The raw material was first placed in tin cans of 10 mg, then the filled cans were placed in an automatic sampling device. In the analyzer, the sample was combusted in a special gas environment with a supply gas flow of 110 mL/min, as well as 110 mL/min of nitrogen gas and 180 mL/min of oxygen gas. To calculate the obtained amounts of chemical elements, the "Element Analysis Software" was used, which provides the percentage of chemical elements present in the studied raw materials. Determination of carbon, nitrogen, and sulfur (CNS) contents was achieved by the Dumas method.

Determination of calorific value and ash content

During the study, thermal properties and ash content of morphological parts (stem, inflorescence, and leaves) of the above-ground part of industrial hemp were determined. According to the methodology of the LST EN 14918 (2010) standard, calorific value measurements were performed using an IKA C2000 calorimeter (IKA-Werke GmbH & Co, Staufen, Germany). The sample tablet formed from the corresponding crushed raw material of the 1.0 mm size fraction was weighed and placed in the calorimetric bomb. During the research, it is burned and the upper calorific value of the analyzed sample $Q_{an.sam.}^{v}$ is determined. Using the obtained results of calorific value and moisture determination, $Q_{d.}^{v}$ is the upper calorific value for dry mass and was calculated using the formula,

$$Q_{gr.d}^{v} = Q_{gr}^{v} \times \left(\frac{100}{100-\omega}\right) \tag{5}$$

where $Q^{v}_{gr.d}$ is the upper calorific value of dry raw material (kJ/kg); Q^{v}_{gr} is the upper calorific value of the raw material (kJ/kg); and ω is the moisture content of the raw material (%).

When determining the ash content, the methodology used is presented in the LS EN 14775 (2010) standard. Each 1 g mass of industrial hemp stems, inflorescences, and leaves, which had previously been crushed to a size fraction of 1.0 mm, was placed in crucibles. The crucibles were previously weighed empty and, after adding the samples, reweighed with raw material. After that, the crucibles were placed in the Czylok heating furnace and heated according to the procedure specified in the standard up to 550 °C. At the end of the heating process, the crucibles were weighed with the rest of the raw material - ash. After assessing the moisture content of the raw material, the ash content A_d was calculated,

$$A_d = \frac{(m_3 - m_1)}{(m_2 - m_1)} \times \left(\frac{100}{100-\omega}\right) \tag{6}$$

where m_1 is the mass of the empty crucible (g); m_2 is the mass of crucible with raw material before heating, g; m_3 is the mass of crucible with ash (after heating) (g); and ω is the moisture content of the raw material (%).

In parallel with the ash content and calorific value tests, the moisture content of the studied raw material was determined: the samples were dried (at least 5 units of each raw material) at a temperature of 105 ± 0.5 °C in a Memmer UF 450 PLUS drying cabinet to a constant mass.

Statistical Analysis

The results of the studies were determined after at least eight replicates and evaluated statistically using the Microsoft Excel ANOVA (analysis of variance) subroutine of the data package, and estimating the standard error using the correlation coefficient, when significance levels were $P \leq 0.05$ and $P \leq 0.01$.

RESULTS AND DISCUSSION

The dry mass of the above-ground part of the hemp (*Cannabis sativa* L.) plant of the "Felina 32" variety was randomly selected and varied from 22.3 g DM (61.7 g wet mass) to 105.6 g DM (269.1 g wet mass). Plants weighing 40 to 49.9 g, 30 to 39.9 g, and 50 to 50.9 g dominated (Fig. 1). They accounted for 66.7% of the plants used in the studies, 25.5%, 22.4%, and 18.8%, respectively. Less than 30 g DM weighing plants accounted for only 3.6% of industrial hemp, and more than 100 g DM – only 1.0%. The average mass of the industrial hemp plant was 53.2 ± 2.45 g DM (Table 1), *i.e*., 138.9 ± 6.16 g of wet mass (average moisture content of the above-ground part of the industrial hemp plant is 61.7 ± 0.53%). In 2020, the average mass of the industrial hemp plant was 59.9 ± 3.98 g DM (154.0 ± 10.20 g wet mass). This is 28.5% more than the average plant mass in 2021, 46.6 ± 2.21 g DM (123.9 ± 5.61 g wet mass).

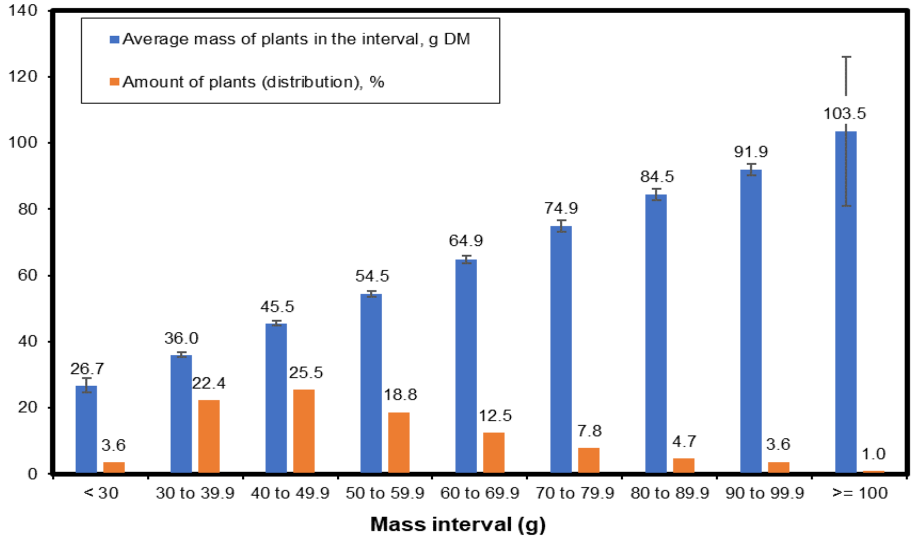

Fig. 1. Characteristics of hemp plants used for research in 2020 to 2021

Industrial hemp of the "Felina 32" variety is a relatively high biomass-accumulating plant with stable properties. The "Felina 32" variety of industrial hemp is one of the most commonly grown in European countries such as Italy or France (Raymunt 2020). In Lithuania, industrial hemp of this variety accounted for 5.59% of the total cultivated hemp area in 2018 to 2021, occupying from the 3rd to the 6th place in terms of the most cultivated area among the other varieties (VATZUM 2024). This variety is distinguished by the average amount of biomass and seeds produced, compared to other varieties (HEMPOINT 2024). From 2013 to 2016, comparative studies of nine industrial hemp varieties were conducted in Lithuania (Černiauskienė *et al*. 2017): the mass of the above-ground part of different hemp plant varieties varied from 45.34 ± 29.18 g (variety "Wojko") to 102.22 ± 62.65 g (variety "Beniko") wet mass. The mass of the above-ground part of "Felina 32" variety hemp was 87.80 ± 29.19 g wet mass, *i.e*., 1.31 times higher than the average plant mass of all cultivars used in the study, 66.86 g wet mass. In addition, "Felina 32" plants had the lowest mass dispersion: the ratio between the confidence interval and its descriptive value was the lowest, only 0.66. According to the mass of the plant and the intensity of its accumulation, it is possible to judge the power of the plant (powerful) (Dimitriev *et al*. 2021). It also reveals the prevailing growing conditions. The analysis and comparison of research results obtained in 2020 to 2021 with the data provided by Černiauskienė *et al*. (2017) confirmed the influence of crop density on hemp plants. A crop with a lower number or plants and hence a larger nutritional area create conditions for the formation of plants of greater mass and larger dimensions (Campiglia *et al*. 2014; Swanepoel *et al*. 2018; Dimitriev *et al*. 2021). In 2020 to 2021, the sowing rate was reduced from 3.2 to 1.1 million seeds per hectare (from 320 plants/m^2 to 110 plants/m^2) and the row spacing was increased from 10 to 12 cm, resulting in 1.58 times greater the mass of the above-ground part of the plant and its dispersion (confidence interval) 4.74 times lower than in 2013 to 2016. An inverse relationship between plant mass and crop density was also found by Campiglia *et al*. (2017). After a 3-fold reduction in the planting density of "Felina 32" plants - from 120 stems/m^2 to 40 stems/m^2, the average mass of industrial hemp stems increased 1.8 and 2.0 times, respectively, when 50 kg/ha and 100 kg/ha of N fertilization rates were used. Based on the obtained research results and research conducted by other scientists, a relationship was established between the mass of the above-ground part of hemp variety "Felina 32" and plant density in the crop (Fig. 2), where the coefficient of determination was 0.937:

$$m_a = 1021 \times n^{0.983} \tag{7}$$

In Eq. 7, m_a is the dry mass of the above-ground part of the hemp plant (g), and n is the density of plants in the crop (crop density), (units/m^2).

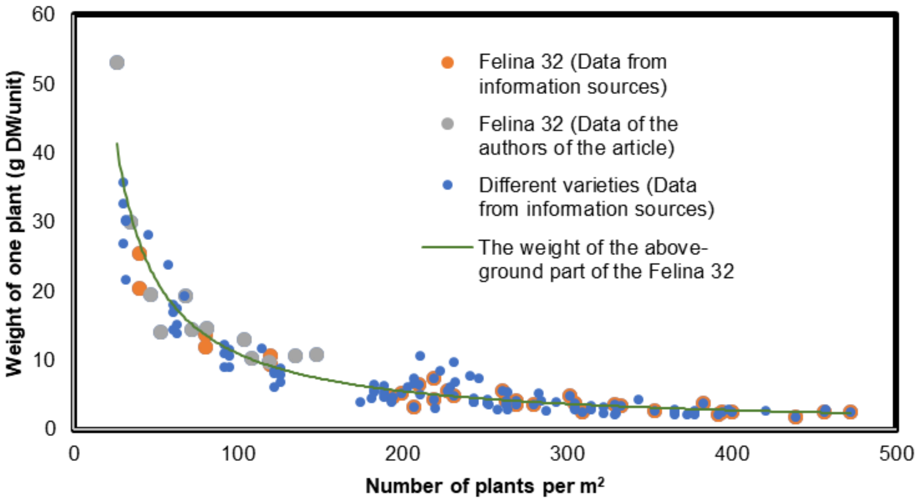

Fig. 2. The dry mass of the above-ground part of "Felina 32" and other hemp varieties (according to the data of the authors of the article and other researchers) (Burczyk *et al*. 2009; Jankauskienė and Gruzdevienė 2010; Campiglia *et al*. 2017; Maumevičius *et al*. 2019; Kołodziej *et al*. 2023)

In the control field strips of "Felina 32", from which plants were taken for the research of the authors of the article, the average crop density was 26.0 ± 3.72 plants/m^2, and the average dry mass of the above-ground part of one plant was 53.2 ± 2.45 g (Fig. 2). Across the industrial hemp field, the crop density ranged from 18 plants/m^2 to 164 plants/m^2 in different test plots. At that time, the mass of the above-ground part of the plants varied from 105.2 g DM up to 5.49 g DM. A gradual dependence of plant mass on crop density has also been recorded for other varieties of industrial hemp.

The obtained results confirmed the conclusions of other researchers that with increasing crop density, industrial hemp produces lower mass (Burczyk *et al*. 2009; Campiglia *et al*. 2017; Maumevičius *et al*. 2019), smaller diameter and lower stems

(Jankauskienė and Gruzdevienė 2010; Campiglia *et al*. 2017; Tang *et al*. 2017; Dimitriev *et al*. 2020; Kołodziej *et al*. 2023). Campiglia *et al*. (2017) found that plants were taller in a sparser crop at full bloom: 183.5 cm in a crop with a density of 120 plants/m^2 and 227 cm in a crop with a density of 40 plants/m^2. In a dense crop, plants grow taller only at the beginning of the growing season. The competition for light, nutrients, and the desire to reach the reproductive stage faster encourage young plants to develop and shoot upwards faster (Amaducci *et al*. 2008; Flajšman and Kocjan Ačko 2020). Later, the growth of industrial hemp slows down and the older internodes stop elongating altogether. Their diameter changes more actively than their length (Behr *et al*. 2017). This changes the mechanical properties of the plant stem and increases its resistance to breakage (Livingstone *et al*. 2022). The diameters of industrial hemp stems vary relatively more than the height of the plants. In the reviewed articles, the stem diameter of different cultivars of industrial hemp ranged from 3.3 mm to 41.9 mm (ratio 12.70) and height from 0.799 m to 3.56 m (ratio 4.46) (Černiauskienės *et al*. 2017; Flajšman and Kocjan Ačko 2020; Amarasinghe *et al*. 2022; Panahi *et al*. 2024). In addition, a more active response of stem diameter to growing conditions is recorded. Depending on fertilization, plant stem diameters ranged from 6.5 mm to 8.5 mm (ratio 1.85) and heights from 2.077 m to 2.671 m (ratio 1.29) in studies reported by Schäfer (2005). Depending on the seeding density, plant stem diameters varied from 7.3 mm to 12.9 mm (ratio 1.77) and heights from 2.392 m to 3.024 m (ratio 1.26) in the research results presented by Dimitriev *et al*. (2021).

Crop density has a significant impact on biometrics not only for industrial hemp. It also influences the choice of harvesting system and mechanical treatment strategy, the suppressive effect on weeds, and the quality indicators of the future harvest. Therefore, when growing industrial hemp for textile purposes, a crop density of more than 300 plants/m^2, with a sowing rate of 50 to 60 kg of seeds per hectare is recommended (Riddlestone *et al*. 2006; Tang *et al*. 2017; Dimitriev *et al*. 2020; Kołodziej *et al*. 2023). At that time, industrial hemp seeds are advised to grow at a density of 70 to 100 plants/m^2 per crop, using a seeding rate of 10 kg seeds per hectare (Tang *et al*. 2017; Kołodziej *et al*. 2023; Yazici 2023), and dual-purpose industrial hemp at 90 to 150 plants/m^2 density in the crop (Tang *et al*. 2017; Flajšman *et al*. 2020). For the cultivation of industrial hemp for biomass and energy purposes, cropping density recommendations range from 90 to 100 plants/m^2 (Flajšman *et al*. 2020) to 200 plants/m^2 (Tang *et al*. 2017; Kołodziej *et al*. 2023): there is unanimous agreement for a sowing rate of less than 30 kg of seeds per hectare. For the effective suppression of weeds, which strongly influence the yield of industrial hemp (Swanepoel *et al*. 2018; Flajšman *et al*. 2020), a sufficiently dense plant canopy is necessary: a crop density of at least 80 plants/m^2 is recommended, with a row width of up to 15 cm, and a crop density of 160 plants/m^2 at a row width of up to 30 cm (Swanepoel *et al*. 2018).

However, the height of the plant and the diameter of its stem are primarily determined by the genotype and the prevailing meteorological conditions during the growing year (Campiglia *et al*. 2017; Tang *et al*. 2017; Flajšman *et al*. 2020). In 2020, the "Felina 32" variety of hemp plant were heavier and taller. The largest part of the plants was 2.20 to 2.29 m in height and 60 to 69.9 g DM in mass (Table 1). Cooler and drier 2020 May (10.6 ± 1.0 °C temperature and 17.8 mm precipitation, climatic norm 12.7 ± 3.8 °C and 52.2 mm) and July (17.6 ± 0.87 °C temperature and 21.9 mm of precipitation) months had less impact on plant productivity than a prolonged hot and dry period in the summer of 2021: in June the average temperature and precipitation were 19.6 ± 1.1 °C and 10 mm (climatic norm 15.8 ± 1.7 °C and 62.3 mm), and in July - 22.9 ± 0.86 °C and 7 mm (climatic norm 17.0 ± 2.1 °C and 74.7 mm). In August 2021, the environmental conditions became more favorable. The average ambient temperature decreased to 16.3 ± 0.67 °C, and the amount of precipitation increased to 50.3 mm (climatic norm 17.3 ± 4.3 °C and 74.2 mm). However, hemp plants had already failed to make up for the early summer development losses. In hotter and drier years, hemp does not grow as large (Campiglia *et al*. 2017): in 2021 the average height of hemp stems was 9.76% lower than in 2020 (1.987 ± 0.062 m) and reached only 1.793 ± 0.049 m. A significant dominance of plants of the lower height interval - 1.90 to 1.99 m was recorded. They accounted for 17.71% of plants. 45.8% of the plants consisted of plants belonging to three height intervals: 1.90 to 1.99 m, 1.80 to 1.89, and 2.00 to 2.09 m. Therefore, the crop in 2021 was relatively homogeneous. It can also be said that for the development of industrial hemp, poorer environmental conditions led to a larger number of low plants, and at the same time, of lower mass, which accumulated less biomass.

Table 1. Biometric Data of the Above-ground Part of Industrial hemp of "Felina 32" Variety

Year	Height Interval (m)	Distribution of Plants (%)	Average plants:			Comparative Stem Diameter (mm/m)	Comparative Plant Mass (g DM/m)
			Height (m)	Stem Diameter (mm)	Mass (g DM)		
2020 to 2021	< .4	5.21	1.367 ± 0.020	8.93 ± 0.242	38.8 ± 4.29	^{1} 6.54 ± 0.184	^{1} 28.4 ± 3.13
						^{2} 6.57 ± 0.416	^{2} 27.8 ± 7.90
						^{3} 6.51 ± 0.291	^{3} 28.8 ± 4.60
	1.4 to 1.49	6.25	1.456 ± 0.017	9.36 ± 0.267	37.8 ± 3.56	^{1} 6.43 ± 0.194	^{1} 26.0 ± 2.65
						^{2} 6.00 ± 0.087	^{2} 27.8 ± 4.13
						^{3} 6.52 ± 0.182	^{3} 25.6 ± 3.23
	1.5 to 1.59	8.33	1.549 ± 0.017	9.55 ± 0.326	36.7 ± 4.31	^{1} 6.17 ± 0.197	^{1} 23.7 ± 2.81
						^{2} 6.14 ± 0.291	^{2} 26.1 ± 5.81
						^{3} 6.19 ± 0.326	^{3} 21.8 ± 2.81
	1.6 to 1.69	7.81	1.648 ± 0.017	10.19 ± 0.299	47.0 ± 5.71	^{1} 6.18 ± 0.158	^{1} 28.6 ± 3.48
						^{2} 6.21 ± 0.406	^{2} 32.8 ± 5.10
						^{3} 6.17 ± 0.170	^{3} 25.7 ± 4.31
	1.7 to 1.79	9.90	1.756 ± 0.014	10.52 ± 0.314	42.9 ± 4.39	^{1} 5.99 ± 0.174	^{1} 24.4 ± 2.49
						^{2} 5.98 ± 0.271	^{2} 23.5 ± 4.17
						^{3} 6.00 ± 0.278	^{3} 25.5 ± 3.42
	1.8 to 1.89	11.46	1.845 ± 0.012	10.92 ± 0.266	45.2 ± 3.84	^{1} 5.92 ± 0.138	^{1} 24.6 ± 2.09
						^{2} 5.98 ± 0.184	^{2} 24.2 ± 6.70
						^{3} 5.89 ± 0.196	^{3} 24.8 ± 1.80
	1.9 to 1.99	14.58	1.947 ± 0.011	11.45 ± 0.221	55.9 ± 4.03	^{1} 5.88 ± 0.107	^{1} 28.7 ± 2.05
						^{2} 5.99 ± 0.175	^{2} 30.4 ± 3.85
						^{3} 5.81 ± 0.139	^{3} 27.6 ± 2.49
	2.0 to 2.09	10.42	2.043 ± 0.015	12.11 ± 0.337	51.9 ± 5.47	^{1} 5.92 ± 0.145	^{1} 25.4 ± 2.62
						^{2} 6.09 ± 0.191	^{2} 24.7 ± 5.85
						^{3} 5.81 ± 0.198	^{3} 25.9 ± 3.01
	2.1 to 2.19	9.90	2.142 ± 0.015	12.85 ± 0.321	67.0 ± 5.72	^{1} 6.00 ± 0.141	^{1} 31.3 ± 2.75
						^{2} 6.01 ± 0.195	^{2} 32.3 ± 3.86
						^{3} 5.97 ± 0.253	^{3} 29.1 ± 3.37

	2.2 to 2.29	8.33	2.245 ± 0.015	13.54 ± 0.375	71.3 ± 8.01	^{1} 6.03 ± 0.158 ^{2} 6.00 ± 0.178 ^{3} 6.20 ± 0.740	^{1} 31.8 ± 3.61 ^{2} 32.7 ± 3.76 ^{3} 25.4 ± 6.03
	2.3 to 2.39	3.65	2.336 ± 0.032	14.14 ± 0.697	80.7 ± 13.60	^{1} 6.05 ± 0.270 ^{2} 6.04 ± 0.335 ^{3} 6.09 ± 0.540	^{1} 34.5 ± 5.73 ^{2} 36.2 ± 4.85 ^{3} 24.2 ± 5.16
	2.4 to 2.49	2.08	2.450 ± 0.068	15.48 ± 1.114	83.6 ± 25.7	^{1} 6.32 ± 0.401 ^{2} 6.32 ± 0.401 ^{3} -	^{1} 34.1 ± 9.83 ^{2} 34.1 ± 9.83 ^{3} -
	≥ 2.5	2.08	2.525 ± 0.042	15.67 ± 1.306	88.9 ± 16.06	^{1} 6.20 ± 0.425 ^{2} 6.20 ± 0.425 ^{3} -	^{1} 35.2 ± 6.83 ^{2} 35.2 ± 6.83 ^{3} -
	All plants	100	1.890 ± 0.042	11.43 ± 0.250	53.2 ± 2.45	6.06 ± 0.050	27.8 ± 0.885
2020	All plants	100	1.987 ± 0.062	12.06 ± 0.393	59.9 ± 3.98	6.08 ± 0.064	29.7 ± 1.423
2021	All plants	100	1.793 ± 0.049	10.79 ± 0.259	46.6 ± 2.21	6.05 ± 0.078	25.9 ± 0.929

Note: 1 – 2020 to 2021 harvest; 2 - 2020 harvest; 3 – 2021 harvest; yellow color - no significant difference; green color - significant difference when $P < 0.01$; blue color - significant difference at $P < 0.05$ (essential differences were checked in the height range between the results of different years, as well as the final results were compared between the overall results and the results of different years)

In 2021, there were 2.67 times more plants less than 1.5 m tall than in 2020, 16.67% and 6.25%, respectively. At that time, plants taller than 2.4 m were recorded only in 2020. They accounted for 8.34% of all plants.

The diameters of the analyzed stems of "Felina 32" variety hemp at the base ranged from 8.34 mm to 16.66 mm. Plants with stems 9.0 to 12.99 mm in diameter were mostly recorded. They accounted for 74.5% of all industrial hemp: with stems with a diameter of 9.0 to 9.99 mm - 15.63%, with stems with a diameter of 10.0 to 10.99 mm - 23.96%, with stems with a diameter of 11.0 to 11 .99 mm diameter stems - 17.71%, with 12.0 to 12.99 mm diameter stems - 17.19%. Fixed exponential dependence of the stem diameter of industrial hemp on plant height (Fig. 3), coefficient of determination – 0.886:

$$d_s = 4.51 \times e^{0.486 \times L} \tag{8}$$

where d_s is the diameter of the industrial hemp stem at the base (mm) and L is the plant height (m).

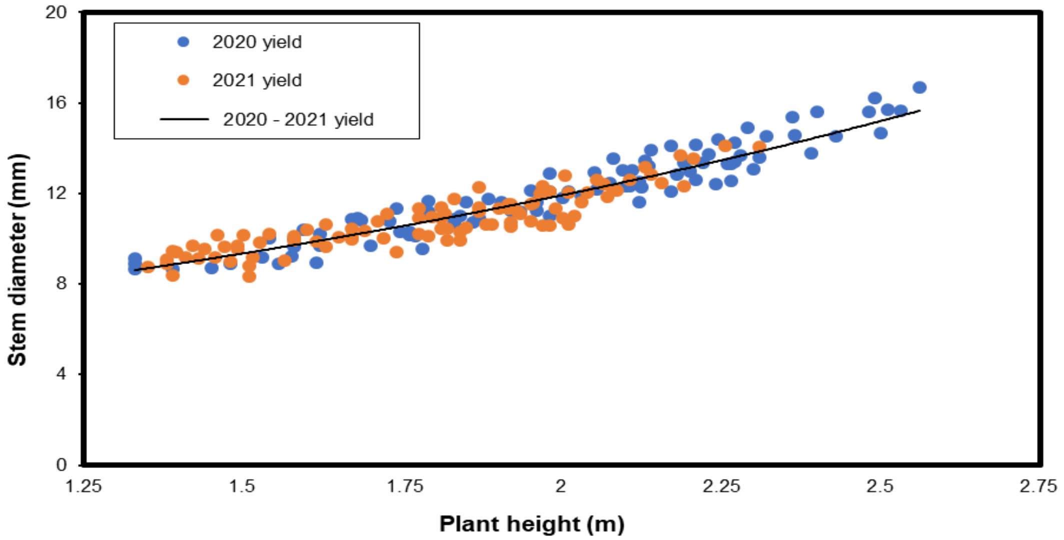

Fig. 3. Dependence of stem diameter of industrial hemp variety "Felina 32" on plant height

The average diameter of industrial hemp stems at the base was 11.43 ± 0.250 mm: 12.06 ± 0.393 mm in 2020 and 10.79 ± 0.259 mm in 2021 (Table 1). Thus, in 2020, the average diameter of the industrial hemp stems of the "Felina 32" variety was 11.77% larger, and the fixed difference between them was substantial. However, in 2020 the plants were also taller. After calculating and comparing the comparative diameters - the ratio between the diameters of industrial hemp stems and plant heights (mm/m), the essential difference between the plant dimensions of 2020 and 2021 was not confirmed. The significant difference was not confirmed when comparing both the average comparative diameters of all plants and the comparative diameters of plants in separate height intervals (at $P < 0.01$).

Comparing the average comparative weights of industrial hemp in 2020 and 2021, respectively, 29.7 ± 1.423 g DM/m and 25.9 ± 0.929 g DM/m, a significant difference was confirmed. However, the condition of testing for a significant difference was not confirmed when comparing the relative plant weights at different height intervals (at $P < 0.01$). The obtained results did not confirm the effect of hydrometeorological conditions on the comparative indicators of the industrial hemp of "Felina 32" variety grown in different years - comparative diameter and comparative weight. In the less favorable year 2021, plants of smaller dimensions grew, but the proportions of plant development were within the limits of error. The dominance of smaller plants also led to the significance of the difference between the average comparative weights of industrial hemp. In 2021, the average height of the industrial hemp stem (1.793 ± 0.049 m) was 9.76% lower, and the average comparative mass of the industrial hemp plant (25.9 ± 0.929 g DM/m) was 12.79% lower than in 2020.

Analyzing the masses of industrial hemp of the "Felina 32" variety at different heights, it was found that tall and short plants require different above-ground plant mass accumulation dynamics (Fig. 4). A significant change was confirmed when the plants reached a height of 1.9 to 1.99 m.

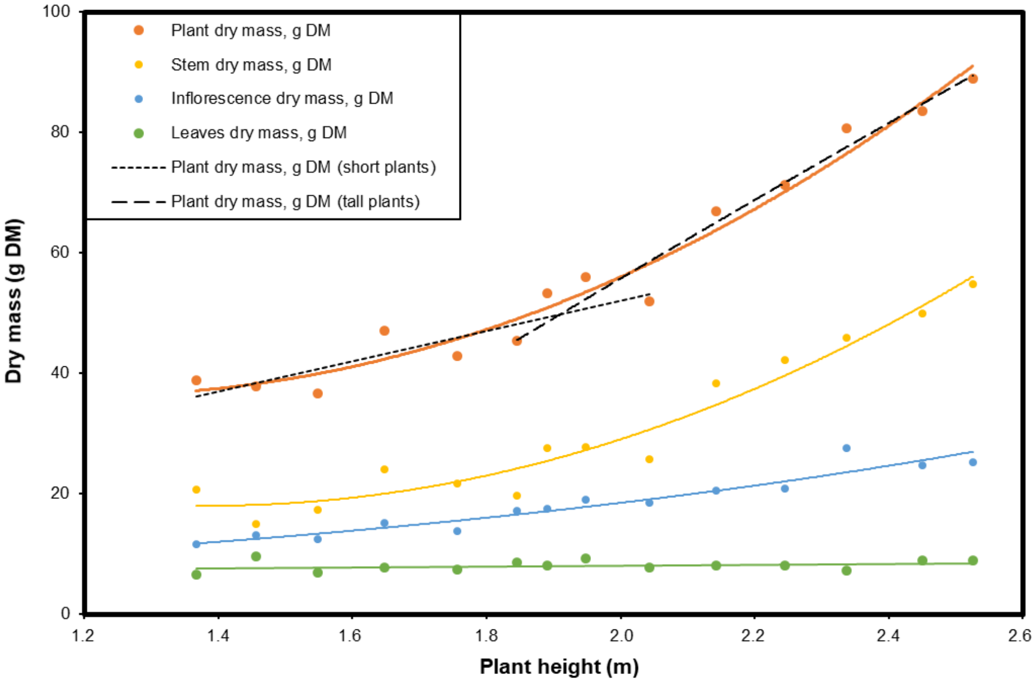

Fig. 4. Masses of industrial hemp plants and their morphological parts of different heights

Taller hemp accumulates more above-ground plant mass. In addition, as the height of the plant increases, the intensity of biomass accumulation also increases. As the height of industrial hemp increases 1.0 m, plants below 2 m tall accumulate mass at a rate of 25.0 g DM/m, and plants above 1.9 m tall at a rate of 64.6 g DM/m, *i.e.*, 2.58 times faster (Figs. 4 and 5).

Differences in the development of morphological parts of the plant are also characteristic of lower and higher industrial hemp. The most striking changes occur with the stems of industrial hemp. In plants up to 2 m tall, the length of the stems increases faster than their diameter. Therefore, the stems of industrial hemp become relatively thinner, and their comparative diameters decrease. After reaching a height of 1.9 to 1.99 m, plant growth slows down: stem lengths increase more slowly than their diameters, industrial hemp stalks thicken. At the same time, their mass increases more intensively. In plants taller than 1.9 m, biomass of industrial hemp stems accumulates 3.99 times faster than in plants shorter than 2.0 m, corresponding to 51.0 g DM/m and 12.8 g DM/m.

In the second half of August, when the plant samples of the “Felina 32” variety were cut in the fields, the difference in the masses of the industrial hemp inflorescences used for the research of lower and higher plants was not essential. Inflorescences of industrial hemp below 2.0 m in height weighed on average 15.4 ± 0.965 g DM, and the intensity of mass accumulation was only 11.0 g DM/m. In plants taller than 1.9 m, the inflorescence mass accumulation rate was only 1.25 times (13.7 g DM/m) higher, and their average mass was only 20.6 ± 1.308 g DM.

The conducted studies did not confirm the influence of plant height on leaf biomass: the leaves of plants lower than 2.0 m in height weighed 8.16 ± 0.666 g DM, and those taller than 1.9 m - 8.37 ± 0.658 g DM. Both shorter and taller industrial hemp plants grown under the same conditions accumulated similar amounts of leaf biomass. No significant difference was found between them. Furthermore, in contrast to stems and inflorescences, leaf biomass accumulated more intensively in plants below 2.0 m than in taller plants. For "Felina 32" variety industrial hemp taller than 1.9 m, there was a fixed trend in the rate of leaf mass accumulation to decrease rather than increase.

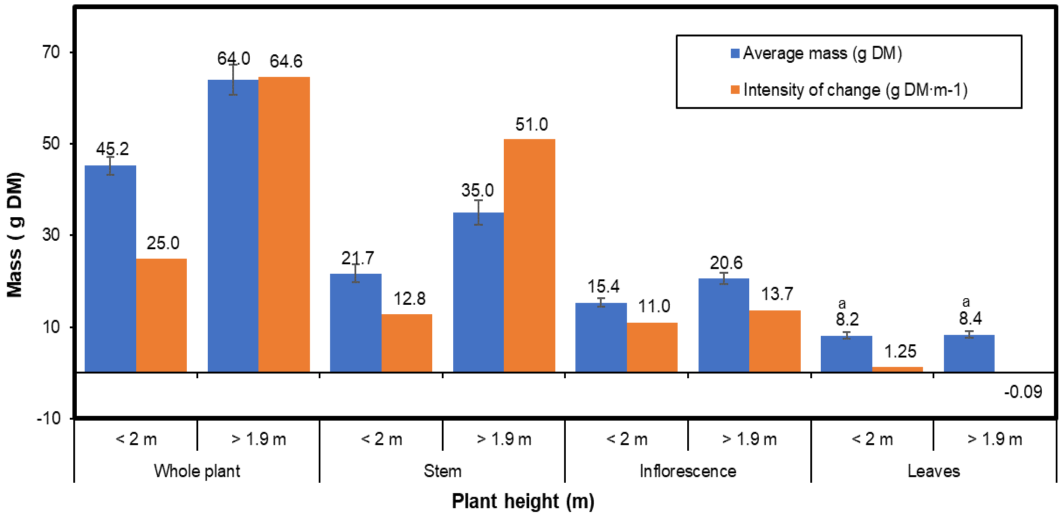

Fig. 5. Above-ground plant mass accumulation in short (< 2.0 m) and tall (> 1.9 m) "Felina 32" variety hemp (between the columns marked with the symbol a, there is no significant difference at P > 0.05)

Industrial hemp of different heights of the variety "Felina 32" differed in mass distribution between the morphological parts of the plant due to the features of plant mass accumulation. As the height of industrial hemp increased from 1.367 ± 0.020 m to 2.525 ± 0.042 m, the share of stem mass in the total plant mass increased from 51.9 ± 4.42% to 61.5 ± 3.93%. However, the mass of inflorescences and leaves decreased: the mass of inflorescences in the total plant mass decreased from 29.9 ± 2.46% to 28.4 ± 4.05%, and the mass of leaves decreased from 18.2 ± 2.11% to 10.1 ± 4.89%. Each morphological part of the plant has its own chemical composition and physical properties. Therefore, the change in the mass ratio of different morphological parts of the plant also determines the chemical composition of the entire plant biomass and its other properties (Fig. 6).

Hemp leaf biomass is characterized by a relatively high ash content and low heat content (Žiūra *et al*. 2023). When used for biofuel, the biomass properties of industrial hemp stalks are more favorable: their upper calorific value (19.29 ± 0.17 MJ/kg) is 1.27 times higher and their ash content (2.86 ± 0.09%) 8.65 times lower than the upper calorific value (15.23 ± 0.46 MJ/kg) and ash content (24.75 ± 1.61%) of industrial hemp leaf biomass. After evaluating the distribution of the mass of the plant between different morphological parts, the average industrial hemp plant of "Felina 32" variety, with a height of 1.890 ± 0.042 m, stem diameter at the base of 11.43 ± 0.250 mm, mass of the above-ground part 53.2 ± 2.45 g DM, the calorific value of the above-ground part was 18.37 MJ/kg (Table 2) and was similar to the calorific value of large-stemmed herbaceous plants, *e.g.*, miscanthus - 18.29 ± 0.06 MJ/kg, artemisia - 18.50 ± 0.66 MJ/kg (Černiauskienė *et al*. 2017). The calorific value of the industrial hemp stem was found to be higher than the calorific value of the entire above-ground part of the industrial hemp plant and was closer to the calorific value of woody plant biomass: spruce sawdust pellets - 19.85 ± 0.04 MJ/kg, oak sawdust pellets - 19.25 ± 0.12 MJ/kg (Stolarski *et al*. 2022), fraxinus pellets - 19.09 ± 0.31 MJ/kg (Telmo and Lousada 2011). Literature sources state that the calorific value of industrial hemp biomass is between 15 and 19 MJ/kg (Poiša and Adamovics 2011; Komlajeva *et al*. 2012; Mańkowski *et al*. 2014; Černiauskienė *et al*. 2021).

Table 2. Characteristics of the Above-ground Part of an Average Industrial Hemp Plant (1.890 ± 0.042 m Tall)

Indicator	Unit of Measurement	Morphological Part of the Plant			
		Whole Plant	Stem	Leaves	Inflorescence
Height	m	1.89 ± 0.042	–	–	–
Diameter	mm	–	11.43 ± 0.25	–	–
Mass	g DM	53.2 ± 2.45	28.7 ± 1.99	8.62 ± 0.49	15.85 ± 0.92
Mass fraction	%	100	54	16.2	29.8
Calorific value	MJ/kg	18.37 ± 0.34	19.29 ± 0.17	15.23 ± 0.46	18.41 ± 0.09
Ash content	%	7.97 ± 0.38	2.86 ± 0.09	24.75 ± 1.61	13.29 ± 0.32
Carbon (C)	%	38.39 ± 1.57	45.0 ± 2.26	40.0 ± 9.21	25.53 ± 0.96
Nitrogen (N)	%	1.81 ± 0.09	0.5 ± 0.03	4.9 ± 0.14	2.51 ± 0.24
Sulfur (S)	%	0.332 ± 0.02	0.201 ± 0.02	0.690 ± 0.05	0.376 ± 0.03
Chlorine (Cl)	%	2.5 ± 0.19	2.27 ± 0.23	3.46 ± 0.30	2.38 ± 0.18

A greater difference was recorded between the ash level in the above-ground part – including stem, leaves and inflorescence, of the industrial hemp plant and the stem ash content – a difference of 2.79 times. Even small amounts of inflorescences and especially leaves, which are characterized by a high ash content (Table 2), in the biomass of industrial hemp, greatly affect its ash content and reduce its value. The ash content of the entire above-ground part of industrial hemp is significantly different from the ash content of wood (0.4% to 1.2%) (Spirchez *et al*. 2019) and is close to that of herbaceous plants, *e.g.*, tall fescue - 7.52%, ryegrass - 6.67% (Amalevičiūtė-Volungė *et al*. 2020), and wheat straw - 5.70% (Spirchez *et al*. 2019). Literature sources state that the ash content of industrial hemp biomass is 2.5 to 4.3% (Žiura *et al*. 2023), but the ash content in its individual morphological parts was found to range from 2.86 ± 0.09% (stem biomass) to 24.75. ± 1.61% (leaf biomass).

Biomass type, morphological part, and chemical composition are among the main factors affecting its calorific value, ash content (Tumuluru *et al*. 2012; Zając *et al*. 2018; Černauskienė *et al*. 2021), and other properties. A higher concentration of carbon in the raw material determines its higher calorific value (Žiūra *et al*. 2023). However, during combustion it turns into carbon dioxide or monoxide, nitrogen into nitrogen gas N_2, and unwanted nitrogen oxides (NO, NO_2, N_2O), sulfur and chlorine into gases that tend to condense. Nitrogen, and especially chlorine and sulfur, also promote the formation of aggressive compounds that contaminate the working surfaces of conversion units and cause serious corrosion problems, lowering the ash melting point (Carool and Finnan 2012; Iqbal and Lewandowski 2016; Hupa *et al*. 2017; Wnorowska *et al*. 2020; Singhal *et al*. 2021; Link *et al*. 2022). For these reasons, it is desirable that these chemical elements are present as little as possible in the biomass that is intended to be used in thermochemical conversion technologies. Even a small concentration of them can fundamentally change the properties of biofuel and its impact on the environment.

The above-ground part of “Felina 32”' hemp variety contained an average of 1.81 ± 0.09% nitrogen, 0.33 ± 0.02% sulfur, and 2.50 ± 0.19% chlorine. At that time, the nitrogen concentration in the leaves reached 4.9 ± 0.14%, sulfur - 0.69 ± 0.05%, and chlorine - 3.46 ± 0.30%. This is, respectively, 1.95, 1.84, and 1.45 times more than in inflorescence biomass, 9.8, 3.43, and 1.52 times more than in stem biomass. Higher concentrations of nitrogen, chlorine, and sulfur in non-woody morphological parts of plants are not only characteristic of industrial hemp. Higher concentrations of these chemical elements in herbaceous biomass or non-woody and morphological parts of the plant with many “green” cells are also reported by other researchers. Zhao *et al*. (2022) found that the average sulfur concentration in plant leaves was 2.32 g/kg, *i.e*., 15.47 times higher than in stems (0.15 g/kg). Studies of some *Bruguiera parviflora* trees have also recorded 15 times higher sulfur concentrations in the leaves than in the stems. On average, sulfur concentration in tree stems ranged from 0.2% to 0.45%, and in leaves - about 1.3%, which is about 2.89 to 6.50 times higher than in stems. The difference between the nitrogen concentration in leaves and stems of *Bruguiera parviflora* trees reached 5.0 to 7.0 times: nitrogen concentration in leaves was 1 to 1.4%, in stems - 0.2% (Hossain *et al*. 2003).

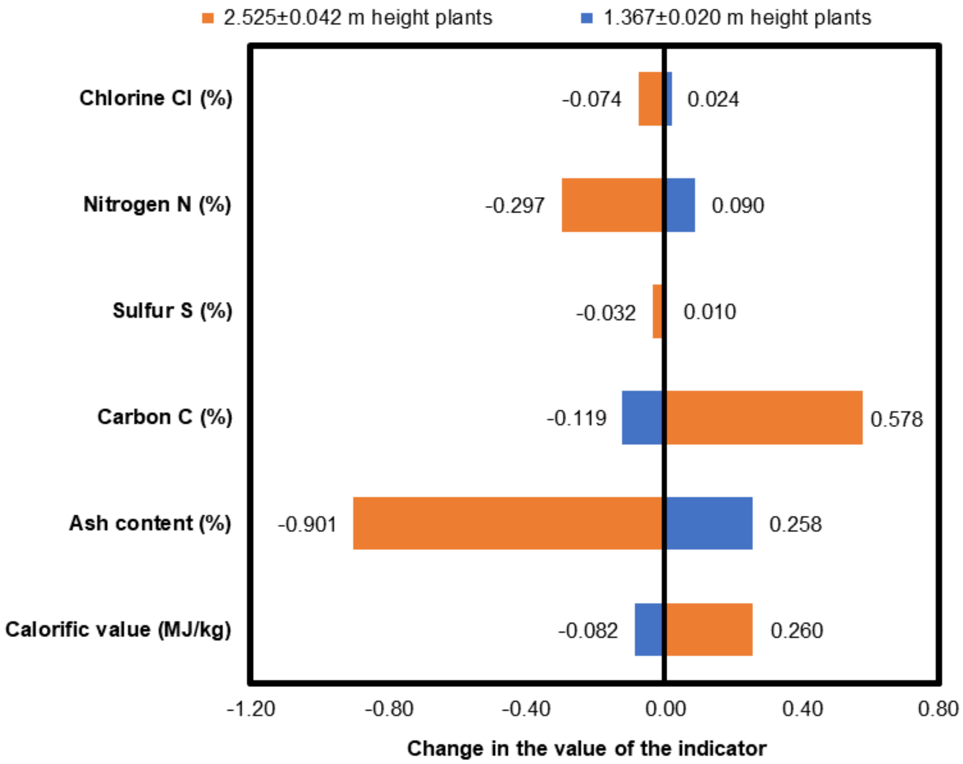

Fig. 6. Changes in the properties of industrial hemp with a mean height of 1.987 ± 0.062 m compared to the properties of industrial hemp belonging to the height intervals ≥ 2.5 m (mean height 2.525 ± 0.042 m) and < 1.4 m (mean height 1.367 ± 0.020 m)

The difference in nitrogen concentrations between different morphological parts is recorded even in herbaceous plants: it was 2 times more in cornflower leaves than in stems, 13.4 to 15 g/kg and 7 to 7.4 g/kg, respectively (Pederson *et al*. 2002). Thus, industrial hemp plants of various heights are characterized not only by growth dynamics and the mass of the above-ground part of the plant, but also by its distribution between the morphological parts of the plant and its chemical composition (Fig. 7).

Changes in industrial hemp higher than 1.9 m in height were found to result in more intensive mass accumulation, higher plant mass, and better biomass chemical composition. The dry mass of plants belonging to the ≥ 2.5 m height interval (2.525 ± 0.042 m height) was 88.9 ± 16.06 g. They weighed 35.7 g more than medium height (1.890 ± 0.042 m height) industrial hemp plants. At that time, the difference in dry weight between plants belonging to the height interval < 1.4 m (average height 1.367 ± 0.020 m) and plants with an average height of 1.890 ± 0.042 m was only 14.4 g. Industrial hemp at a height of 2.525 ± 0.042 m accumulated about 1.67 times more biomass than plants with an average height of 1.890 ± 0.042 m and about 2.29 times more biomass than plants with a height of 1.367 ± 0.020 m. Compared to industrial hemp belonging to the height interval < 1.4 m, industrial hemp belonging to the height interval ≥ 2.5 m had a higher calorific value of 0.342 MJ/kg, and an ash content of 1.16% lower. Beneficial changes in chemical composition were also recorded: biomass carbon concentration increased 0.70%, sulfur, nitrogen, and chlorine concentrations decreased 0.042%, 0.387%, and 0.098%, respectively.

CONCLUSIONS

1. Based on the results of the conducted research and data analysis, a gradual dependence of the mass of the above-ground portion of plants of the hemp variety (*Cannabis sativa* L.) “Felina 32” on the crop density (determination coefficient - 0.937) was determined with a fundamental change in the dynamics of the effect when the crop density reaches 90 to 150 plants per 1.0 m^2.
2. The analysis of the biometric data of industrial hemp above-ground portion of the plant confirmed the influence of meteorological conditions on the height, mass, and diameter of the stem, but a significant effect on the comparative mass of industrial hemp (g DM/m) and for the comparative stem diameter (mm/m).
3. In 2020-2021, the above-ground part of “Felina 32” variety industrial hemp (*Cannabis sativa* L.) grown in the cool temperate climate zone (Lithuania) was on average 1.890 ± 0.042 m high and 53.2 ± 2.45 g DM mass: plant height varied in crops from 1.367 ± 0.020 m to 2.525 ± 0.042 m, and the mass - from 38.8 ± 4.29 g SM in lower plants, to 88.9 ± 16.06 g SM in taller ones, which are respectively 51.9 ± 4.42% and 61.5 ± 3.93% was stem mass, 29.9 ± 2.46% and 28.4 ± 4.05% inflorescence mass, 18.2 ± 2.11% and 10.1 ± 4.89% leaves mass.
4. Analyzing the masses of the “Felina 32” variety at different heights, it was found that plants of different heights and their different morphological parts were characterized by specific dynamics of biomass accumulation: the mass of the above-ground part of plants taller than 1.9 m increased at a rate of 64.6 g DM/m, the mass of stems - at a speed of 51.0 g DM/m, mass of inflorescences - at a speed of 13.7 g DM/m, *i.e.*, 2.58,

3.99, and 1.25 times faster, respectively, than in plants less than 2 m tall. At that time, the effect of plant height on leaf mass was not confirmed. In addition, there was a decreasing trend in the rate of leaf mass accumulation, rather than an increase, in plants taller than 1.9 m.

5. The differences in morphological composition and physico-chemical properties, which are characteristic of industrial hemp of different heights, create prerequisites for managing the quality of plant biomass: compared to 1.367 ± 0.020 m high, 2.525 ± 0.042 m high "Felina 32" variety, the mass of the above-ground part of the industrial hemp plant is 2.29 times (50.1 g DM), calorific value 0.342 MJ/kg, carbon concentration 0.70% higher, and ash content 1.16%, sulfur concentration 0.042%, nitrogen concentration 0.387%, and chlorine concentration 0.098% lower.

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Arial submitted: May 14, 2024; June 29, 2024; Revised version received and accepted: July 11, 2024; Published: July 24, 2024.
DOI: 10.15376/biores.19.3.6380-6402