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Comparative study of biochemical composition of *Paulownia tomentosa* (Thunb.) Steud. genotypes

Olena Vergun*, Dzhamal Rakhmetov, Svitlana Rakhmetova, Valentyna Fishchenko

M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, Kyiv, Ukraine

ORCID Olena Vergun: https://orcid.org/0000-0003-2924-1580
Dzhamal Rakhmetov: https://orcid.org/0000-0001-7260-3263
Svitlana Rakhmetova: https://orcid.org/0000-0002-0357-2106
Valentyna Fishchenko: https://orcid.org/0000-0003-3647-7858

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The review of previous studies on *Paulownia* spp. showed that these plants are valuable raw materials with polyfunctional use among which are medicinal, forage, energetic, etc. This study demonstrated the accumulation of selected biochemical components in the different parts of *Paulownia tomentosa* (Thunb.) Steud. genotypes plants by the end of vegetation collected from experimental collections of M. M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine. The accumulation of selected nutrients in the leaves was the following: a dry matter of 24.09–29.44%, lipid content of 5.01–8.58%, total sugar content of 5.51–9.82%, mono sugar content of 1.73–6.17%, ash content of 1.09–8.96%, phosphorus content of 0.47–1.60%, calcium content of 1.41–3.43%, and heating value of raw material of 4,083.09–4,353.11 $Kcal.kg^{-1}$. In the branches of investigated genotypes on average accumulated 37.5–46.0% of dry matter, 3.69–6.52% of lipids, 6.66–19.96% of total sugar content, 1.95–5.75% of mono sugar content, 1.43–2.93% of ash content, 0.38–0.89% of phosphorus content, 0.515–1.61% of calcium content, and 3,911.45–4,290.78 $Kcal.kg^{-1}$of heating value. The trunks had 40.09–51.5% of dry matter, 2.0–6.14% of lipids, 6.44–20.48% of sugars, 1.6–3.67% of mono sugars, 1.18–2.53% of ash, 0.22–0.40% of phosphorus, 0.37–0.63% of calcium, and 4,073.45–4,525.28 $Kcal.kg^{-1}$ of heating value. A very strong correlation was found between sugars and mono sugars content in the leaves (r = 0.859), lipids and phosphorus (r = 0.864) in the branches, heating value, and calcium (r = 0.820) in the trunks. Due to the increasing interest in the growth and use of *P. tomentosa* during the last time, this study can be useful for further breeding work with this species as biofuel, forage, and medicinal plants.

Keywords: *Paulownia*, sugars, lipids, ash, heating value, correlation

Introduction

Paulownia tomentosa (Thunb.) Steud. belongs to the Paulowniaceae Nakai family, although numerous authors attribute this genus to Scrophulariaceae Juss. (Xia et al., 2019). This species is native to China and was introduced to Central Europe in 1834 as an ornamental plant (Kiermeier, 1977). This is a fast-growing and multi-purpose agroforestry tree, the leaves of which are used for domestic animal feeding and exhibit an antimicrobial effect (Bodnar et al., 2020). This tree is one of the few with a C_4 path of photosynthesis and its leaves can be used as green fertilizer (Woźniak et al.,

***Corresponding Author:** Olena Vergun, M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine, Timiryzevska str. 1, 01014 Kyiv, Ukraine
en_vergun@ukr.net

2018). *Paulownia* tree is a good adapted to a wide range of climate and soil conditions and possesses some indicators of invasiveness (Essl, 2007; El-Kader and El-Ghit, 2015). But this tree is used by horticulturalists and gardeners as an ornamental plant due to its attractive lavender blossoms (Snow, 2015). This is a deciduous tree with medicinal properties. Leaves, flowers, roots, and seeds in different countries such as China, and Korea are used in folk herbal medicine to treat hemorrhoids, carbuncles, inflammatory bronchitis, gonorrhea, bacteriological diarrhea, etc. Seeds can be used for diabetic complications (He et al., 2016). According to Singh et al. (2018), the leaves of this tree contain ursolic acid and matteucinol, and raw demonstrates the cardioprotective and antioxidant potential.

Essential oil of fresh flowers of *P. tomentosa* exhibited antimicrobial activity and contains numerous compounds among which geranyl, geraniol, nonanal, heptadecane, pentacosane, etc. (Ibrahim et al., 2013). Also, the presence of flavonoids raw in these plants exhibited anticancer (Moon and Zee, 2001), antiradical, antioxidant (Shneiderová et al., 2013; He et al., 2016), and immunological (Yang et al., 2019) activities. Fruits of *P. tomentosa* demonstrated an anti-inflammatory effect (Ryu et al., 2017). *Paulownia* nitrogen content can be comparable with some leguminous that allows for use as green crops by farmers in China (Yadav et al., 2013), leaves of *P. elongata* can accumulate up to 17.5% of proteins (Stewart et al., 2018; Al-Sagheer et al., 2019). Among essential amino acids prevailed histidine (4.8% of crude protein), leucine (4.6%), phenylalanine (4.4%), valine (4.3%), and among nonessential amino acids prevailed proline (13.6%) (Al-Sagheer et al., 2019). A tree has a large size of inflorescences and these plants relate to honey species (Yadav et al., 2013). *P. tomentosa* raw rich in dietary flavonoids and fruit extracts of it can reduce blood pressure (Shneiderová and Šmejkal, 2015). According to Stewart et al. (2018), lignin content in the leaves was 10–22%, and the lowest content of lignin was found in *P. elongata*. Polysaccharides from this plant exhibited immunomodulatory activity (Chen et al., 2021).

Due to the high productivity of this plant, it can be used for biofuel goals (Rodríguez-Seoane et al., 2020; Jakubowski, 2022). The wood chemical composition of *P. tomentosa* (up to 3 years) showed 40% of cellulose, 36% of hemicellulose, and 24% of lignin content (Esteves et al., 2021).

Along with other tree *Paulownia* species can be used for phytoremediation purposes due to their tolerance to high concentrations of metals (Drzewiecka et al., 2021). In total, the sequential biorefinery of plant raw of *Paulownia* species allows using different plant parts for various purposes such as medicinal, biofuel, forage, etc. (Rodríguez-Seoane et al., 2020). According to Youseff et al. (2020), the optimization of micropropagation of *P. tomentosa* using proline can improve the salinity tolerance of this plant.

This study aimed to determine the biochemical composition of different parts of *P. tomentosa* plants of various genotypes as a potential source of raw material for energetic value.

Material and methodology

Plant material

The fresh leaves, branches, and trunks of *Paulownia tomentosa* Steud. genotypes such as f. PSA, f. PL, f. PB, f. PN, f. PO, f. PKS were studied. Plant raw was collected from an experimental collection of the Cultural Flora Department of M.M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine in October 2020–2021.

Biochemical analysis

Dry matter determination

Plant samples were dried in a drying oven at 105 °C till constant weight in aluminum boxes. Results are given in percentages (Hrytsajenko et al., 2003).

The total content of sugars and mono sugars determination

The total content of sugars was investigated by Bertrand's method in water extracts. 4 g of fresh mass was mixed and homogenized with distilled water (approximately 50 ml) in the 100 ml test-tubes and heated in the water bath at 70 °C during 15–20 min. After cooling in the obtained mixtures added 1 ml of the phosphate-oxalate mixture. After this was added 1.5 ml of lead acetate. The obtained mixture brings to the mark (100 ml) with water. After filtration from obtained solution took 50 ml and mixed with 8 ml of 20% HCl (at 70 °C in a water bath for 5 min) after cooling was neutralized by 12% NaOH and brought to the mark by distilled water (100 ml). 3 ml of the obtained solution was mixed with 6 ml of Fehling's solution reagent (6 min boiling in the water bath). The obtained mixture was analyzed for the total content of sugars. The monosugar content was determined from the solvent without the inversion procedure following adding Fehling's solution reagent. In this case, 3 ml of water extracts were mixed with 6 ml of reagent (Fehling's solution). The following procedure is the same as with the total content of sugars. Results are given by percentages (Hrytsajenko et al., 2003).

The total content of lipids

The total content of lipids is determined in the Soxhlet apparatus (Yermakov et al., 1972). The low-boiling petroleum ether (40 °C) was used as an extractor. The difference in masses before and after the extraction process is used to calculate the total lipid content.

The heating value of raw

The procedure of caloricity measurement was conducted using a calorimeter IKA C-200 (Germany). 0.1–0.2 g of dried plant raw material was combusted in an oxygen bomb for approximately 15 minutes.

The total content of ash

The total content of ash is determined by combustion in the muffle oven at 200–500 °C for 3 days considering the mass before and after combustion (Hrytsajenko et al., 2003).

Statistical analysis

The results are expressed as mean values of three replications ± standard deviation (SD); hierarchical cluster analyses of similarity between samples were computed based on the Euclidean similarity index. Data were analyzed with the ANOVA test and differences between means were compared through the Tukey-Kramer test ($p < 0.05$).

Results and discussion

The study of the biochemical composition of the whole crop and selected parts of the plant should be considered in the evaluation of raw. The partitioning of biomass may significantly change the biofuel quality, for example, stems of switchgrass (*Panicum virgatum* L.) and *Miscanthus* spp. showed better higher biochemical component content than leaves (Monti et al., 2008). The biochemical composition of plants, especially dry matter content, ash content, mineral composition, and calorific value of energetic plants is a very important parameter for evaluating raw (Vergun et al., 2022). One of the widely used parameters of plant species for energetic purposes is dry matter content. This parameter depends on the period of growth and dry matter accumulated during the vegetation period.

In this study, the dry matter content of leaves, branches, and trunks of *P. tomentosa* genotypes was 24.09–29.44%, 37.5–46.0%, and 40.09–51.5%, respectively, depending on genotypes (Figure 1). As showed the results, the highest content of dry matter was found in the trunks and the lowest in the leaves.

According to Al-Sagheer et al. (2019), paulownia leaf meal had 88.12% of dry matter. The dry matter content closely relates to total biomass productivity and some growth characteristics (Greco and Cowagnaro, 2005).

Lipids are one of the most important components of plant cells and act as signaling and energy storage compounds (Suh et al., 2015; Hou et al., 2016). The content of lipids in the plant is one of the most essential parameters that determine the nutritional value of raw and varies depending on the species and part of the plant (Vergun et al., 2017; Vergun et al., 2020).

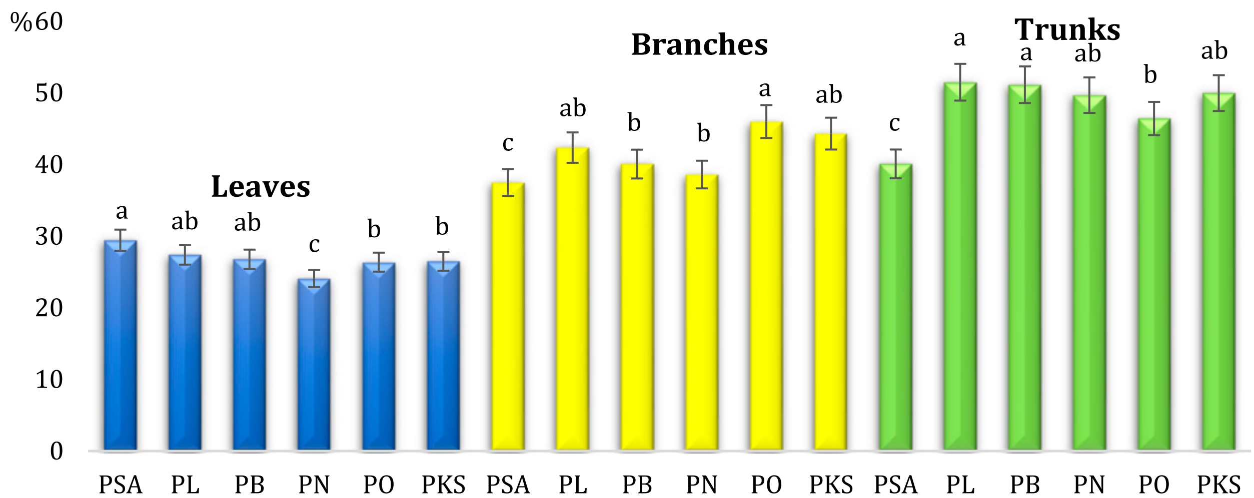

Figure 1 The dry matter content of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at $p < 0.05$

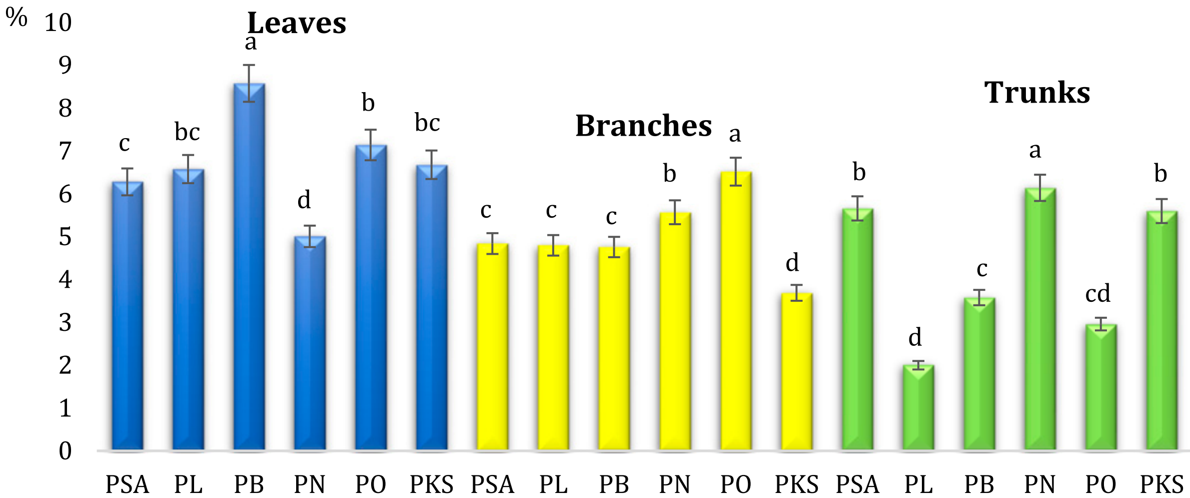

Figure 2 The lipid content of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at p <0.05

The content of lipids in raw *P. tomentosa* genotypes was from 5.01 to 8.58% in the leaves, from 3.69 to 6.52% in the branches, and from 2.0 to 6.14% in the trunks (Figure 2).

According to Stewart et al. (2018), the content of lipids was from 1.9 to 3.8%, and in leaves 2.87%. Angelova-Romova et al. (2011) determined the content of oil in the seeds of *P. tomentosa* of 20.3%.

Sugars play an important role in plant metabolism and they are substrates of energetic processes. They also play a regulatory role in photosynthesis and modulate gene expression (Eckstein et al., 2012). The sugars also influence plant growth (Onto et al., 2001; Lastdrager et al., 2014). According to Ende (2014), a minimal sucrose dose is required for lateral bud outgrowth. The level of sugars in plant parts depends on complex factors such as conditions of growth, stress factors of the environment, and physiological peculiarities of development (Ciereszko, 2018). The total content of sugars in leaves of *P. tomentosa* was 5.51–9.82%, in the branches 6.66–19.96%, and 6.44–20.48% in the trunks depending on genotypes (Figure 3).

According to Rakhmetova et al. (2020), the total content of sugars in the above-ground part of another energetic plant *Panicum virgatum* was 4.44–9.15% depending on genotype and stage of growth.

Along with the total content of sugars was studied mono sugars content in different organs of investigated plants (Figure 4). We found 1.73–6.17% of mono

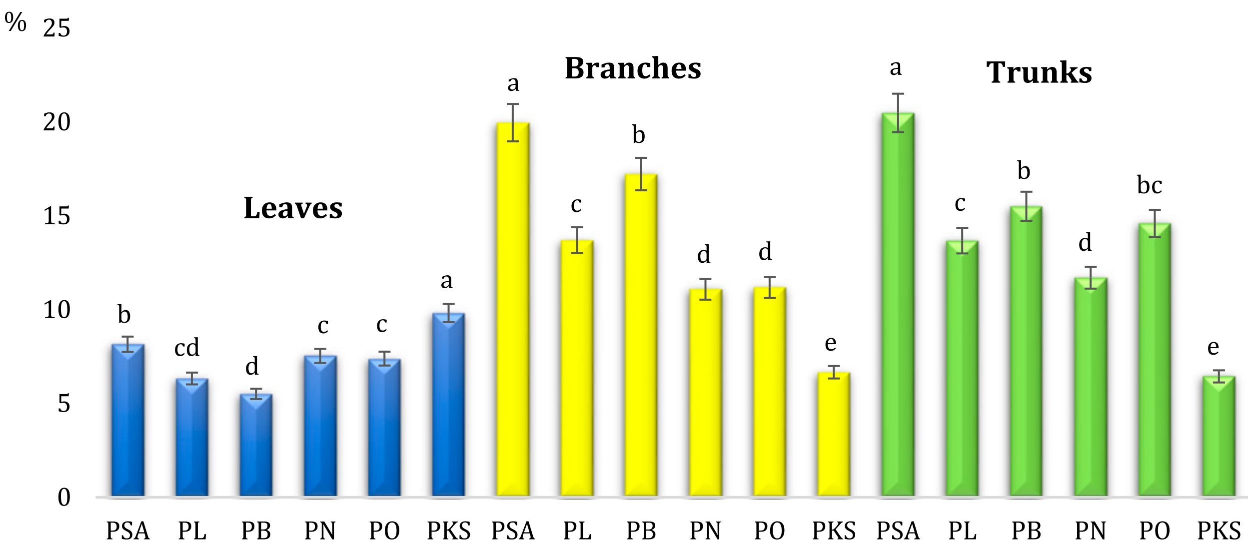

Figure 3 The total sugar content of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at p <0.05

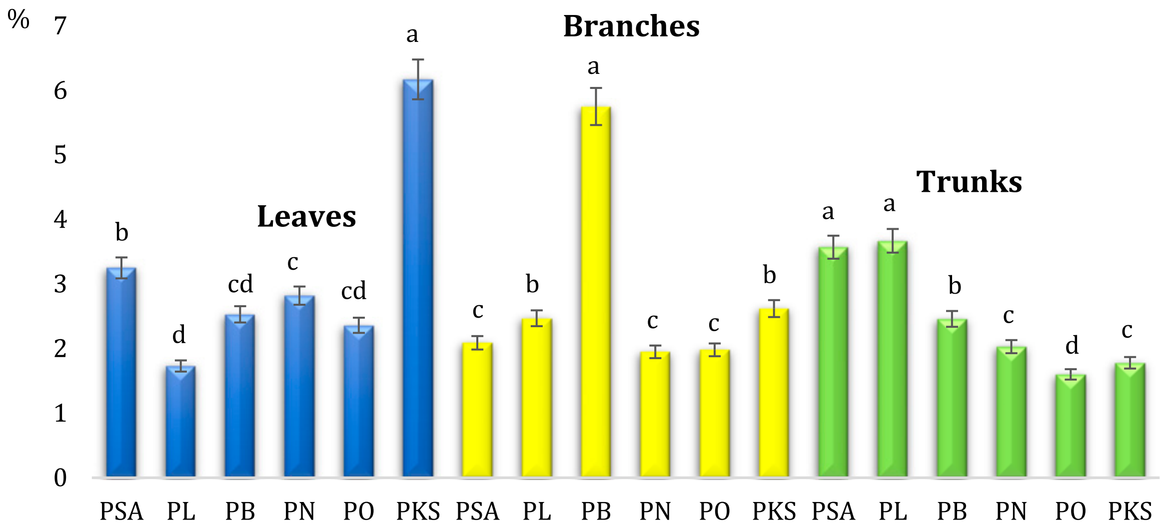

Figure 4 The total mono sugar content of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at p <0.05

sugars in the leaves, 1.95–5.75% in the branches, and 1.6–3.67% in the trunks.

The study of monosaccharide content of *Paulownia fortunei* (Seem.) Hemsl. showed that the most prevailed of them was galactose (Wang et al., 2019).

The study of thermochemical properties of plant raw such as heating value is an important parameter of biofuel evaluation (Senelwa and Sims, 1999). The heating value of leaves of *P. tomentosa* genotypes was in ranges from 4,083.09 to 4,353.11 Kcal.kg^{-1}, from 3,911.45 to 4,290.78 Kcal.kg^{-1} in the branches, and from 4,073.45 to 4,525.28 Kcal.kg^{-1} in the trunks (Figure 5). The recalculation of obtained data allowed us to find results in MJ.kg^{-1}: 17.09–18.22 in leaves, 16.37–17.96 in branches, and 17.05–18.94 in the trunks.

Stewart et al. (2018) found 18.6–19.6 kJ.kg^{-1} of heating value in leaves. According to Yavorov et al. (2015), the heating value of *P. elongata* raw was 17,970 kG.kg^{-1} which corresponds 4,292 Kcal.kg^{-1} and is close to our results. Qi et al. (2016) found 4,521.5, 4,593.3, 4,114.8, and 4,258.4 Cal.g^{-1} of heating value for stems, branches, leaves, and barks, respectively. The heating value of one-year leaves of this species was 15.9–18.7 MJ.kg^{-1} (or 3,798–4,467.4 Kcal.kg^{-1}) as reported Jacek and Litwińczuk (2016).

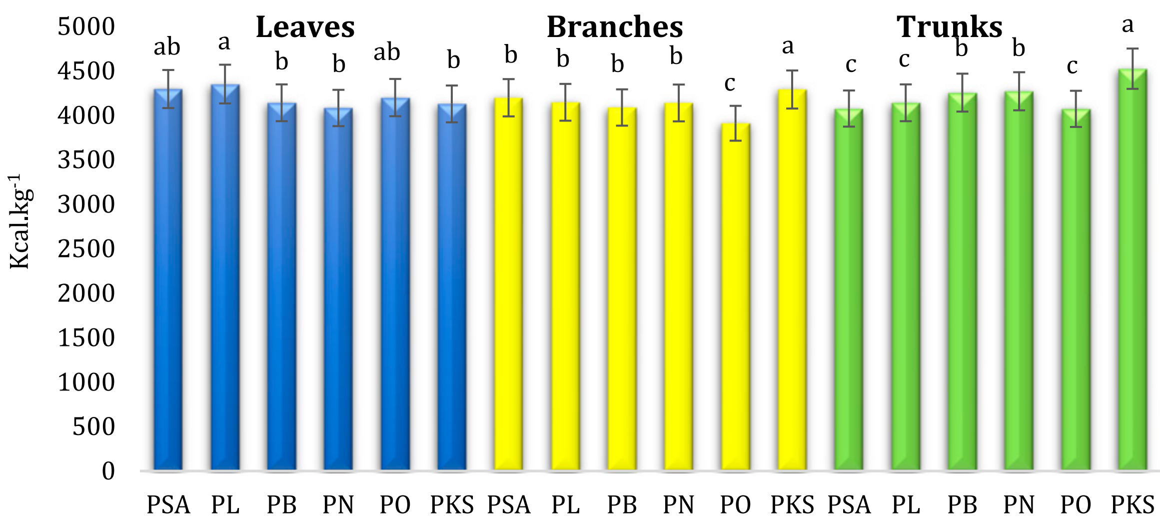

Figure 5 The heating value of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at p <0.05

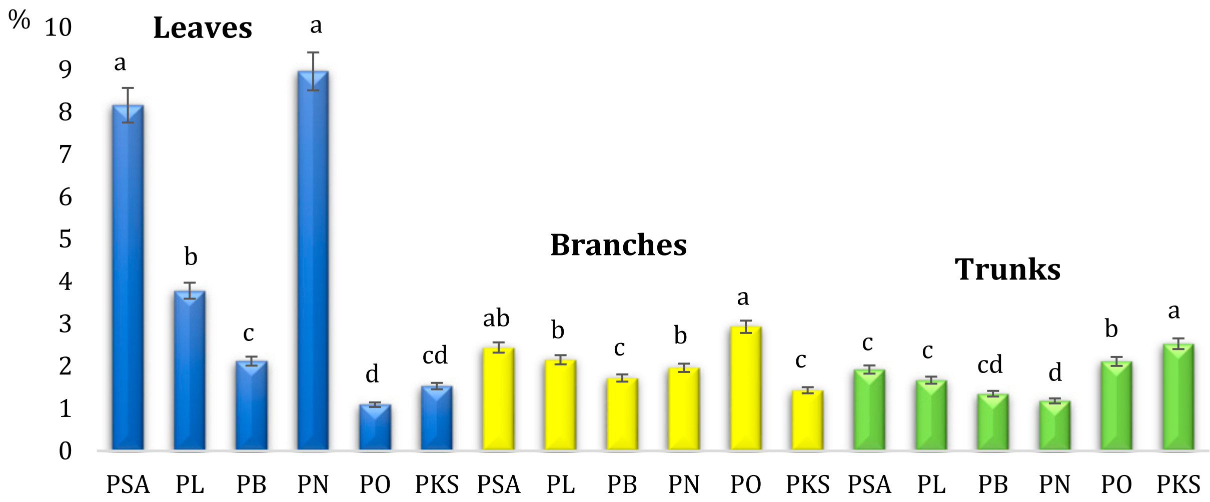

Figure 6 The total ash content of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at p <0.05

One of the important parameters of the nutritional composition of plant raw is the assessment of ash content (Godočiková et al., 2019). The total ash content in raw *P. tomentosa* genotypes was from 1.09 (f. PO) to 8.96 (f. PN) % in the leaves, from 1.43 (f. PKS) to 2.93 (f. PO) % in the branches, and from 1.18 (f. PN) to 2.53 (f. PKS) % in the trunks (Figure 6).

As reported Prochnow et al. (2009), between the heating value and ash content of energetic plants, exists the correlation. Plants with low content of ash have the highest heating value. In this study, minimal values of ash in the leaves were found for f. PO, in the branches for f. PKS, and in the trunks for f. PN. The study of a trihybrid variety of *P. elongata* × *fortunei* × *tomentosa* showed that the content of ash was 8.9 $g.kg^{-1}$ which was less than that of the initial species (López et al., 2012). In our study leaves of plants of f. PO had close value and was the less. According to Yavorov et al. (2015), the ash content of *P. elongata* raw was 1.03% which is close to *P. tomentosa* f. PO leaves in our study. As reported Stewart et al. (2018), the ash content of *P. elongata* during the growth period was from 6 to 9%, and in the leaves 7.67%. According to Al-Sagheer et al. (2019), paulownia leaf meal had 8.85% of ash which was close to our results related to f. PSA and f. PN. Qi et al. (2016) determined ash content in leaves and barks of 6.0 and 2.89%, respectively. As reported Ganchev et al. (2019), the ash content of the leaves of *P. elongata*

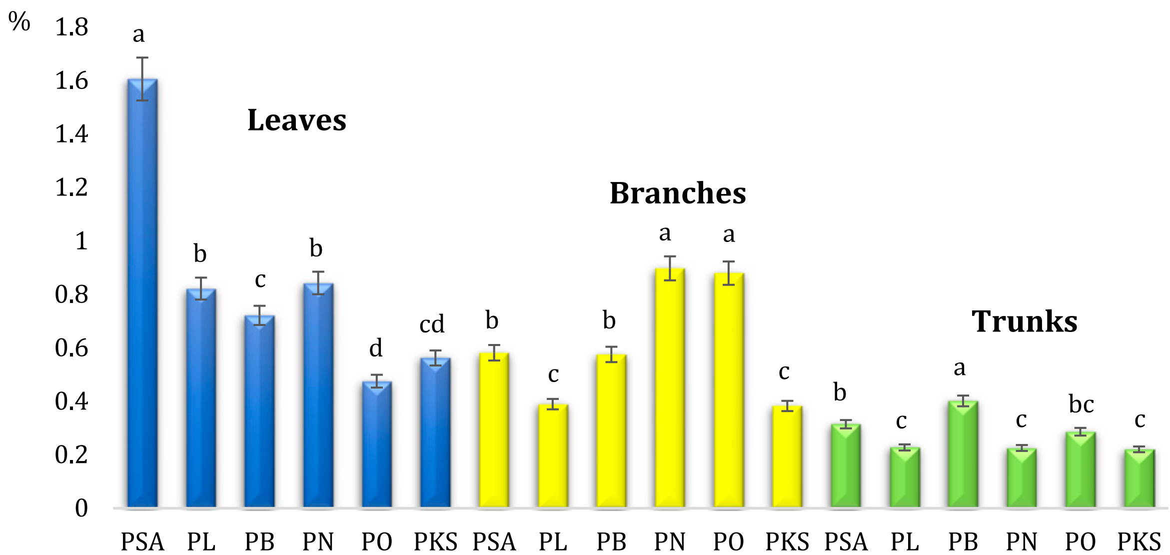

Figure 7 The total phosphorus content of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at p <0.05

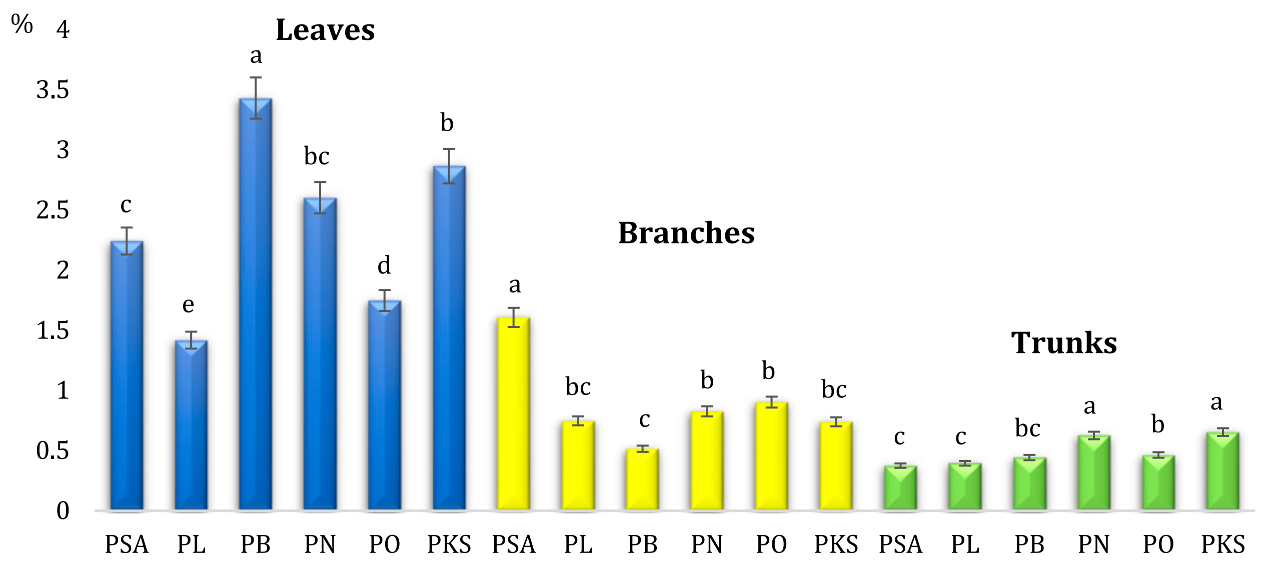

Figure 8 The total calcium content of raw *Paulownia tomentosa* (Thunb.) Steud. genotypes at the end of vegetation; different superscripts in each column indicate the significant differences in the mean at p <0.05

was 14.94% which was higher than in the leaves of *P. tomentosa* in our study. Özelçam et al. (2020) determined the mean value of 9.21% of ash content in the leaves of this plant.

One of the most essential components of ash is phosphorus which plays an important role in enzyme regulation, biosynthesis of nucleic acids, is a key element in some plant physiological processes (like photosynthesis and transpiration), etc. (Lambers, 2022). We determined 0.47–1.60% of phosphorus in the leaves, 0.38–0.89% in the branches, and 0.22–0.40% in the trunks of investigated genotypes of *P. tomentosa* (Figure 7). The minimal values of phosphorus were found in the trunks of investigated plant parts.

Our results were 3–10 times higher compared with Al-Sagheer et al. (2019) who reported about phosphorus content of leaves (0.16%). In the study by Özelçam et al. (2020), this parameter in the leaves of *Paulownia* spp. was on average 0.49% which is close to f. PO in our study.

Calcium is an important nutrient that is required for numerous roles in plant organisms on a cellular level and adequate concentration in plant natural habitats varied from 0.1 to 5% of dry weight (White and Broadley, 2003). The calcium content in the leaves, branches, and trunks of *P. tomentosa* varieties was 1.41–3.43%, 0.515–1.61%, and 0.37–0.63%, respectively (Figure 8). The minimal accumulation of calcium was fixed in the trunks of investigated raw.

As resulted Al-Sagheer et al. (2019), the content of calcium in the leaf meal of *P. tomentosa* was 0.36% which was less than in our study. According to Özelçam et al. (2020), the calcium content in the leaf raw of this plant was 1.74% which is close to the leaves of f. PO in our study.

The study of the relationship of biochemical compound accumulation allows determining the level of relationship of studied parameters. Use of coefficient of Pearson can be used in biochemical studies to describe some regularities considering as many as possible parameters (Ngamdee et al., 2016). In this study, a very strong correlation was found between sugars and mono sugars content in the leaves (r = 0.859), lipids and phosphorus (r = 0.864) in the branches, heating value and calcium (r = 0.820) in the trunks (Table 1). The strong correlation was determined between heating value and dry matter (r = 0.759), ash and phosphorus (r = 0.744), dry matter and phosphorus (r = 0.643) in the leaves, between sugars and phosphorus (r = 0.609), mono sugars and phosphorus (r = 0.600), heating value and dry matter (r = 0.511) in the trunks. A moderate correlation was found between ash and calcium (r = 0.578), sugars and calcium (r = 0.489) in the branches, and between phosphorus and heating value (r = 0.461) in the leaves.

It should be noted that a very strong negative correlation was found between lipid content and heating value (r = -0.903) in the branches, between sugars and calcium content (r = -0.856), sugars content and heating value (r = -0.852) in the trunks, between lipids and ash content (r = -0.741), calcium content and heating value (r = -0.727) in the leaves.

Table 1 Correlation between investigated parameters of *Paulownia tomentosa* (Thunb.) Steud. genotypes

Parameter	Dry matter	Lipids	Sugars	Mono sugars	Heating value	Ash	P
				Leaves			
Lipids	0.318*	1	-0.462*	0.097	0.052	-0.741**	-0.299
Sugars	0.021	-0.462*	1	0.097	-0.216	0.058	0.050
Mono sugars	-0.024	0.097	0.859**	1	-0.422*	-0.181	-0.118
Heating value	0.759**	0.052	-0.216	-0.422*	1	0.038	0.461*
Ash	-0.018	-0.741**	0.058	-0.181	0.038	1	0.744**
P	0.643*	-0.299	0.050	-0.118	0.461*	0.744**	1
Ca	-0.225	0.348	0.026	0.447*	-0.727**	-0.046	-0.077
				Branches			
Lipids	0.146	1	0.094	-0.292	-0.903**	0.087	0.864**
Sugars	-0.678*	0.094	1	0.330*	-0.107	0.386*	-0.020
Mono sugars	-0.139	-0.292	0.330*	1	-0.038	-0.388*	-0.261
Heating value	-0.359*	-0.903**	-0.107	-0.038	1	0.296	-0.673*
Ash	-0.844**	0.087	0.386*	-0.388*	0.296	1	0.302*
P	-0.076	0.864**	-0.020	-0.261	-0.673*	0.302	1
Ca	-0.423*	0.103	0.489*	-0.545*	0.148	0.578*	0.101
				Trunks			
Lipids	-0.361	1	-0.161	-0.234	0.445	0.042	-0.175
Sugars	-0.671*	-0.161	1	0.600*	-0.852**	-0.327	0.609*
Mono sugars	-0.272	-0.234	0.600*	1	-0.466	-0.230	0.104
Heating value	0.511*	0.445	-0.852**	-0.466	1	0.288	-0.303
Ash	-0.268	0.042	-0.327	-0.230	0.288	1	-0.289
P	-0.189	-0.175	0.609*	0.104	-0.303	-0.289	1
Ca	0.397	0.586*	-0.856**	-0.731**	0.820**	0.159	-0.522

Note: ** Correlation is significant at $p \leq 0.01$; * correlation is significant at $p \leq 0.05$

The ratio of different biochemical parameters may be unaffected by geographical variation due to accumulation selectivity (Garten, 1976). But some investigations showed that the correlation coefficient depends on many factors such as species and genotypes, periods of growth, and studied parameters (Singh et al., 2011; Dinc and Unay, 2021).

Conclusions

This study demonstrated comparable biochemical composition of different parts of *Paulownia tomentosa* at the end of vegetation that accumulated high content of dry matter, lipids, total sugar and monosugar content, ash, and their components calcium and phosphorus. The heating value of investigated plant parts not differed significantly but had high values that characterized biofuel plants. Among investigated genotypes were fixed the highest values of investigated parameters: dry matter for leaves f. PB (51.5%), lipids for leaves f. PB (8.58%), total sugar content for trunks f. PSA (20.48%), monosugar content for f. PKS (6.17%), heating value for trunks f. PKS (4,525.28 $Kcal.kg^{-1}$), ash content for leaves f. PN (8.96%), phosphorus content for leaves f. PSA (1.61%), and calcium content for leaves f. PB (3.43%). A very strong correlation was found between sugars and mono sugars content in the leaves ($r = 0.859$), lipids and phosphorus ($r = 0.864$) in the branches, heating value, and calcium ($r = 0.820$) in the trunks. Due to the increasing interest in the growth and use of *P. tomentosa* last time, this study can be useful for further breeding work with this species as biofuel, forage, and medicinal plants.

Conflicts of interest

The authors declare no conflict of interest.

Ethical statement

This article doesn't contain any studies that would require an ethical statement.

Aknowledgements

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