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Ligno-cellulose quality and calorific value of green phytomass of *Silphium perfoliatum* L. cultivated on marginal soils under conditions of moderate continental climate of Central Europe

Ligno-celulózová kvalita a energetická hodnota fytomasy *Silphium perfoliatum* L. pestovaného na marginálnych pôdach v podmienkach miernej kontinentálnej klímy strednej Európy

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ABSTRACT

The aim of study was to determine ligno-cellulose quality and calorific value of cup plant *Silphium perfoliatum* L., whereas impact of nutrition, years and sites on the quality were evaluated as main effects within a huge pilot field experiment. Two complete data sets of acid-detergent fiber (ADF), acid-detergent lignin (ADL), crude cellulose (CE), hemicellulose (HEM), neutral-detergent fiber (NDF) and high heating value (HHV) were evaluated, a primary one in terms of quality content and a secondary one in terms of quality yield. Average, minimal and maximal ADF content was 43.73 – 31.32 – 48.94%, ADL 10.22 – 7.21 – 12.54%, CE 33.51 – 24.11 – 37.30%, HEM 4.17 – 2.33 – 5.75%, NDF 48.12 – 34.94 – 54.69% and HHV 15.83 – 15.21 – 16.79 MJ/kg, respectively. Adequate values of ADF yield was 5.461 – 1.021 – 20.827 t/ha, ADL 1.274 – 0.235 – 5.115 t/ha, CE 4.187 – 0.786 – 15.112 t/ha, HEM 0.569 – 0.055 – 2.447 t/ha, NDF 6.041 – 1.139 – 23.273 t/ha and HHV 195.528 – 36.481 – 704.914 GJ/ha, respectively. Ligno-cellulose quality and calorific value of cup plant vary with environment and management practices. In terms of quality content, the influence of the sites was generally the most significant (valid for ADF, ADL, CE and NDF), or alternately with the influence of the years (HEM and HHV) it was higher than a medium influence of the nutrition. In terms of quality yield the years has been confirmed the most important factor (mainly because great increasing of phytomass yield by utility year of that perennial crop), followed by nutrition and then by sites with the least impact, whereas that impact order was valid for each of parameter.

Keywords: cup plant, *Silphium perfoliatum*, calorific value, lingo-cellulose quality, marginal soils

ABSTRAKT

Cieľom predkladanej práce je zhodnotiť ligno-celulózovú kvalitu a spaľovaciu hodnotu presilfia zrastenoslistého *Silphium perfoliatum* L., pričom vplyv výživy, ročníka a lokality sú hodnotené ako hlavné faktory v rámci rozsiahleho pilotného poľného pokusu. Dva kompletné súbory údajov acidodetergentnej vlákniny (ADF), acidodetergentného lignínu (ADL), hrubej celulózy (CE), hemicelulózy (HEM), neutralnodetergentnej vlákniny (NDF) a spaľovacieho tepla (HHV) boli vyhodnotené, prvotný z hľadiska obsahu kvality a druhotný z hľadiska úrody kvality. Priemerná, minimálna a maximálna hodnota obsahu ADF bola 43,73 – 31,32 – 48,94%, ADL 10,22 – 7,21 – 12,54%, CE 33,51 – 24,11 – 37,30%, HEM 4,17 – 2,33 – 5,75%, NDF 48,12 – 34,94 – 54,69%, resp. HHV 15,83 – 15,21 – 16,79 MJ/kg. Adekvátne hodnoty úrody ADF boli 5,461 – 1,021 – 20,827 t/ha, ADL 1,274 – 0,235 – 5,115 t/ha, CE 4,187 – 0,786 – 15,112 t/ha, HEM 0,569 – 0,055

– 2,447 t/ha, NDF 6,041 – 1,139 – 23,273 t/ha, resp. HHV 195,528 – 36,481 – 704,914 GJ/ha. Ligno-celulózová kvalita a spaľovacia hodnota presilfia zrastenolistého kolísala v závislosti od podmienok prostredia a pestovateľských opatrení. Z hľadiska obsahu kvality bola najvýznamnejším faktorom lokalita (platná pri ADF, ADL, CE a NDF), prípadne striedavo s ročníkom (pri HEM a HHV) mala vyšší vplyv ako stredný vplyv výživy. Z hľadiska úrody kvality bol najvýznamnejším faktorom ročník (hlavne pre veľký nárast úrody sušiny pribúdajúcim úžitkovým rokom trvácej plodiny), nasledované výživou a naokoniec lokalitou s najnižším vplyvom, pričom toto poradie platilo pri každom kvalitatívnom ukazovateli.

Kľúčové slová: presilfium zrastenolisté, *Silphium perfoliatum*, spaľovacie teplo, lingo-celulózová kvalita, okrajové pôdy

INTRODUCTION

Lesser-known plants with the prospect of being used not only for energy purposes include the cup plant *Silphium perfoliatum* L, a promising novel crop that is still not widely distributed (Marišová et al., 2016; Cumplido-Marin et al., 2020; Hauptvogel et al., 2022; Reinhardt et al., 2022). The indisputable advantage of the cup plant is the suitability of the phytomass for various uses, while most of recent research works are focused on potential in biogas production (Siwek et al., 2019; Guo et al., 2020; Kowalska et al., 2020; von Cossel et al., 2020; Witaszek et al., 2022) and there is little knowledge and information enabling reliable cultivation technology (Shittenhelm et al., 2021; Hryniewicz et al., 2021; Tsugkiev et al., 2021; MarieEnde at al., 2021). Even the forms of usability themselves are not yet sufficiently parameterized and it concerns further energy and feed purposes, pharmaceutical uses or honey production, and the protection of animals and their living space is also worth mentioning. Cup plant is one of the perennial crops whose expansion can be helped by efforts to reduce production costs when growing phytomass of annual crops for first or second generation technologies, as well as the use of less valuable marginal soils and efforts to introduce various soil protection measures, e.g. anti-erosion, phytoremediation etc. (Franzaring et al., 2015; Chmelikova and Wolfrum, 2019; Koniuszy et al., 2020; Makovnikova et al, 2020; Radzikowski et al., 2020).

The lack of study about the cup plant is particularly related to the production of bioethanol by second-generation technologies, where the concept of marginal soils has been re-emerged, and therefore the yield quality aspect needs to be parameterized in more detail (Tóth, 2020). The aim of the presented paper was to determine ligno-cellulose quality and calorific value of cup plant, whereas nutrition, years and sites were statistically evaluated as main effects within a huge, large-scale pilot field experiment conducted under continental climate conditions of Central Europe. Within the work two equal aspects of quality was followed, a primary one the content-basis quality and a secondary one the yield-basis quality.

MATERIAL AND METHODS

Pilot field trials during 2016/17-2020

As a part of a huge large-scale pilot experiment with newly introduced energy crops, field trials with cup plant *Silphium perfoliatum* L. was established and carried out on 2 sites under continental Central European climate, during 2016/17-2020. The sites are characterized with marginal heavy soils and mutually contrasting climatic conditions:

- Site-1: locality Pozdišovce with heavy soil and humid conditions,
- Site-2: locality Košický Klečenov with heavy soil and semi-humid conditions.

The variety ÓVÁRI-ÓRIÁS were tested in the experiments, whereas three levels of nutrition intensity (i) intensive nutrition by dose of 245.0 kg/ha NPK (125:60:60 kg/ha pure nutrients, PK in oxide form), (ii) semi-intensive nutrition by dose of 122.5 kg/ha NPK (62.5:30:30 kg/ha pure nutrients, PK in oxide form), and (iii) untreated control without nutrition treatment 0.0 kg/ha NPK. The experimental lay-out was randomized block design. The trial was established in the autumn of 2016 and was running up to 2020, while the crop phytomass was collected in 2018, 2019 and 2020. More detailed description of the field experiments in terms of used nutrition, agronomy, soil-climatic conditions, plant material, biometric parameters and collection of plant samples will be presented in a separate study.

Laboratory analyses

Collection of cup plant green phytomass samples was timed to optimal harvest maturity in terms of crop development, whereas the crop stands was not desiccated before harvest. The sampling, storage and processing was done in relevance to Slovakian national law no. 151/2016 Z.z. (Codex). The samples were analyzed in the laboratory of NPPC-VUA Michalovce, while standard methodology was used regarding folowed quality indicators.

Acid-detergent fiber (ADF), neutral-detergent fiber (NDF), acid-detergent lignin (ADL), crude cellulose (CE) and hemicellulose (HEM) were determined according to the regulation of MPRV SR no. 2136 / 2004-100 by extraction systems: Fiber extractor - Fibertest, Model F-6 and Cold Extraction Unit, Model EF-6. Combustion heat (HHV), high heating value respectively were determined by IKA C 5000 calorimetric system, in accordance to STN standard ISO 1928.

Statistical methods

The presented research evaluates 256 original quality data, exactly half of it in terms of quality content and second half in terms of quality yield. A primary data set consists of 128 quality content data, whereas each of the data is average of two analytical repetitions (classic twins analyzes) done within every plant sample for each of the 6 quality indicators. A secondary set of 128 data was generated in terms of quality yield (quality profit respectively), whilst simple equation was used: quality yield = quality content x crop yield (dry matter yield).

Multi-factorial ANOVA was performed to identify significant factors having influence on quality variability using Statgraphics 15.2.14, where each of the quality indicators was valuated within both data sets.

Moreover, second order polynomial function in the case of trend analyses for the quality indicators were also used. For this purpose, it was applied to another 384 biometric data as independent variables, whereas these complementary parameters (crop yield, plant height and dry matter content at harvest) will be the subject of the separate paper. Finally, simple linear equations are given only for dependences with the highest reliability index, the dependence of quality yield on dry matter yield and plant height, adequate indexes of determination are given also.

RESULTS

Mean values and main effects

Average, minimal and maximal ADF content of the cup plant green phytomass was 43.73 – 31.32 – 48.94%, ADL 10.22 – 7.21 – 12.54%, CE 33.51 - 24.11 – 37.30%, HEM 4.17 – 2.33 – 5.75%, NDF 48.12 – 34.94 – 54.69% and HHV 15.83 – 15.21 – 16.79 MJ/kg, respectively. Adequate values of ADF yield was 5.461 – 1.021 – 20.827 t/ha, ADL 1.274 – 0.235 – 5.115 t/ha, CE 4.187 – 0.786 – 15.112 t/ha, HEM 0.569 – 0.055 – 2.447 t/ha, NDF 6.041 – 1.139 – 23.273 t/ha and HHV 195.528 – 36.481 – 704.914 GJ/ha, respectively. Range data, the absolute minimal and maximal values are presented according to the years (Figure 1), total average data was overcalulated.

In terms of quality content, the influence of the sites was generally the most significant (valid for ADF, ADL, CE and NDF), or alternately with the influence of the years (HEM and HHV) it was higher than a medium influence of the nutrition (Table 1).

In terms of quality yield the years have been confirmed the most important factor followed by nutrition and then by sites with the least impact, whereas that impact order was valid for each of the solved parameter (Table 2).

Concerning quality content, in contrast to stated general trend the nutrition had the least impact on ADL, whereas the impact was not significant.

Figure 1 presents range and average values of quality indicators by years, whereas data in terms of quality content are shown in subfigure A and quality yield in subfigure B.

Table 1. Parameters of statistical analyses of variance for main effects for data set of quality content

Main source / parameter	ADF			ADL			CE			HEM			NDF			HHV		
	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value
sites	1	22.82	0.0005	1	14.75	0.0024	1	9.15	0.0106	3	0.00	0.9861	1	25.05	0.0003	3	0.53	0.4812
years	3	0.90	0.4315	2	3.94	0.0482	3	0.63	0.5507	1	11.83	0.0014	3	1.58	0.2462	1	6.71	0.0111
nutrition	2	2.20	0.1531	3	0.44	0.6568	2	1.42	0.2788	2	4.64	0.0322	2	2.86	0.0965	2	1.56	0.2495

IO – impact order, an order based on F-ratio

Table 2. Parameters of statistical analyses of variance for main effects for data set of quality harvested

Main source / parameter	ADF			ADL			CE			HEM			NDF			HHV		
	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value	IO	F-ratio	P-value
sites	3	1.16	0.3025	3	1.77	0.2076	3	0.96	0.3473	3	0.66	0.4322	3	1.13	0.3089	3	0.43	0.5224
years	1	11.92	0.0014	1	9.34	0.0036	1	12.56	0.0011	1	11.53	0.0016	1	11.83	0.0015	1	8.11	0.0008
nutrition	2	5.24	0.0231	2	4.46	0.0356	2	5.38	0.0215	2	4.79	0.0296	2	5.18	0.0238	2	5.75	0.0177

IO – impact order, an order based on F-ratio

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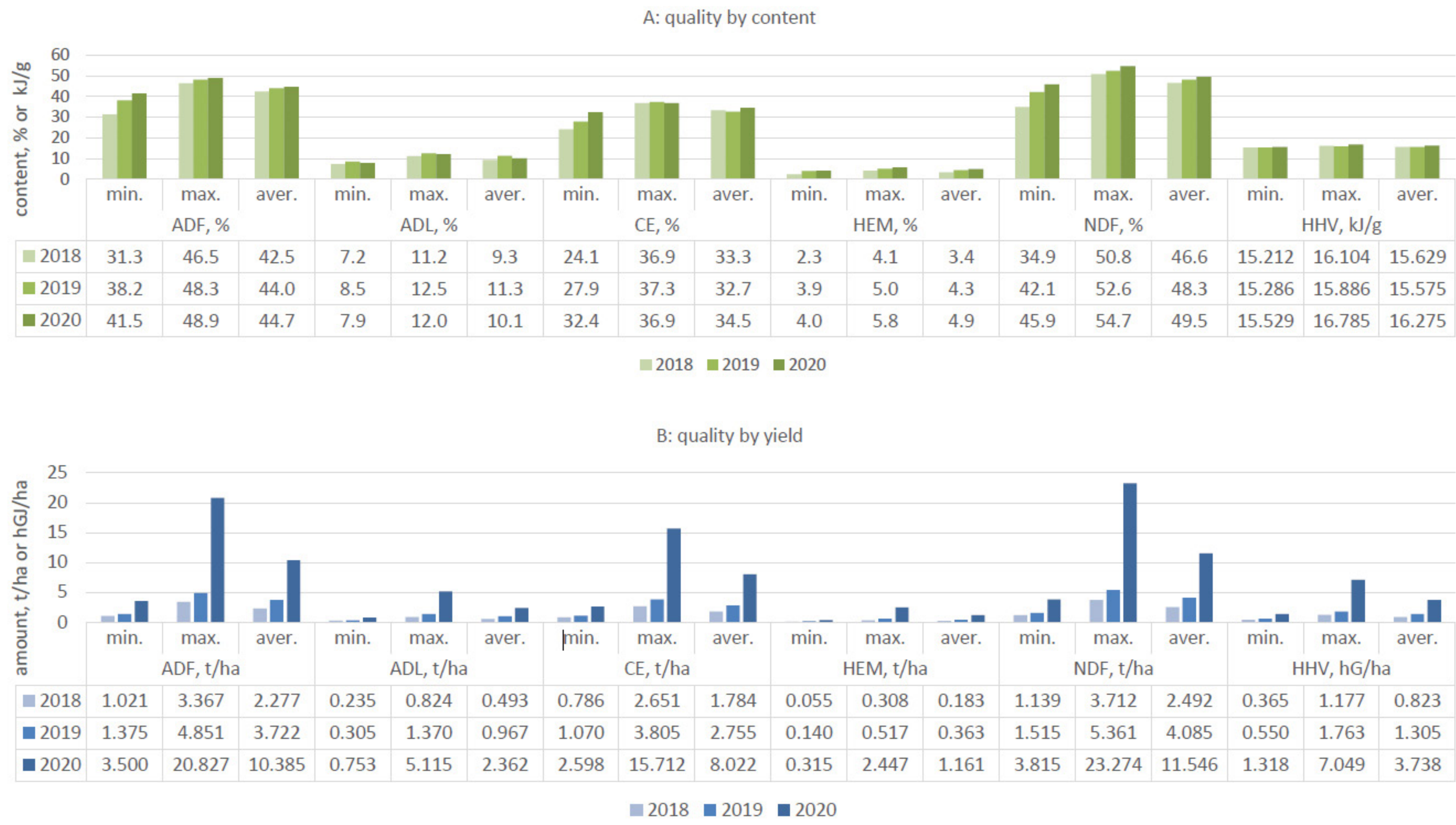

	ADF, % min.	ADF, % max.	ADF, % aver.	ADL, % min.	ADL, % max.	ADL, % aver.	CE, % min.	CE, % max.	CE, % aver.	HEM, % min.	HEM, % max.	HEM, % aver.	NDF, % min.	NDF, % max.	NDF, % aver.	HHV, kJ/g min.	HHV, kJ/g max.	HHV, kJ/g aver.
2018	31.3	46.5	42.5	7.2	11.2	9.3	24.1	36.9	33.3	2.3	4.1	3.4	34.9	50.8	46.6	15.212	16.104	15.629
2019	38.2	48.3	44.0	8.5	12.5	11.3	27.9	37.3	32.7	3.9	5.0	4.3	42.1	52.6	48.3	15.286	15.886	15.575
2020	41.5	48.9	44.7	7.9	12.0	10.1	32.4	36.9	34.5	4.0	5.8	4.9	45.9	54.7	49.5	15.529	16.785	16.275

	ADF, t/ha min.	ADF, t/ha max.	ADF, t/ha aver.	ADL, t/ha min.	ADL, t/ha max.	ADL, t/ha aver.	CE, t/ha min.	CE, t/ha max.	CE, t/ha aver.	HEM, t/ha min.	HEM, t/ha max.	HEM, t/ha aver.	NDF, t/ha min.	NDF, t/ha max.	NDF, t/ha aver.	HHV, hG/ha min.	HHV, hG/ha max.	HHV, hG/ha aver.
2018	1.021	3.367	2.277	0.235	0.824	0.493	0.786	2.651	1.784	0.055	0.308	0.183	1.139	3.712	2.492	0.365	1.177	0.823
2019	1.375	4.851	3.722	0.305	1.370	0.967	1.070	3.805	2.755	0.140	0.517	0.363	1.515	5.361	4.085	0.550	1.763	1.305
2020	3.500	20.827	10.385	0.753	5.115	2.362	2.598	15.712	8.022	0.315	2.447	1.161	3.815	23.274	11.546	1.318	7.049	3.738

Figure 1. Minimal, maximal and average values of quality indicators – A (content, in % or kJ/g), B (profit, in t/ha or hGJ/ha)

To include HHV values into the Figure, while three or five orders of magnitude higher, appropriate values in both units (kJ/g and hGJ/ha) were recalculated with a conversion factor, which changed the values in the decimal resolutions (kJ/kg and GJ/ha applied in Figure 2, respectively).

Levels of main effects

Quality content

Statistical evaluation of levels of the main effects shows on differentiated forming of homogenous groups (Table 3), whereas

- the sites were accompanied with the highest proportion of differentiated homogeneous groups, while
    - the highest average values within indicators majority (ADF, ADL, CE and NDF) significantly belongs to Site-1,
    - and the highest values of both remaining indicators (HEM and HHV) insignificantly belongs to Site-2.
- the years were accompanied with medium proportion of differentiated homogeneous groups, while
    - the highest average values within indicators majority (ADF, CE, HEM, NDF and HHV) was achieved in 2020
    - except the remaining one (HEM) for its highest average value was achieved in 2019.
- the nutrition was accompanied with the highest proportion of the same homogeneous group, while
    - the highest average values of indicators majority (ADF, CE, NDF and HHV) are associated with intensive nutrition
    - and the highest average values of both remaining indicators are associated as with semi-intensive (ADL) as with untreated control (HEM).

Quality yield

Similar evaluation of main effects levels on homogenous groups forming (Table 4) points to

- sites were accompanied with zero proportion of differentiated homogeneous groups, however
    - the highest average values of each indicators always belongs to Site-1 (the site with the highest DM yield).
- years were accompanied with creating two homogenous groups with one scheme identical to the crop increasing productivity in general, while
    - the highest average values of each indicator were achieved always in 2020 (the year with the highest DM yield).
- nutrition was accompanied with creating two homogenous groups with one scheme identical to the crop increasing productivity in general, similar to the years, while
    - the highest average values of each indicator always belongs to intensive nutrition and the least one always belongs to untreated control without nutrition.

Impact of plant height, DM yield and DM content

Figure 2 shows dependencies of quality content and yield on plant height, dry matter yield and dry matter content at harvest. Within the Figure 2 a second-order polynomic trends are used and reliability indexes are revealed, whereas figures are optimized to show whole data cluster.

In terms of quality content, it was characteristic that the evaluated dependencies had a weak reliability

- R^2 ranging within 0.0053 – 0.0721 concerning ADL, ADF, CE and NDF on plant height
- R^2 ranging within 0.0316 – 0.1620 concerning ADL, ADF, CE and NDF on DM yield
- R^2 for HHV achieved 0.2087 when on plant height, and 0.3658 when on DM yield,

with exceptions of middle ones of HEM on plant height and DM yield, with the R^2 values of 0.6320 and 0.5674,

Table 3. Homogenous groups (H) and parameters of statistical analyses of variance for data set of quality content within levels of main effects, quality indicators in % (ADF, ADL, CE, HEM, NDF) or in J/g (HHV)

Main source / parameter	ADF			ADL			CE			HEM			NDF			HHV		
	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma
sites																		
Site-1	a	46.930	0.94741	a	11.350	0.4145	a	35.580	0.9699	a	4.1644	0.1761	a	51.539	0.9665	a	15889.	122.774
Site-2	b	40.530	0.94741	b	9.0988	0.4145	b	31.431	0.9699	a	4.1689	0.1761	b	44.699	0.9665	a	15763.	122.774
years																		
2018	a	42.520	1.16033	b	9.2667	0.5077	a	33.253	1.1879	b	3.3817	0.2157	a	46.568	1.1837	b	15629.	150.347
2019	a	43.993	1.16033	ab	11.277	0.5077	a	32.717	1.1879	a	4.2617	0.2157	a	48.255	1.1837	b	15575.	150.347
2020	a	44.677	1.16033	a	10.130	0.5077	a	34.547	1.1879	a	4.8567	0.2157	a	49.533	1.1837	a	16275.	150.347
nutrition																		
intensive	a	44.697	1.16033	a	10.272	0.5077	a	34.425	1.1879	b	3.7350	0.2157	a	49.355	1.1837	a	16025.	150.347
semi-int.	a	44.752	1.16033	a	10.533	0.5077	a	34.218	1.1879	ab	4.1067	0.2157	a	49.192	1.1837	a	15802.	150.347
control	a	41.742	1.16033	a	9.8683	0.5077	a	31.873	1.1879	a	4.6583	0.2157	a	45.810	1.1837	a	15652.	150.347

H – homogenous group (MANOVA determines which means are significantly different from which others at the statistical 95.0% confidence level, *P*<0.05 respectively)

Table 4. Homogenous groups (H) and parameters of statistical analyses of variance for data set of quality yield within levels of main effects, quality indicators in t/ha (ADF, ADL, CE, HEM, NDF) or in GJ/ha (HHV)

Main source / parameter	ADF			ADL			CE			HEM			NDF			HHV		
	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma	H	LS Mean	LS Sigma
sites																		
Site-1	a	6.2406	1.0229	a	1.5186	0.2597	a	4.7220	0.7732	a	0.6409	0.1252	a	6.9032	1.1473	a	211.67	34.649
Site-2	a	4.6819	1.0229	a	1.0294	0.2597	a	3.6525	0.7732	a	0.4970	0.1252	a	5.1789	1.1473	a	171.38	34.649
years																		
2018	b	2.2770	1.2528	b	0.4931	0.3180	b	1.7840	0.9470	b	0.1829	0.1533	b	2.4924	1.4052	b	82.331	42.436
2019	b	3.7220	1.2528	b	0.9668	0.3180	b	2.7552	0.9470	b	0.3631	0.1533	b	4.0851	1.4052	b	130.46	42.436
2020	a	10.385	1.2528	a	2.3622	0.3180	a	8.0224	0.9470	a	1.1609	0.1533	a	11.546	1.4052	a	373.79	42.436
nutrition																		
intensive	a	8.2016	1.2528	a	1.9339	0.3180	a	6.2677	0.9470	a	0.9012	0.1533	a	9.1027	1.4052	a	294.25	42.436
semi-int.	ab	5.7009	1.2528	ab	1.2971	0.3180	ab	4.4039	0.9470	ab	0.5756	0.1533	ab	6.3011	1.4052	ab	201.35	42.436
control	b	2.4812	1.2528	b	0.5911	0.3180	b	1.8901	0.9470	b	0.2302	0.1533	b	2.7193	1.4052	b	90.981	42.436

H – homogenous group (MANOVA determines which means are significantly different from which others at the statistical 95.0% confidence level, $P<0.05$ respectively)

respectively. Also a weak reliability was achieved concerning the evaluated dependencies of quality content on DM content at harvest, when R^2 ranging within 0.0133 – 0.2609 and the highest value of reliability deals with ADF.

In accordance to the weak reliability of quality content, also a weak reliability was achieved concerning the dependencies of quality yield on DM content at harvest, whereas R^2 ranging 0.0489 – 0.0925 and being lower those of content ones. While in contrast to quality content, the adequate trend lines of quality yield are typical of

- middle reliability with R^2 ranging 0.4520 – 0.5631 within the dependencies on plant height
- strong reliability with R^2 ranging 0.9570 – 0.9994 within the dependencies on DM yield,

whereas these general trends are valid for all indicators of ligno-cellulose quality and combustion value. Although Figure 2 does not include polynomial equations, Table 5 collected parameters for a simple linear formula y = ax + b concerning the evaluated dependencies of quality yield where medium or strong reliability within the second-order polynomic trend was achieved. Shape-type of the second-order polynomial trend line is close to be linear in the case of DM yield is independent variable (subfigure 2E). In the cases where plant height is the independent variable (subfigure 2D), the polynomial trend is more appropriate then the linear one, whereas determination index of linear dependence achieved a lower value than adequate value of reliability index of polynomial dependence.

Table 5. Parameters of linear dependence of quality yield on dry matter yield and plant height according indicators

Parameter	Dependence of quality yield on DM yield		Dependence of quality yield on plant hight	
	LF	ID	LF	ID
ADF	y = 0.4690x – 0.2452	R^2 = 0.9887	y = 0.0411x – 1.9782	R^2 = 0.4426
ADL	y = 0.1089x – 0.0506	R^2 = 0.9488	y = 0.0095x – 0.4394	R^2 = 0.4181
CE	y = 0.3601x – 0.1945	R^2 = 0.9916	y = 0.0317x – 1.5388	R^2 = 0.4460
HEM	y = 0.0558x – 0.1096	R^2 = 0.9783	y = 0.0049x – 0.3258	R^2 = 0.4480
NDF	y = 0.5241x – 0.3368	R^2 = 0.9882	y = 0.0459x – 2.2584	R^2 = 0.4407
HHV	y = 16.5594x – 5.9714	R^2 = 0.9992	y = 1.5039x – 76.5063	R^2 = 0.4797

LF - linear formula y = ax + b, where x = dry matter yield in t/ha, or x = plant height in cm; ID – index of determination, equal to r^2, where r = correlation coefficient

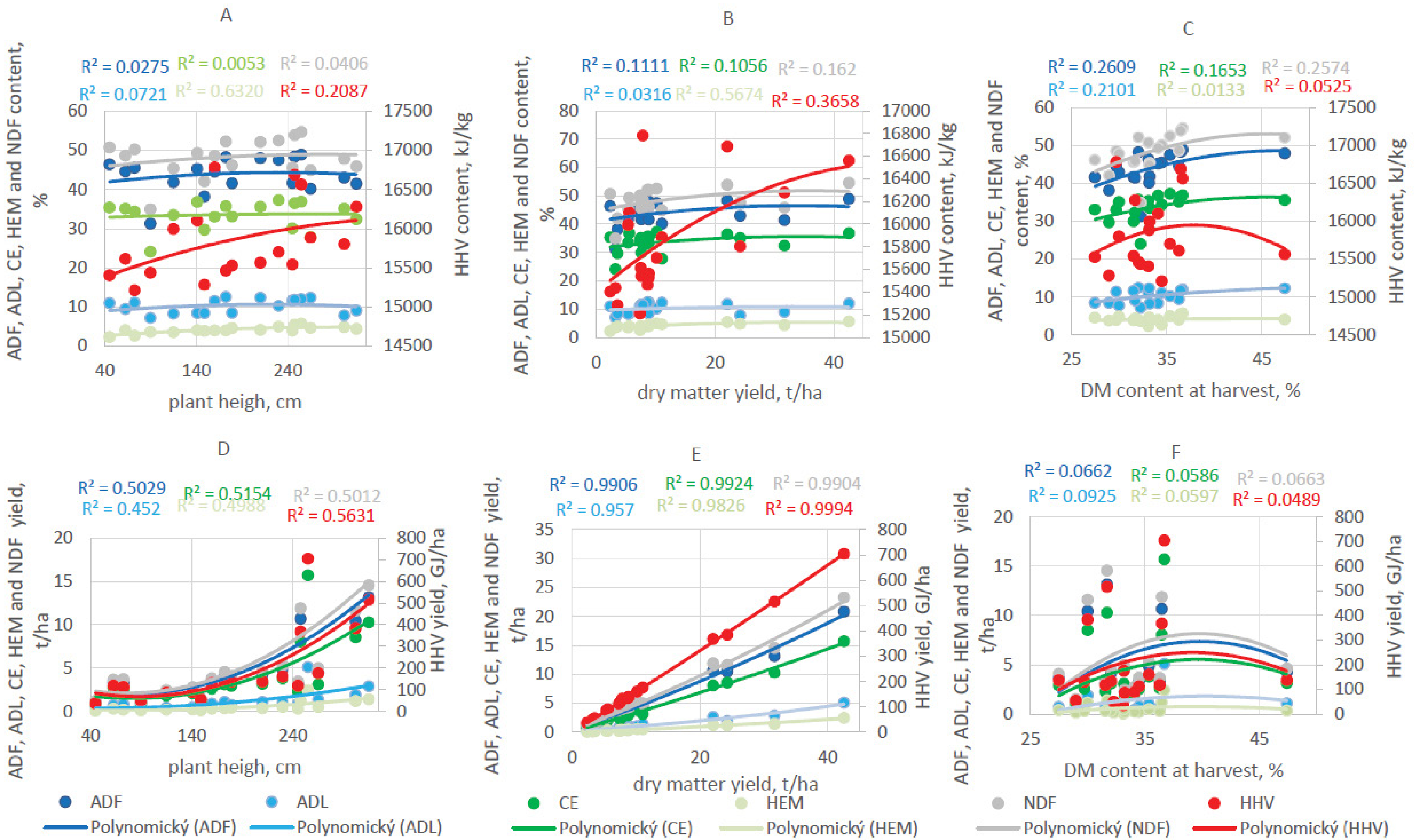

Figure 2. Dependence of quality content on plant height (A), dry matter yield (B) and dry matter content at harvest (C), and dependence of quality yield on plant height (D), dry matter yield (E) and dry matter content at harvest (F)

DISCUSSION

By gaping research of Bury et al. (2020) the calorific value of cup plant phytomass was 16.61 MJ/kg on average over three years, while HHV ranging 14.59 – 17.87 MJ/kg and indicating differences both between the method of establishing the plantation (by seeds or planting) and years of research (2017-2019). Based on the study of Jasinskas et al. (2014) the average HHV of cup plant was higher and varied from 17.2 to 18.7 MJ/kg. According to Šaudinis et al. (2015) the HHV of the cup plant dry masses were 17.19 to 17.48 MJ/kg correlating with the biomass crude fibre content, while energy outputs ranging 200-236 GJ/ha and the energy expenses of the cup plant cultivation (including planting and harvesting year) reached 8630-29,264 MJ/ha.

By conclusion of Witaszek et al. (2022) the calorific value of cup plant phytomass as solid biofuel generated a relatively low amount of heat in comparison with the expected amount of heat from a biogas-powered cogeneration system due to the high energy consumption of the processes of drying and agglomeration of raw material for the production of pellets. The energy balance of the calorific value of biofuel in the form of cup plant pellets showed that 858.28 kWht could be generated from 1 Mg of the raw material.

In contrast to combustion value, literature data on ligno-cellulose quality of cup plant are not available in desired extent, especially studies on agronomy impact still absent.

The primary components (cellulose, hemicellulose and lignin) are vital resources in (i) sugar platform (fermentation of biomass sugars) or (ii) thermochemical platform (e.g. gasification followed by biological or chemical processing) technologies (Monomo et al., 2013). According to a large study of Peni et al. (2022) the application of fertilizers increased the fixed carbon and volatile matter content, higher heating value, chlorine, hemicellulose and cellulose content. The moisture content of cup plant green phytomass harvested in September was 75.8%, while cellulose and lignin contents was 24.47% and 8.29% DM, respectively.

CONCLUSIONS

Ligno-cellulose quality and calorific value of cup plant vary with environment and management practices. The impact of nutrition, years and sites are calculated as main effects on acid-detergent fiber, acid-detergent lignin, crude cellulose, hemicellulose, neutral-detergent fiber and high heating value, whereas two equal aspects of quality are evaluated in the study, a primary one which deals with content-basis quality (% or kJ/g), which is considered to be a general indicator of phytomass quality, and a secondary one which deals with yield-basis quality (kg/ha or GJ/ha), which will be important to processors as it will impact the area required to create sustainable supply-chain for a processing plants.In terms of quality content, the influence of the sites was generally the most significant (valid for ADF, ADL, CE and NDF), or alternately with the influence of the years (HEM and HHV) it was higher than a medium influence of the nutrition. In terms of quality yield the years have been confirmed the most important factor (mainly because of the great increase in phytomass yield by utility year of that perennial crop), followed by nutrition and then by sites with the least impact, whereas that impact order was valid for each of parameter. Moreover, influence of plant height, dry matter (DM) yield and DM content at harvest on quality were also evaluated by second-order polynomic trends. In terms of quality content, it was characteristic that the evaluated dependencies had a weak reliability in general, only with some exceptions of a middle ones within impact of plant height and DM yield. Also a weak reliability was achieved concerning dependencies in terms of quality yield on DM content at harvest, but strong reliability was typical within impact of DM yield on the quality yield and middle ones within impact of plant height, respectively. These general trends, within terms of quality yield, was valid for all indicators of ligno-cellulose quality and calorific value. Therefore, both plant height and DM yield are a good indicator of profit of lignocellulosic quality and energy yield as well, while DM content at harvest appears to be optimal at 35-40% what requires more data to should be evaluated in more precisely

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