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INTERNODE MORPHOLOGICAL AND DRY MATTER CONTENT DIFFERENCE OF SWEET SORGHUM (*Sorghum bicolor* (L) Moench) HYBRIDS

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ABSTRACT

Background. Field studies carried out at Pawlowice Research Station near Wroclaw in the years 2006–2008. Research aimed at the comparison of the morphology of the internodes of two sorghum hybrids: Sucrosorgo G–1990 (photoperiodically sensitive – headless) and Sucrosorgo 506 (photoperiodically insensitive – headed).
Material and methods. Stem with small and large diameter were collected separately from both hybrids. The effect of the place from which the internodes were collected (lower, middle, upper part of stem) on morphological features was determined. The length, mass and the diameter of stem were specified. The morphological measurement of internodes were identical for whole material and the content of leaves, rind (outer internode part) and pith (inner part) in dry matter was determined.
Results. The headed hybrid of sorghum was taller (by 29.7%) and had higher mass (by 40%) but lower diameter (1.83 cm) than the photoperiodically sensitive hybrid. The lower internode was shortest (13.2 cm) while longest one was collected from middle part of stem (19.7 cm). The lowest mass (35.2 g) and the smallest diameter (1.7 cm) has upper internode. Stem with larger diameter had shorter internodes (by 5.0 cm), higher mass (by 36.3 g) and larger diameter (by 0.8 cm). In the lower internodes dry matter content was highest. In the headed hybrid, the percentage of pith was the highest in the lower internode (44.3% – large diameter stem and 45.0% – small diameter stem). In the lower internode of the photoperiodically sensitive hybrid the rind dominated (42.8% dry matter from large diameter stem and 42.5% dry matter from small diameter stem).
Conclusion. Pith part content constituted 39.9–42.8% of internode dry mass and depends on place from the internode was collected. The rind dominated in the lower part of the stem.

Key words: headed hybrid, headless hybrid, leaves, pith part, rind part

INTRODUCTION

Sorghum originally from north-east Africa (Ethiopia), with the first records of cultivation dating 4000 BC (Sene *et al.*, 2001). It is a short day photoperiodical sensitive crop, and flowering is accelerated when decrease length of day (Folliard *et al.*, 2004). In agricultural practice environment conditions, selection of hybrids, production direction and sowing density are the main factors. Sweet sorghum (*Sorghum bicolor* (L) Moench) is considered a species with the very high productivity and high yield of biomass (Sowiński and Szydełko-Rabska, 2013; Tari *et al.*, 2013). Sorghum crops cultivated throughout the world

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in different environment conditions for different utilization (Hodnett *et al.*, 2005). This species has not been intensively studied in Central Europe climatic conditions and the primary results of experiments are promising (Sowiński and Liszka-Podkowa, 2008; Szumiło and Rachoń, 2008; Sowiński *et al.*, 2017).

Over the years, approximately 25 species were cultivated and more than 10,000 varieties or genotypes (Liu *et al.*, 2014). Broad sorghum genotypes range seems to be the most suitable, species, for the production of seeds or biomass for energy, fodder, raw material for industrial applications and other purposes (Dahlberg *et al.*, 2011).

Sweet sorghum are particularly important among the functional types of *Sorghum bicolor* ssp. bicolor. The above ground biomass of sorghum is composed of leaves, stems, heads and their percentage changes depending on the growth stage, environment conditions, agrotechnical factors and hybrids characteristics (Baez--Gonzalez and Jones, 1995; Sowiński and Liszka--Podkowa, 2008). For sweet sorghum, the basic component of biomass, which decides about its suitability for energy and forage production are stalks – stem without leaves (Tsuchihashi and Goto, 2005; Fujii *et al.*, 2014) which constitute ca. 60–70% of the mass (Sowiński and Liszka-Podkowa, 2008; Audilakshmi *et al.*, 2010). Agrotechnical treatments influence on the length of internodes which decides about the length and mass of stalks (Tsuchihashi and Goto, 2005). For fodder production, higher percentage of leaves in the yield of sorghum is beneficial, in order to obtain highly nutritional fodder – higher protein and lower fiber content. Fontaneli *et al.* (2001) suggest the harvest of sorghum for forage when it is 50–60 cm tall and the content of leaves in the yield exceeds 70%.

The field conditions, sowing density and fertilization influence the length, mass of stems and the number of internodes. Szumiło and Rachoń, (2008) indicated that the percentage of leaves and stalks depends on the density of plants. Sowiński and Liszka-Podkowa (2008) observed hybrid differences (headed and headless) in the plant biomass structure.

The aim of the present study was to examine the structure of leaves, rind and pith in the internodes of sweet sorghum. The following hypothesis was verified in the study: morphological differentiation of internodes depends on the hybrid type, and the place from which the internode is collected. It was assumed that the sorghum hybrids will influence on the percentage of leaves and the structure of stalk (rind and pith). Place from which internodes are collected and the diameter of the stem will differentiate also the percentage of the studied fractions and will have an influence on the content of dry matter and quality of sorghum feedstock.

MATERIAL AND METHODS

The experiments were carried out in the years 2006-2008 in Pawłowice (51°09' N; 17°06' E), south-west Poland. The experiments were conducted on loamy sand classified as light soil.

Sweet sorghum, seed material (*Sorghum bicolor* (L) Moench) of two hybrids: Sucrosorgo G–1990 (headless) and Sucrosorgo 506 (headed), produced by Sorghum Partners, Inc. was used. Plants with stem of various diameters groups were collected separately. The stems were selected based on diameter measurement. Internodes were collected as follows: in both hybrids of sorghum, the lower internode was the first full visible over the soil surface, the middle was located in medium of the stem length. In headed sorghum, upper internode (the first below the head one) was also collected. In the headless (photoperiodically sensitive hybrid – Sucrosorgo G–1990), the upper internodes were very short and the amount of plant material for analysis (especially for dry matter content) was insufficient.

The results are presented according to the following layout of the factors:

1) hybrids: headless sorghum – Sucrosorgo G–1990, headed sorghum – Sucrosorgo 506;
2) stem thickness: small diameter ∅ < 2 cm, large diameter ∅ ≥ 2 cm;
3) the stem place from which the internode was collected: lower, middle, upper (only for Sucrosorgo 506 hybrid).

Before the experiments, nitrogen fertilizers (130 $kg \cdot ha^{-1}$), phosphorus (39.5 $kg \cdot ha^{-1}$ P) and potassium (100 $kg \cdot ha^{-1}$ K) were applied and then mixed with soil using a Howard harrow with toothed packer roller. The sowing of 20 $seeds \cdot m^{-2}$ was performed between 10^{th} and 20^{th} of May using a Wintersteiger seed drill.

Sorghum plant samples were collected, at the grain filling stage (Sucrosorgo 506 hybrid). The photoperiodically sensitive hybrid (Sucrosorgo G–1990) was in the full developed vegetative growth stage.

The mass, length of stem and its diameter at the base were measured for each plant. Next, internodes were collected and divided into the following fractions: leaves, rind – outer and pith – inner part of the stem (Fig. 1).

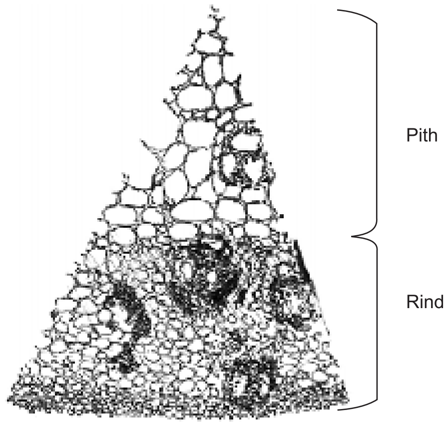

Fig. 1. Sorghum stem cross-section (Sowiński based on Hatfield *et al.*, 1999)

The mass of fraction and dry matter content were measured separately for each biomass part. Basic chemical analysis was done and presented on other paper (Sowiński and Liszka-Brandau, 2019).

The results were statistically analyzed using STATISTICA 9.0 software and ANOVA/MANOWA variance analysis was performed. Significant intervals were tested at level $P < 0.05$. Only the results of the measurements from the lower and middle internode were used in the statistical analysis of the data concerning the differences between hybrids. Curves of regression between dry matter and same chemical compounds composition content were plotted.

RESULTS

In comparison sorghum with stem of small diameter, the mass and diameter were higher in headed type (Table 1). No interaction between the hybrid and the diameter of the stem and stem length was observed. Headed sorghum was, on average, taller (by 29.7%) and had higher mass (by 40.0%) than headless sorghum. The differences between the diameter of stem (at the base ~5 cm above soil surface) within both hybrids were not statistically different. A stem of large diameter had a higher mass (by 204%) than with small diameter.

Table 1. Sorghum stem characteristic; average from years 2006–2008

Sorghum hybrid	Stem with	Stem length, cm	Stem mass, g	Stem diameter, cm
Sucrosorgo G–1990*	large diameter	204.0	886.5	2.57
	small diameter	220.1	283.2	1.45
Sucrosorgo 506**	large diameter	272.5	1228.5	2.19
	small diameter	277.7	409.5	1.48
Probability		$P > 0.05$	$P < 0.05$	$P < 0.05$
Average for:				
Sucrosorgo G–1990	–	212.1	584.9	2.01
Sucrosorgo 506	–	275.1	819.0	1.83
Probability		$P < 0.05$	$P < 0.05$	$P > 0.05$
–	large diameter	245.1	1091.7	2.34
–	small diameter	254.7	359.0	1.47
Probability		$P > 0.05$	$P < 0.05$	$P < 0.05$

* headless sorghum
** headed sorghum

No interaction between the hybrids and the stem diameter and the place from which internode was collected was observed in the internode length, mass and diameter (Table 2).

Table 2. Sorghum internode parameters; average from years 2006–2008

Sorghum hybrid	Stem with	Internode from part	Internode parameters		
			length, cm	mass, g	diameter, cm
Sucrosorgo G–1990	large diameter	lower	6.3	52.4	2.9
		middle	12.0	67.5	2.3
		upper	–	–	–
	small diameter	lower	14.8	31.0	1.5
		middle	19.6	32.8	1.4
		upper	–	–	–
Sucrosorgo 506	large diameter	lower	13.2	82.2	2.6
		middle	22.4	92.1	2.2
		upper	15.6	50.2	1.8
	small diameter	lower	18.4	38.6	1.6
		middle	24.8	40.2	1.3
		upper	16.9	20.2	1.1
Probability			$P > 0.05$	$P > 0.05$	$P > 0.05$

Sorghum hybrid	Stem with	Internode from part	length, cm	mass, g	diameter, cm
Sucrosorgo G–1990	large diameter	lower	6.3	52.4	2.9
		middle	12.0	67.5	2.3
		upper	–	–	–
	small diameter	lower	14.8	31.0	1.5
		middle	19.6	32.8	1.4
		upper	–	–	–
Sucrosorgo 506	large diameter	lower	13.2	82.2	2.6
		middle	22.4	92.1	2.2
		upper	15.6	50.2	1.8
	small diameter	lower	18.4	38.6	1.6
		middle	24.8	40.2	1.3
		upper	16.9	20.2	1.1
Probability			$P > 0.05$	$P > 0.05$	$P > 0.05$

Headed sorghum had statistically longer internodes (by 41%), but statistical analysis did not show any differences between the mass and diameter. Thicker stems were characterized by shorter internodes (by 5 cm), lower mass (by 36.3 g) and larger diameter (by 0.8 cm). Differentiation of the parameters of internodes depending on the place from which they were collected. The lower internode was shortest

(13.2 cm) whereas the upper one had the lowest mass (35.2 g) and diameter (1.7 cm).

No interaction between the hybrid and the diameter of the stem and the place from which internode was collected was observed in the content of dry mass in leaves, rind and pith part of the internode (Table 3). In headed sorghum, only the content of dry mass was higher in the rind part of the internode (by 4.6 percentage points – p.p.) than in headless sorghum. The differences in leaves and pith part of the internode were not confirmed. No differences in the content of dry mass depending on the diameter of the stem were observed. The lower internodes were characterized by a higher dry mass content in the leaves (as a result of dying process) – 50.2%.

Table 3. Dry matter content at internode parts; average from years 2006–2008

Sorghum hybrid	Stem with	Internode from part	Percentage of D.M. in		
			leaves	rind	pith
Sucrosorgo G–1990	large diameter	lower	37.3	32.5	17.3
		middle	24.3	28.5	16.4
		upper	–	–	–
	small diameter	lower	45.0	30.9	21.2
		middle	26.9	25.9	16.8
		upper	–	–	–
Sucrosorgo 506	large diameter	lower	53.5	37.2	20.3
		middle	24.6	35.9	23.7
		upper	26.7	28.6	16.7
	small diameter	lower	65.1	35.8	18.3
		middle	27.7	37.5	20.1
		upper	27.5	29.8	18.0
	Probability		$P > 0.05$	$P > 0.05$	$P > 0.05$
		Average for:			
Sucrosorgo G–1990	–	–	33.4	29.5	17.9
Sucrosorgo 506	–	–	37.5	34.1	19.5
	Probability		$P > 0.05$	$P < 0.05$	$P > 0.05$
–	large diameter	–	33.3	32.5	18.9
–	small diameter	–	33.4	32.0	18.9
	Probability		$P > 0.05$	$P > 0.05$	$P > 0.05$
–	–	lower	50.2	34.1	19.3
–	–	middle	25.9	31.9	19.2
–	–	upper	27.1	29.2	17.3
	Probability		$P < 0.05$	$P > 0.05$	$P > 0.05$

Stem dry matter content influenced on chemical composition and sweet sorghum utilization for animal feeding and as feedstock for bioethanol processing (Figs. 2–4). Total protein content negatively corelated with dry matter content (slope – 0.705). Increased dry matter content enhanced fibre and their fraction content slopes 0.697, 0.378, 0.719 (respectively for crude fibre, NDF and ADF content). The same tendency observed beside of fraction for correlation between dry matter and crude protein content (Fig. 3). NDF concentration increased with enhanced dry matter content only for leaves fraction. For pith and rind NDF negative correlation with dry matter content observed (Fig. 4).

In the lower internode of headed sorghum, the percentage of the rind part was the highest (44.3% – stem with a large diameter and 45% – stem with a small diameter), whereas in headless sorghum, the pith part dominated in the internode collected from lower part (42.8% of dry mass – large diameter, 42.5% of dry mass – small diameter) (Fig. 5). In both hybrids of sorghum (irrespective of the diameter of the internode), the percentage of leaves in dry mass was increasing when the place from which the internode was collected was moving towards the top of the plant.

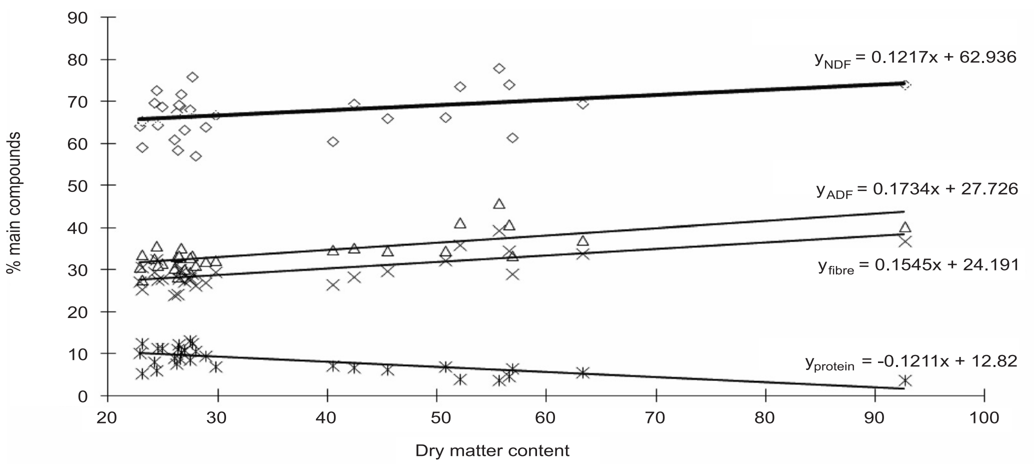

Fig. 2. Relation between dry matter content and total protein, crude fibre and fibre fraction

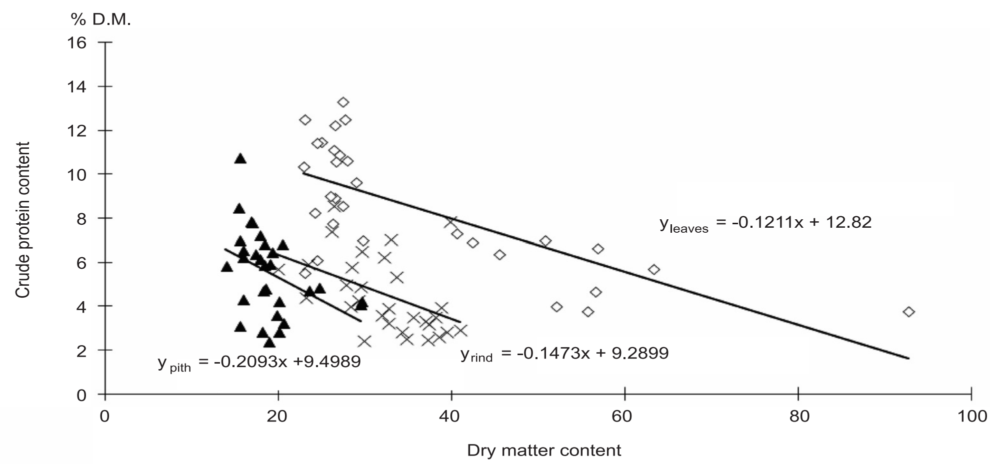

Fig. 3. Relation between dry matter content and total protein content at stem fractions

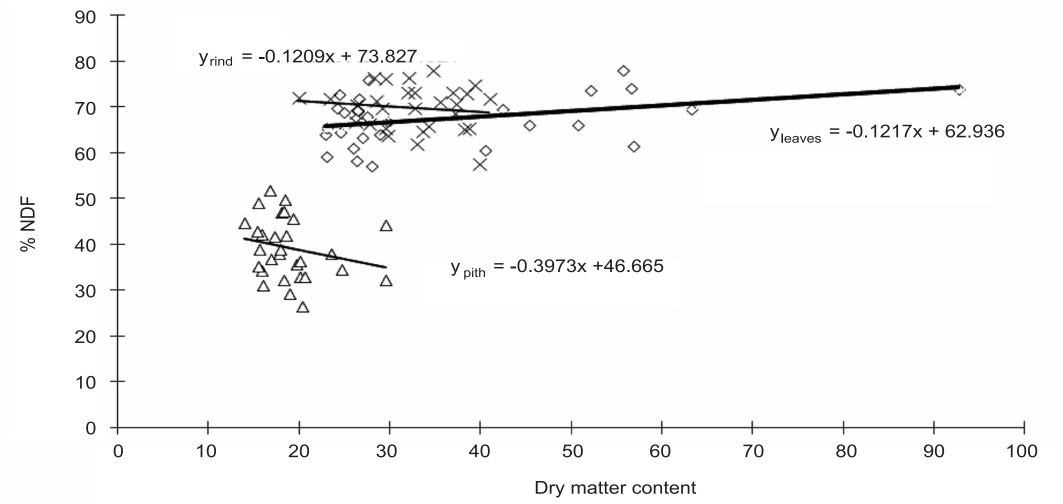

Fig. 4. Relation between dry matter content and NDF fraction at stem fractions

The percentage of the pith part showed little differentiation depending on the diameter of the stem. The pith part on stem with small diameter was lower – from 0.3 to 7.7 pp. The diameter of stem had a similar influence on the internode biomass structure, irrespective of the hybrid.

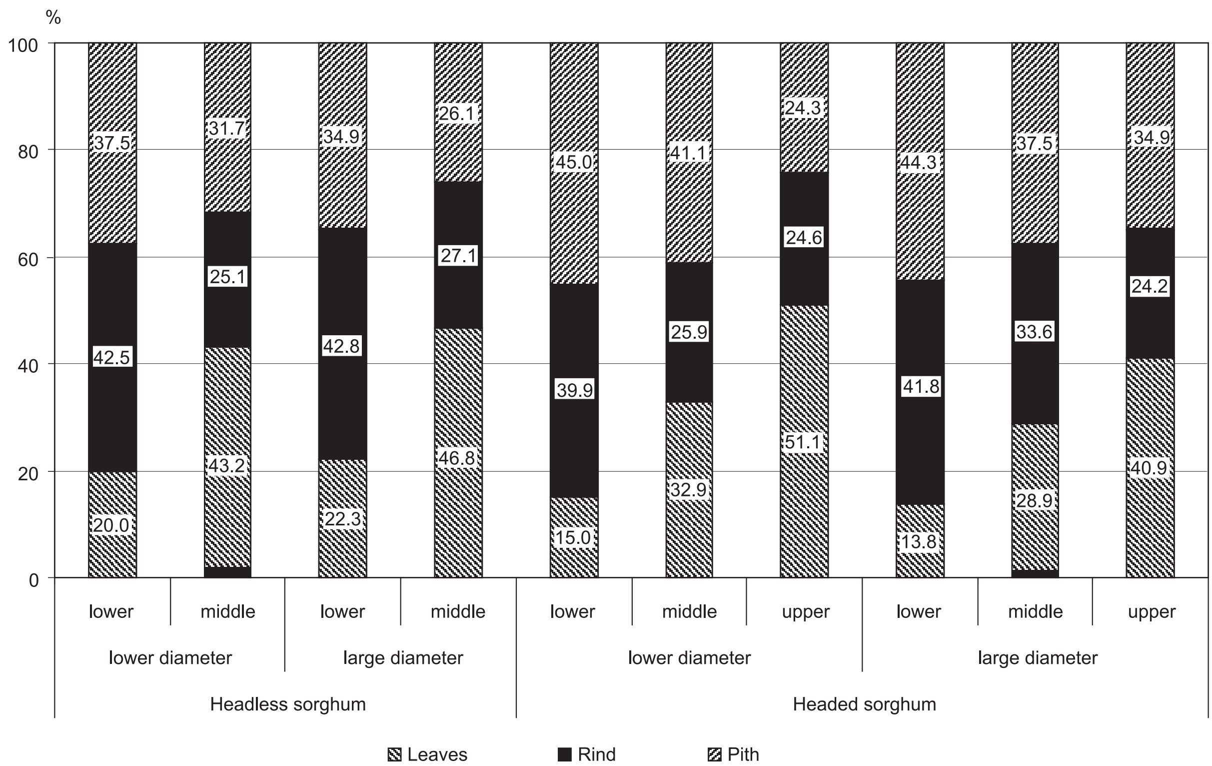

Fig. 5. Structure of sorghum internodes in percentage of D.M; average from years 2006–2008

DISCUSSION

At high density, plants compete for environment conditions, are taller and their diameter is lower. Increasing the density from 30 to 50 plants·m^{-2} resulted in decreasing the diameter from 1.16 to 1.07 cm (Ayub *et al.*, 2002). In the present study, the diameter of the stem was more diversified and varied from 1.45 to 2.57 cm. Goto *et al.* (1994) indicate that, in the early stages of the development, the plants were taller at higher density, by in the end of vegetation, sorghum plants from lower density were taller. As a result of increased sowing density, the internodes in lower parts of the stem were longer and those in the upper part were shorter. The diameter of stems had a similar influence on the results, irrespective of the hybrid. The largest differentiation was observed in the mass which was 300% higher in stems with large diameter than in plants with small diameter. In the study conducted by Tsuchihashi and Goto (2004), the same sweet sorghum hybrid height range from 279 to 360 cm. Many biotic and abiotic factors influenced on plant height. In own study, the plants reached a maximum of 278 cm. The mass of stems varied a lot, from 283 g (headless sorghum with small diameter) to 1228 g (headed sorghum with large diameter).

Nakamura *et al.* (2011) showed that sorghum creates 19 internodes, the first five are short, not growing and not visible. The internodes from 10 to 14 were the longest and reached up 20 cm. According to (Fujii *et al.*, 2014) and Tsuchihashi and Goto, (2004), the internodes up to 4–5 were longer, the next ones were gradually shorter and the head internode was clearly the longest. In the present study, the length of internodes depended on all experiment fators and ranged from 6.3 cm to 19.2 cm. The headless hybrid was characterized shorter internodes (by 29% avg.), lower mass (by 14.8%) and larger diameter (by 10%) than the headed hybrid. However, it was characterized by a lower dry mass content in all examined parts of the stem.

Nakamura *et al*. (2011), Tsuchihashi and Goto (2004) showed that diameter of internodes decreased with successive of internode. The internodes in the middle part of the stem had the largest diameter and that decreased both towards the base and the top of the plant. In our study, the diameter in headed sorghum hybrid decreased from 2.6 cm (lower internode, large diameter) to 1.1 cm (upper internode, small diameter). In the headless hybrid, the diameter of internodes ranged from 1.4 cm (middle internode, small diameter) to 2.9 cm (lower internode, large diameter). Tsuchihashi and Goto (2005) indicate that internodes from 3 to 5 were characterized highest mass. In the upper parts of the stem, the mass of internodes was lower. In the present study, the highest mass (58.2 g) was observed in the middle internode.

Sweet sorghum is crops enclose pith cell, which contain 25-50% of stem weight (Jones *et al.*, 1979). Billa *et al.* (1997) show that the pith constituted 65% of sorghum dry mass. Pith is rich in soluble sugars (Jones *et al.*, 1979) and in the Piedmont System concept is to separate pith from stalks and pass only the pith fraction for improvement of juice pressing efficiency (Vaughan and Cundiff, 1992). Sorghum pith has good pore structure and could be use as material for activated carbon preparation (Senthilkumara *et al.*, 2011). In present study, the content of the pith depended on the place from the internode was collected. Constituted from 39.9 to 42.8% dry mass in the lower part of the stem and decreased in the upper part (from 24.2 to 24.6% dry mass). The rind dominated in the lower part of the stem. When the place from which internodes were collected moved towards the head, the percentage of leaves increased and the percentage of rind and pith decreased.

CONCLUSIONS

Currently European plant varieties catalogue include hundreds of sorghum hybrids divided on three main groups. Present research shows specific differences among groups which is important for different sorghum utilization. The most valuable part of sorghum stem is inner – pith-fraction. Content of this part depend on the place of internode on stem. In the lower part was highest and decreased in the upper. Leaves are the main part of upper sorghum internode with lower dry matter content. For leaves fraction dry matter correlated more deeply with protein content. Sorghum biomass chemical composition depends on dry matter content at harvest. Crude fibre and their fraction percentage at biomass are positively corelated with dry matter. For total protein observed opposite tendency. Sweet sorghum stem diameter hasn't any influence on stem morphological differences and chemical composition. For pith fraction separation stem with large diameter are more useful and separation process can run faster.

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ZRÓŻNICOWANIE MORFOLOGII I ZAWARTOŚCI SUCHEJ MASY W MIĘDZYWĘŹLACH MIESZAŃCÓW SORGA CUKROWEGO (*Sorghum bicolor* (L) Moench)

Streszczenie

Doświadczenie polowe przeprowadzono w Pawłowicach koło Wrocławia w latach 2006–2008, na polach należących do Instytutu Agroekologii i Produkcji Roślinnej Uniwersytetu Przyrodniczego we Wrocławiu. W badaniach porównano zróżnicowanie morfologiczne międzywęźli dwóch odmian sorga: Sucrosorgo G–1990 (odmiana fotoperiodycznie wrażliwa – bezwiechowa) i Sucrosorgo 506 (odmiana fotoperiodycznie obojętna – wiechowa). Rośliny o małej i dużej średnicy źdźbła dla każdej z odmian pobierano oddzielnie. Określono wpływ miejsca pobrania międzywęźla (dolna, środkowa i górna część źdźbła) na różnice w morfologii źdźbła. Zmierzono długość i średnicę międzywęźla oraz oznaczono jego masę. Następnie każde międzywęźle rozdzielono na liście, część zewnętrzną i wewnętrzną źdźbła i określono w każdej frakcji – dla każdego miejsca pobrania oraz odmiany – zawartość suchej masy. Rośliny odmiany Sucrosorgo 506 były wyższe o 29,7% i miały większą masę o 40%, ale mniejszą średnicę o 1,83 cm niż rośliny odmiany Sucrosorgo 1990. Najniżej położone międzywęźle było najkrótsze (13,2 cm), podczas gdy najdłuższe wykazano w środkowej części pędu (19,7 cm). Najniższą masę (35,2 g) oraz średnicę (1,7 cm) stwierdzono u międzywęźli pobranych z górnej części źdźbła. Źdźbła o większej średnicy miały krótsze międzywęźla (o 5,0 cm), o większej masie (o 36,3 g) i większej średnicy (o 0,8 cm). Zawartość suchej masy w najniższym międzywęźlu była najwyższa. U sorga wiechowego największy udział części wewnętrznych źdźbła był w najniżej osadzonym międzywęźlu (44,3% – u źdźbła o większej średnicy i 45,0% – dla źdźbła o mniejszej średnicy). U odmiany Sucrosorgo 1990 w dolnym międzywęźlu dominował udział części zewnętrznych źdźbła (42,8% u źdźbła o dużej średnicy i 42,5% dla źdźbła o małej średnicy). Część wewnętrzna źdźbła stanowiła 39,9–42,8% masy międzywęźla, a jej udział zależał od miejsca, z którego zostało ono pobrane. Część zewnętrzna dominuje w dolnym międzywęźlu.

Słowa kluczowe: część wewnętrzna, część zewnętrzna, liście, sorgo bezwiechowe, sorgo wiechowe