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Productivity of Triticale Depending on the Content of Photosynthesizing Pigments at Anthesis

Abstract. Photosynthetic pigments play an important role in the accumulation of dry matter and they can be the markers of stress. Change in the ratio of chlorophyll A and B indicates physiological changes and adaptation of the organism to changes of environmental conditions. Sowing terms and application of nitrogen fertilizers are long-term factors, so the content of chlorophylls in the flag leaf indicates long-term adaptation of the photosynthetic system. Establishing a relationship between the chlorophyll content at anthesis and the accumulation of dry matter in posy-anthesis period indicates the varietal response of triticale to fertilization and sowing dates. It was conducted a three-factor field experiment. There are studied two winter and one facultative triticale cultivar, two autumn sowing terms and fertilization system with application the different rates of nitrogen fertilizers in different growth stages. It was found that the content of photosynthetic pigments in each variety diverged depending on sowing term and fertilizer system in terms of mg per 1 g of dry matter for chlorophyll A, B and the amount of A+B. At the same time, the difference between the factors and their interactions was insignificant for the total chlorophyll mass per unit area (g/m2) for chlorophyll A and the amount of A+B, but it was significant for chlorophyll B by the fertilizer system factor. This indicates that the main stress signal is chlorophyll B, so the ratio of chlorophyll A and B differed significantly depending on this factor. Cla: Clb ratio in the optimal sowing period is 5.3-8.1 in cv. Pidzimok kharkivskiy, 4.8-8.3 in cv. Amur and 5.0-6.7 in cv. Obriy mironivskiy. All cultivars have a strong positive correlation between the chlorophyll content at anthesis and accumulation of dry matter at post-anthesis perion under optimal conditions, but facultative triticale Pidzimok kharkivskiy has a negative correlation with unfavorable, due to increased chlorophyll, without increasing dry matter accumulation. Further research of the relationship between chlorophyll

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content and the synthesis of primary and secondary metabolites is promising in the study of varietal response to stress and agronomic factors

Keywords: chlorophyll, correlation, dry matter, facultative triticale

INTRODUCTION

Morphological features of the flag leaf of cereals significantly affect its productivity (Yang *et. al.*, 2016). The basis of the photosynthetic system of the plant are green pigments chlorophyll A and B, which have a similar structure, but differ in the spectrum of waves that absorb (Britton, 1983). Content and ratios of pigments are a varietal feature of cereals (Pryadkina & Makharinska, 2021), and chlorophyll content is higher and varies greatly in triticale (Arough *et al.*, 2016). Productivity of photosynthesis depends on the amount of these pigments in the plant, and their content in the flag leaf can predict the yield potential (Simpson, 1968).

The fertilizer system has an important effect on plant growth and development, but its impact on chlorophyll content is indirect. Nitrogen concentration in plants is related to chlorophyll content, and therefore indirectly to one of the basic plant physiological processes: photosynthesis (Haboudane *et al.*, 2002; Amaliotis *et al.*, 2004). Cereals have a different requirement to nitrogen in different growth stages (Akhter *et al.*, 2016), so chlorophyll content varies similar (Shadchina & Dmitrieva, 1995). Chlorophyll content can be a stress indicator in plants under unfavorable conditions or nutrient deficiency (Tejada-Zarco *et al.*, 2004). Nitrogen as a structural element of chlorophyll and its deficiency can impact on photosynthesis and dry matter accumulation (Ray Tucker, 2004).

MATERIALS AND METHODS

Field experiments were conducted in 2016-2019 in the Right-bank Forrest-Steppe of Ukraine (49°46´N, 30°44´E). The soil is typical low-humic black, the arable layer of which is characterized by the following agrochemical and agro-physical indices: humus content – 4.31-4.63%; pH – 7.2, easily hydrolyzed nitrogen (according to Kornfeld) – 152.3-167.0 mg; P_2O_5 in acetic acid extract (according to Chirikov) – 109.0-142.0 mg; exchangeable potassium (according to Chirikov) – 127.0-132.0 mg per 1 kg of soil.

Field experiment was conducted by 3-factorial scheme. Factor A is a cultivar, factor B is a sowing term and factor C is a fertile system. Pidzimok kharkivskiy (facultative), Amur (winter) and Obriy mironivkiy (winter) were observed. Each cultivar was sowed in two terms – 2nd and 3rd decade of October. Fertilization system included 4 options. There are $P_{36}K_{72}$ as a fone (B1), and 3 options with different nitrogen fertilizations (B2 – $P_{36}K_{72}$ + $N_{25(11-13)}$; B3 – $P_{36}K_{72}$ + $N_{25(11-13)}$ + $N_{55(23)}$; B4 – $P_{36}K_{72}$ + $N_{25(11-13)}$ + $N_{55(25)}$ + $N_{20(49)}$).

Tillage system included only one plowing after preceding crop harvesting (soybean). Cultivation on sowing depth (2-4 cm) was conducted before sowing. Triticale was sown with 15 cm inter-row spacing with rate 450 grains per square meter. Any pesticides were applied during the research. The experiment was established in 4 replications. The size of elementary plots was 32 m^2 (25.2 m^2 to harvesting).

10 plants were collected in anthesis and wax ripeness for establishing crop growth rate (Hunt *et al.*, 2002) and chlorophyll content in flag leaf at anthesis. Chlorophyll content was determined by spectrophotometric method and calculating according Wellburn (1994). Statistical elaboration date was done by

multifactorial analysis ANOVA in Statistica 13.0. Difference between variant was established by Fisher LSD post-hoc test.

RESULTS

Content of photosynthetic pigments in the flag leaf at anthesis is an important indicator of the productivity potential of triticale. Flag leaf can accumulate almost up to half of the dry matter of the seed under normal conditions, so the increase in its content indicates an increase in assimilation processes. Plants of different sowing terms in a certain phase may have different contents of photosynthetic pigments, have different ratios of chlorophyll species, and their concentration will depend on the structure of the leaf, area and nutrition. Time of anthesis will be different, so the weather conditions will also make their adjustments.

Content of chlorophyll A and B in the dry matter of the flag leaf (mg/g) varied significantly depending on the variety and sowing period (Table 1 and 2). Cultivar is one of the main factors in the variation of chlorophyll A and B, as well as their sum, it is necessary to consider each variety separately.

Table 1. Content of chlorophyll A and B in flag leaf at anthesis (average 2016-2019 years)

Sowing term	Fs	Pigment weight in dry matter							CGR, g/m² per day
		Cl_a, mg/g	Cl_b, mg/g	$Cl_a + Cl_b$, mg/g	Cl_a/Cl_b	Cl_a, g/m²	Cl_b, g/m²	Cl_a+Cl_b, g/m²	
Pidzimok kharkivskiy									
I	B1	6.59^{cd}	1.08^{b}	7.67^{bc}	6.1	40.0^{abc}	6.5^{bcd}	46.6^{abcd}	4.93
	B2	6.69^{cd}	1.02^{b}	7.71^{bcd}	6.6	33.3^{ab}	5.0^{abc}	38.4^{abc}	4.47
	B3	5.88^{bc}	0.73^{a}	6.61^{ab}	8.1	28.4^{a}	3.5^{a}	31.9^{ab}	4.15
	B4	7.79^{de}	1.48^{d}	9.27^{de}	5.3	44.4^{abc}	8.4^{d}	52.8^{bcd}	4.42
II	B1	5.11^{ab}	0.83^{a}	5.94^{a}	6.2	27.3^{a}	4.4^{ab}	31.7^{a}	6.02
	B2	4.15^{a}	1.07^{b}	5.22^{a}	3.9	27.8^{a}	7.2^{bcd}	34.9^{abc}	5.61
	B3	8.85^{e}	1.38^{cd}	10.23^{e}	6.4	48.3^{bc}	7.6^{cd}	55.8^{cd}	5.02
	B4	7.53^{de}	1.30^{c}	8.83^{cde}	5.8	52.5^{c}	9.1^{d}	61.6^{d}	5.41
Amur									
I	B1	11.72^{d}	2.45^{c}	14.17^{e}	4.8	43.6^{a}	9.1^{c}	52.8^{b}	5.23
	B2	10.64^{cd}	1.28^{a}	11.92^{cd}	8.3	45.3^{a}	5.4^{ab}	50.7^{ab}	4.64
	B3	8.31^{ab}	1.35^{a}	9.66^{ab}	6.2	40.2^{a}	6.6^{bc}	46.8^{ab}	4.17
	B4	8.01^{ab}	1.41^{a}	9.42^{ab}	5.7	36.1^{a}	6.4^{bc}	42.4^{ab}	3.93
II	B1	8.46^{b}	1.31^{a}	9.77^{abc}	6.5	33.9^{a}	5.3^{ab}	39.2^{ab}	4.75
	B2	9.39^{bc}	0.98^{a}	10.37^{bc}	9.6	31.3^{a}	3.3^{a}	34.6^{a}	4.50
	B3	10.73^{cd}	2.01^{b}	12.78^{de}	5.3	45.8^{a}	8.6^{c}	54.4^{b}	4.73
	B4	6.47^{a}	1.16^{a}	7.63^{a}	5.6	43.9^{a}	7.9^{bc}	51.8^{ab}	5.06

Table 1, Continued

Sowing term	Fs	Pigment weight in dry matter							CGR, g/m^2 per day
		Cl_a, mg/g	Cl_b, mg/g	$Cl_a + Cl_b$, mg/g	Cl_a/Cl_b	Cl_a, g/m^2	Cl_b, g/m^2	Cl_a+Cl_b, g/m^2	
Obriy mironivskiy									
I	B1	13.83^{d}	2.14^{d}	15.97^{d}	6.5	38.9^{a}	6.0^{ab}	44.9^{ab}	4.25
	B2	13.13^{d}	1.97^{cd}	15.10^{d}	6.7	43.8^{a}	6.5^{ab}	50.4^{ab}	4.71
	B3	8.07^{ab}	1.23^{a}	9.30^{ab}	6.6	36.8^{a}	5.6^{a}	42.3^{ab}	3.95
	B4	10.60^{c}	2.12^{d}	12.73^{c}	5.0	39.0^{a}	7.8^{bc}	46.8^{ab}	4.22
II	B1	8.94^{b}	1.77^{c}	10.71^{b}	5.1	44.4^{a}	8.8^{c}	53.3^{b}	4.56
	B2	6.96^{a}	1.11^{a}	8.07^{a}	6.3	41.4^{a}	6.6^{ab}	48.0^{ab}	3.92
	B3	7.87^{ab}	1.17^{a}	9.04^{ab}	6.7	34.0^{a}	5.1^{a}	39.1^{a}	3.50
	B4	8.64^{b}	1.48^{b}	10.12^{b}	5.8	43.7^{a}	9.0^{c}	52.7^{b}	4.22
LSD_{05}		**1.57**	**0.28**	**1.78**	**x**	**14.3**	**2.48**	**16.6**	

Note: *CGR – crop growth rate*

Table 2. ANOVA of chlorophyll content in flag leaf at anthesis

Effect	*df*	MS					
		Cl_a, mg/g	Cl_B, mg/g	Cl_{a+B}, mg/g	Cl_a, g/m^2	Cl_b, g/m^2	Cl_a+Cl_b, g/m^2
Cultivar (C)	2	70.70**	1.90**	95.58**	45.6^{ns}	1.42^{ns}	58.9^{ns}
Sowing term (ST)	1	39.87**	0.72**	51.31**	2.6^{ns}	4.24^{ns}	13.6^{ns}
Fertile system (FS)	3	2.94*	0.54**	4.66*	133.1^{ns}	19.48**	247.6^{ns}
C x ST	2	14.16**	0.36**	18.37**	40.7^{ns}	5.55^{ns}	76.2^{ns}
C x FS	6	13.51**	0.59**	17.98**	163.3^{ns}	9.13**	216.6^{ns}
FS x ST	3	25.18**	0.84**	34.85**	285.3*	7.46*	374.5*
C x ST x FS	6	1.73^{ns}	0.19**	2.44^{ns}	118.8^{ns}	9.23**	183.7^{ns}
Error	48	0.92	0.30	1.18	76.0	2.29	102.0

Note: * – $p<0.05$; ** – $p<0.01$; ^{ns} – factor/interaction insignificant at 95% level ($p>0.05$)

Cv. Pidzimok kharkivskiy is characterized by a much lower content of chlorophyll A in the flag leaf than other cultivars. Content of chlorophyll A in the variants without nitrogen application and at the rate of 25 kg/ha do not differ significantly, because the habitus of plants is similar, and the area of the flag leaf and its weight did not differ significantly. The content of chlorophyll A is significant in the plants of the first sowing term only at the norms of 100 kg/ha, and such effect was already at the norms of 80 kg/ha and 100 kg/ha in the second one. That is, the effect of nitrogen was prolonged, the content of chlorophyll B also increased accordingly, but the ratio of Cl_a:Cl_b differed significantly, and its low value is evidence of stress.

Cv. Amur has a different reaction to nitrogen fertilization according to the chlorophyll A content depending on the sowing term. Content of Cl_a is significantly reduced at the rates of application of 80-100 kg/ha of nitrogen compared to the options without application 25 kg/ha in plants of first sowing term. For other side, content of chlorophyll A increases when nitrogen is applied at the rate of 25-80 kg/ha, but fertilization at 100 kg/ha significantly reduces its content.

Cultivar Obriy myironivskiy was characterized by a much higher content of chlorophyll A than other varieties, although the trends during the first sowing period were similar to cv. Amur, but the nitrogen rate of 100 kg/ha had a stimulating effect. During the second sowing period, the chlorophyll content did not have a significant difference between the fone, and rates of 80 and 100 kg/ha, but significantly decreased at the rate of 25 kg/ha of nitrogen.

Chlorophyll content (A and B) differed significantly between cultivars, sowing terms, but the effect of the fertilizer system was ambiguous (Table 2). Content of chlorophyll A (figure 1) in the cv. Amur and cv. Obriy mironivskiy did not differ significantly, but the content of chlorophyll B was higher in cv. Obriy mironivskiy compared to other cultivars.

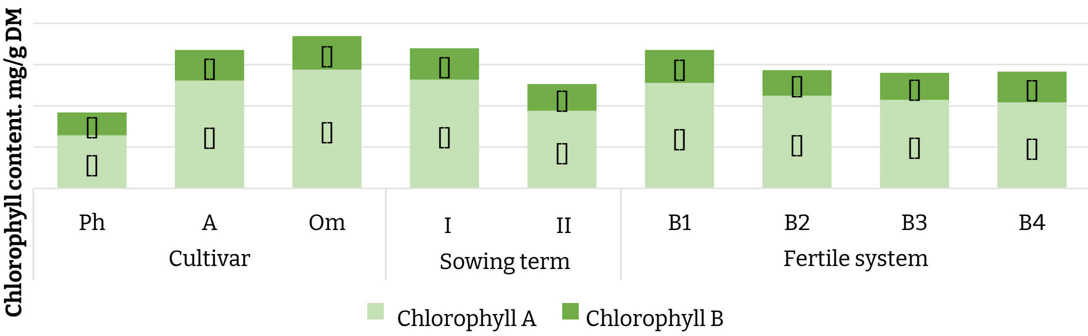

Figure 1. Chlorophyll content depends on cultivar, sowing terms and fertile system

The interaction of FS x ST factors is one of the strongest among other interactions (exclude primeval factors), which indicates a different reaction of crops of different sowing terms to the fertilizer system, i.e., the lack of a specific algorithm for fertilization for each variety. At the same time, the interaction of C x ST and C x FS also significantly affects the content of chlorophyll A and B. Interaction of primeval factors at the same time was insignificant, which indicates an independent reaction of each cultivar.

The weight of chlorophyll A and B per unit area (g/m^2) is almost independent of the factors and their interactions, but the FS x ST relationship is significant for both the amount of chlorophyll A, B and their sum. If the amount of chlorophyll A was almost unaffected by the main factors and their interactions, the amount of chlorophyll B significantly depended on the fertilizer system and its interaction with the varietal factor, sowing term and their combination.

According to the results of ANOVA and post-hoc Fisher`s LSD found that plants of the first sowing term formed more photosynthetic pigments on average than the second term. The effect of the fertilizer system was manifested in a significant decrease in the content of chlorophyll A with increasing the rate to 80 and 100 kg/ha compared to the fone, but insignificant compared to the rate of 25 kg/ha of nitrogen.

The content of chlorophyll B decreased at the norms of 25 and 80 kg/ha, while it did not have a significant difference with the fone at the rates of 100 kg/ha, its content increased compared to fertilization with lower rates. Change in the amount of chlorophyll B is the plant's response to stressful conditions and the adaptation of the photosynthetic system to these changes. It was found in resent research (Spanic *et al.*, 2013) that the grain yield of winter wheat did not depend on photosynthesis in optimal conditions, but on other physiological process which might be related to the energy usage efficiency. The present research showed a strong correlation between chlorophyll content (Cl_a+Cl_b) at anthesis with dry matter accumulation after anthesis (Fig. 2).

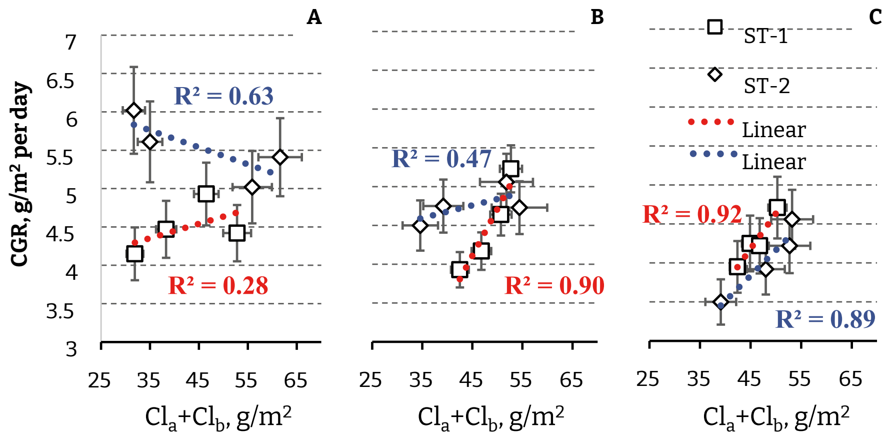

Figure 2. Relation between crop growth rate (CGR) in period "anthesis – wax maturity" and chlorophyll content at anthesis

Note: Annex. Cultivars: A – Pidzimok kharkivskiy; B – Amur; C – Obriy mironivkiy. Sowing term: ST-1 – II decade of October, ST-2 – III decade of October; means presented with standard errors (SE)

Silva *et al.* (2014) established that chlorophyll photosynthetic potential, characterizing the total amount of chlorophyll in the aboveground plant parts during the vegetative period under optimal environmental and climatic conditions correlated with the yield. This statement is true if the growth and development of triticale and wheat follows a typical path. In a previous study (Mazurenko & Novytska, 2020), it was found that the accumulation of dry matter in those varieties of triticale corresponded to the normal development cycle, and the accumulation of dry matter had a strong correlation with yield. All studied cultivars have a strong positive correlation between chlorophyll content and dry matter accumulation in optimal condition (sowing term: II decade of October), but they have a difference in these relations in unfavorable conditions. Pidzimok kharkivskiy has a negative correlation, when winter cultivars have a positive. The reason for this phenomenon may be a significant increase in chlorophyll in facultative triticale, which does not play a photosynthetic role, but is a reaction to stress.

CONCLUSIONS

Winter cultivars have a strong positive correlation between the content of chlorophyll and the accumulation of dry matter in the post-anthesis period. At the same time, this relation differs in facultative triticale Pidzimoc kharkivskiy depend on sowing term. Fertilizer system has a significant effect on these indicators – an increase in the rate of nitrogen leads to an increase in the content of pigments, which in turn increases the CGR in winter cultivars Amur and Obriy mironivskiy. Cv. Pidzimoc kharkivskiy has high CGR values in crops of the second sowing term, so the reaction to the increase in the nitrogen rate is ambiguous, as a larger quantity of pigments does not increase the accumulation of dry matter.

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Продуктивність тритикале залежно від вмісту фотосинтезуючих пігментів в антецезії

Анотація. Фотосинтетичні пігменти відіграють важливу роль у накопиченні сухої речовини і можуть бути маркерами стресу. Зміна співвідношення хлорофілів А і В свідчить про фізіологічні зміни та адаптацію організму до змін умов навколишнього середовища. Строки сівби та внесення азотних добрив є довготривалими факторами, тому вміст хлорофілів у прапорцевому листку вказує на довготривалу адаптацію фотосинтетичної системи. Встановлення взаємозв'язку між вмістом хлорофілів у фазі виходу в трубку та накопиченням сухої речовини в період кущіння-колосіння вказує на сортову реакцію тритикале на удобрення та строки сівби. Проведено трифакторний польовий дослід. Досліджували два озимих і один факультативний сорт тритикале, два осінніх строки сівби та систему удобрення з внесенням різних норм азотних добрив у різні фази розвитку. Встановлено, що вміст фотосинтетичних пігментів у кожного сорту відрізнявся залежно від строку сівби та системи удобрення в перерахунку на мг на 1 г сухої речовини для хлорофілу А, В та суми А+В. При цьому різниця між факторами та їх взаємодією була несуттєвою для загальної маси хлорофілу на одиницю площі (г/м2) для хлорофілу А та суми А+В, але достовірною для хлорофілу В за фактором системи удобрення. Це свідчить про те, що основним стресовим сигналом є хлорофіл В, тому співвідношення хлорофілу А і В суттєво відрізнялося залежно від цього фактора. Співвідношення Cla: Clb за оптимального строку сівби становить 5,3-8,1 у cv. Підзімок харківський, 4,8-8,3 у cv. Амурський та 5,0-6,7 у cv. Обрій миронівський. Всі сорти мають сильну позитивну кореляцію між вмістом хлорофілу в фазі виходу в трубку та накопиченням сухої речовини в післяфазний період за оптимальних умов, але факультативне тритикале Підзімок харківський має негативну кореляцію за несприятливих умов, що пояснюється збільшенням вмісту хлорофілу, без збільшення накопичення сухої речовини. Подальші дослідження взаємозв'язку між вмістом хлорофілу та синтезом первинних і вторинних метаболітів є перспективними при вивченні сортової реакції на дію стресових та агротехнічних факторів

Ключові слова: хлорофіл, кореляція, суха речовина, факультативне тритикале