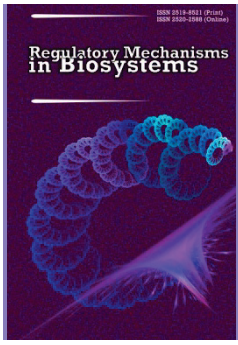


Regulatory Mechanisms in Biosystems

ISSN 2519-8521 (Print)
ISSN 2520-2588 (Online)
Regul. Mech. Biosyst.,
2023, 14(1), 41–47
doi: 10.15421/022307

Emmer wheat productivity formation depending on pre-sowing seed treatment method in organic and traditional technology cultivation

I. V. Korotkova*, T. O. Chaika**, T. P. Romashko*, O. O. Chetveryk*, A. M. Rybalchenko*, O. V. Barabolia*

Poltava State Agrarian University, Poltava, Ukraine
***Academy of Sciences of Technological Cybernetics, Poltava, Ukraine*

Article info

Received 02.01.2023
Received in revised form 24.01.2023
Accepted 26.01.2023

Poltava State Agrarian University, Skovorody st., 1/3, Poltava, 36003, Ukraine.
Tel.: +38-050-702-38-58.
E-mail: 2irinakorotkova10@gmail.com

Academy of Sciences of Technological Cybernetics, Kovalia st., 3, Poltava, 36013, Ukraine.
Tel.: +38-099-433-23-44.
E-mail: chayka_ta@ukr.net

Korotkova, I. V., Chaika, T. O., Romashko, T. P., Chetveryk, O. O., Rybalchenko, A. M., & Barabolia, O. V. (2023). Emmer wheat productivity formation depending on pre-sowing seed treatment method in organic and traditional technology cultivation. Regulatory Mechanisms in Biosystems, 14(1), 41–47. doi:10.15421/022307

Determination of chlorophyll and carotenoid content is an important way of obtaining information about the plant's photosynthetic activity as well as an indirect method of assessing the productivity of plant crops, particularly grain crops. The objective of this study was to evaluate the role of chlorophyll and carotenoid in the productivity formation of emmer wheat (*Triticum dicoccum* (Schrank.) Schuebl) grown under the traditional and organic farming systems and the different pre-sowing seed treatment methods. The base indicators of the photosynthetic apparatus (chlorophyll and carotenoid content, ratio of photosynthetic pigments) were evaluated in the emmer wheat plants as a function of the cultivation technology and pre-sowing seed treatment. The cultivation of the emmer wheat under organic technology was carried out in crop rotation: winter rye – mustard – *T. dicoccum* wheat. The pre-sowing seed treatment in the traditional technology of emmer wheat cultivation was carried out only by the UV-C irradiation. In the organic technology, both UV-C irradiation and treatment with humic preparation of natural origin "1r Seed Treatment" were used. The content of chlorophyll *a* (by 9.2%) and chlorophyll *b* (by 14.5%) increased in the emmer wheat plants under the organic technology cultivation compared to the traditional technology, but with the same method of seed treatment (UV-C irradiation). As a result, the yield increase was 21.0%. The application of the "1r Seed Treatment" humic preparation in the pre-sowing seed treatment led to the increase in yield by ~ 8.0% compared to the plots with UV-C irradiation seeds treatment under organic farming cultivation. An inverse correlation between the ratio of chlorophyll *a*/chlorophyll *b* and the crop yield has been established. The evaluation of economic indicators of the emmer wheat cultivation in the rotation: winter rye-mustard-emmer wheat under organic farming technology, proved its high profitability. So, the photosynthetic pigments' content and their ratio can be used as the indicators of the efficiency of the introduced elements of agrotechnologies and for predicting future yields.

Keywords: emmer wheat; pre-sowing treatment; organic farming system; photosynthetic pigments; crop rotation; winter rye; mustard.

Introduction

In Ukrainian agricultural production and that of most countries of the world, grain is the most important crop group from the economic and agronomic point of view (Tsyliuryk et al., 2017; Tkalich et al., 2020). Recently, the tendency of people to consume natural food has led agronomists to turn to sustainable agriculture and to revive the so-called "ancient wheats".

Triticum dicoccum (Schrank) Schuebl, tetraploid emmer wheat is an ancient grain crop and one of the earliest Triticae domesticated by humankind. But over the centuries, emmer wheat has gradually moved to the background because of the competition with more productive hybrid hard wheat cultivars. Only in the early 2000s, did this crop cultivation began to recover worldwide due to the increasing consumer demand for natural and traditional food and the interest of scientists in emmer wheat as a gene reservoir of many agronomic and nutritional traits of important commercial significance (Lacko-Bartošová & Čurná, 2015b). However, the modern nutrition structure of the Ukrainian population still does not meet modern concepts of rational nutrition due to the insufficient amount of natural products containing native food protein, food fibers and necessary micronutrients. Emmer wheat (*Triticum dicoccum* Schrank) can be considered a promising raw material to produce of high-quality bakery products, because it contains a significant amount of protein and other essential nutrients. In addition, emmer wheat is adapted for cultivation in organic farming. Nowadays, emmer wheat (*T. dicoccum*) is cultivated by organic farmers in many Central European countries (Koutis, 2015; Arzani & Muhamad, 2017; Čurná & Lacko-Bartošova, 2017). Various research on chemical composition showed that emmer wheat is high in protein (13.5–19.1%), starch (55.4–73.3%), dietary fibre (10.0–12.0%), lipids (2.4–3.0%) and total tocopherols (19.7–69.9 mg/g) (Čurná & Lacko-Bartošova, 2017). In emmer wheat grain the selenium content (58.9–68.4 µg/kg), total polyphenols (584–692 mg/kg) (Lachman et al., 2011), the main macroelements P (5.1 g/kg) and K (4.4 g/kg) and microelements Zn (54 mg/kg), Fe (49 mg/kg) and Mn (24 mg/kg) (Suchowilska et al., 2012) proved to be quite high.

In this context, the demand for grain of this crop has been increasing rapidly over the last 20 years and is predicted to increase by about 5.0% annually. Unfortunately, today the share of emmer wheat in the world wheat production is only about 1.0% (Peng et al., 2011).

Emmer wheat was proved to be a profitable crop if grown on marginal areas and under sustainable and organic farming conditions, whereas modern wheat types cannot reach their full productive potential because they have been genetically selected for favourable climatic and agronomic conditions. Emmer wheat is not considered suitable for very high rates of nitrogen fertilizer application, as this would lead to severe lodging and subsequent spike damage, poor grain filling and subsequent yield loss. Emmer wheat cultivars are characterized by good nutrient uptake (the root system is able to absorb nitrogen better), high level of competitiveness to weeds, resistance to diseases and pests, resistance and tolerance to drought. Only under these conditions, is the cultivation of emmer wheat justified and its agronomic characteristics – yields – cost-effective compared to the modern wheat varieties (Lacko-Bartošová & Čurná, 2015a).

As is well known, organic farming suggests using the biological factors to increase natural soil fertility (Gorban et al., 2021), agro-ecological methods and biological means of pest and disease control, creating conditions for the biodiversity conservation (Heckman, 2006). In organic farming, a positive humus balance is formed, primarily through the complete return of by-products to the soil and the maximum saturation of crop rotations with intermediate green manure. In organic farming rotations built under such conditions, a stable ecological balance of agrocenoses is achieved over time (Khalep & Moskalenko, 2020).

However, despite the many advantages of organic farming over traditional farming (Cristache et al., 2018), modern farmers are in no hurry to implement it in practice due to various factors, including financial, in spite of the experience of implementing such a system in grain crop cultivation (Riar et al., 2017). Also, in order to achieve a sustainable competitiveness level of organic production, it is necessary to provide an appropriate pricing mechanism for its operation, as practiced in many countries (Forster et al., 2013; Crowder & Reganold, 2015).

The increasing demand for this wheat type in the world requires improvements in the cultivation technologies in order to obtain quality grain depending on the crop technological properties, soil and climatic conditions and agricultural technology elements. This is why emmer wheat cultivation is more and more turning to organic farming, which can provide ecologically sound and biologically valuable products (Lialina & Matviienko-Biliaieva, 2019).

In our previous study, a technological scheme of the emmer wheat cultivation according to the organic farming system was presented. It was found that the yield increase obtained under this cultivation technology is due to the accumulation of the plant nutrition main elements in the soil, which remain after the green manure and are involved in the soil absorbing complex (Chaika et al., 2021). However, this is not the only indicator of agro-technology that can affect the productivity formation under the organic method of crop cultivation. Effective methods of pre-sowing seed treatment are important. The large number of agrotechnological components, the complex system of their regulation and the influence of environmental factors significantly complicate the identification of traits associated with the high productivity formation of wheat plants under both traditional and organic farming technology. Although plant growth is controlled by many physiological, biochemical and molecular processes, photosynthesis is the key one. The nutrients that are formed and accumulated in the soil play a fundamental role in the structural and functional components of the photosynthetic apparatus, and the optimal supply of nutrients is important for the biosynthesis of photosynthetic pigment' in plants (Cai et al., 2008).

In-depth discussions on the effect of photosynthesis on grain yield increase have been going on for a long time. Some scientists suggest that enhanced photosynthetic capacity of leaves provides the yield improvement (Long et al., 2015; Ren et al., 2016), while others argue that there is a little correlation between increased photosynthesis and crop yield (Driever et al., 2014).

The aim of our work was to study the impact of pre-sowing seed treatment methods on the photosynthetic pigments content and emmer wheat productivity formation under the traditional and organic cultivation technologies.

Materials and methods

Field experiments were carried out during 2019–2021 on low-humus heavy-loamy black soil, whose condition corresponds to the "virgin lands" criterion in Poltava Region (Ukraine). The total area of the experimental plot was 25 ha, the recording area was 1 ha. A field experiment was set up according to a randomized block design, in three replications.

The emmer wheat Holikovska cultivar, selected by the Plant Production Institute named after V. Y. Yuriev Ukraine National Academy of Agrarian Sciences, was chosen for the research. Emmer wheat was cultivated under organic farming technology in crop rotation: winter rye – mustard – *T. dicoccum* wheat without fertilization and any chemical treatment. In organic technology cultivation, the preparation of humic nature "5r SoilBoost" (SoilBiotics company), which contains 84.2% of humic acids, was used for the crop's treatment.

Two agrochemical backgrounds were studied: 1 – carbamide-ammonia mixture (CAM) (traditional cultivation technology); 2 – no fertilizers (organic farming technology). Carbamide-ammonia mixture was applied at the beginning of the growing season at a dose of 40 kg of active substance per hectare. Yields of mustard and emmer wheat as organic products were measured at the stage of "full ripening" recalculated to a humidity of 14.0%.

Pre-sowing seed treatment in traditional technology was carried out by UV-C (200–280 nm) irradiation with a quartz glass lamp ZW20D15W (Jiangyin Feiyang Instrument Co., Ltd) with a capacity of 20 W at a dose of 250 J/m^2 according to the method (Semenov et al., 2020). Two variants of pre-sowing seed treatment were used in organic farming technology: 1 – UV-C irradiation at a dose of 250 J/m^2 (similar to the traditional one); 2 – seed treatment with the "1r Seed Treatment" natural humic preparation at the rate of 2.0 L/t seed. "1r Seed Treatment" is the humic preparation, based on humic, fulvic and ulminic acids derived from Leonardite, and contains 20% of active substance: 10% – humic acids, 3% – fulvic acids, 1% – ulminic acids and approximately 6% of a complex of macro- and microelements: N – 0.21%, P – 0.01%, P_2O_5 – 0.02%, K – 2.29%, K_2O – 2.76%, S – 0.17%, Mg – 0.04%, Ca – 0.34%, Na – 0.07%.

The material for the determination of photosynthetic pigments was processed in the fresh state immediately after collection. The photosynthetic pigments content was quantified using 0.5 g of plant material. The pigments were extracted with 96.0% ethanol. The content of chlorophyll *a*, chlorophyll *b* and carotenoids in flag leaf of emmer wheat was measured according to the method (Wellburn, 1994) also as the authors of the study (Zhang et al., 2021). The absorbance was read at the absorption maximum of chlorophyll *a* – 665 nm, chlorophyll *b* – 649 nm, carotenoids – 470 nm using Spectrophotometer UNICO 1201 (United Products and Instruments, США). The photosynthetic pigments' content was expressed in µg/g fresh weights of leaf tissue.

The economic efficiency of the proposed crop rotation was analyzed by calculating the costs, considering the full works mechanization according to the technological schemes developed by us (Chaika et al., 2021). To ensure the reliability of economic calculations, the diesel and seed cost throughout the research years is given at wholesale domestic prices as of 01.08.2022.

The obtained experimental results were statistically analyzed in Statistica 8.0 (StatSoft Inc., USA) software. The data in Table 1 is presented as $x \pm SD$ (mean ± standard deviation). Differences between the values in the experimental variants were determined using the Tukey test and considered reliable at $P < 0.05$.

Results

In the present research, the effect of different variants of pre-sowing seed treatment on the photosynthetic pigments content – chlorophyll *a*, chlorophyll *b* and carotenoids at different technologies of emmer wheat cultivation was studied. The averaged results of a three-year evaluation of investigated parameters are shown in Table 1.

The pigments content of wheat plants was significantly influenced by the organic cultivation technology, resulting in an increase in total content of chlorophyll (*a* + *b*) of ~10.0% compared to the traditional technology followed by the yield increase (Table 1).

However, the photosynthetic pigment level in wheat plants differed significantly not only depending on the cultivation technologies, but also on the pre-sowing seed treatment methods. Thus, comparing the concentration of chlorophyll *a*, chlorophyll *b* and carotenoids by the traditional and organic cultivation technologies, but with the same method of seed treatment (UV-C irradiation) showed an increase in chlorophyll a concentration by 9.2%, chlorophyll b by 14.5% and decrease in carotenoid content by 14.9% in the emmer wheat plants cultivated under the organic technology. The yield under the traditional technology was 4.26 t/ha and under the organic technology – 5.17 t/ha, i.e., the yields increased by 21.4%.

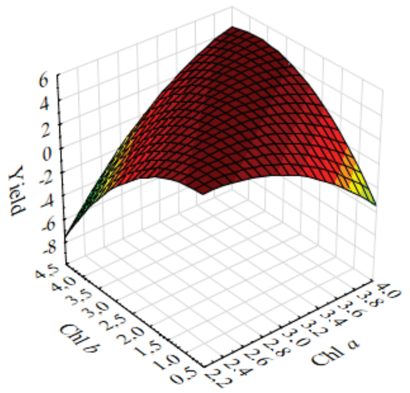
Table 1
Photosynthetic pigment content in emmer wheat plants with different technologies of cultivation ($x \pm SD$, $n = 20$)

Technology	Chlorophyll *a*	Chlorophyll *b*	Chlorophyll *a* + *b*	*a*/*b*	Carotenoids (c)	(*a* + *b*)/c	Yield, t/ha
	mg/g of raw weight of leaves				mg/g of raw weight of leaves		
Traditional (UV-C)	2.73 ± 0.14^a	1.45 ± 0.06^a	4.18 ± 0.50^a	1.88	0.54 ± 0.01^b	7.74	4.26
Organic (UV-C)	2.98 ± 0.15^a	1.66 ± 0.07^a	4.64 ± 0.55^a	1.79	0.47 ± 0.01^b	9.87	5.17
Organic (1r Seed Treatment)	2.91 ± 0.15^b	1.74 ± 0.07^b	4.65 ± 0.56^b	1.67	0.59 ± 0.01^a	7.88	5.58

Note: letters ^{a} and ^{b} indicate values which reliably differed one from another within one line of table according to the results of comparison using Tukey test ($P < 0.05$) with Bonferroni correction.

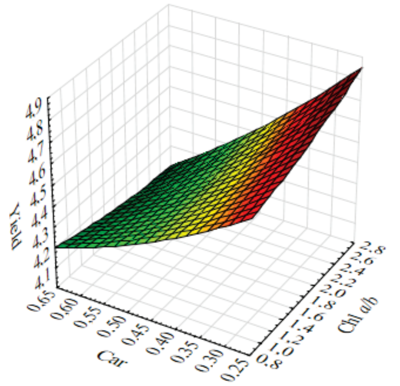
Statistical analysis of the data obtained confirmed the relationship between the yield and chlorophyll *a* and chlorophyll *b* content with appropriate correlation coefficients. We established an average direct correlation between chlorophyll *a* concentration and yield at the traditional ($r = 0.603$) and organic cultivation technology ($r = 0.533$). At the same time, a direct correlation between chlorophyll *b* concentration and the yield with strong relationship at the organic technology ($r = 0.999$), and a weak relationship at the traditional technology ($r = 0.317$) was observed (Fig. 1a). An average and strong inverse dependence between carotenoid concentration and the yield with the correlation coefficients of $r = -0.577$ and $r = -0.999$, respectively, was observed at the traditional (Fig. 1b) and organic cultivation technology (Fig. 2b).

Yield, t/ha = -5.5202+9.758x-5.2146y-2.4777x^2+2.7158xy-0.7412y^2
$R^2 = 0.9900$



a

Yield, t/ha = 4.9737+0.1235x-1.7174y+0.0212x^2-0.3842xy+1,0184y^2
$R^2 = 0.9993$

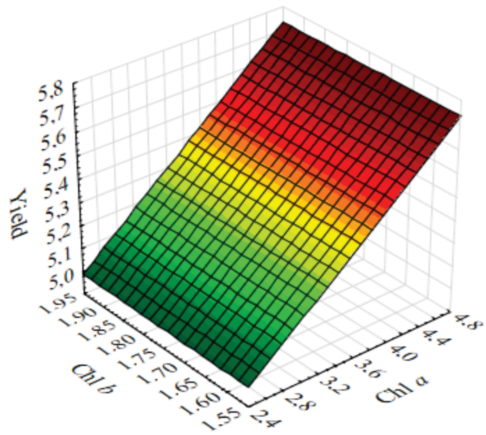


b

Fig. 1. Graphs of quadratic regression of emmer wheat yield from: *a* – chlorophyll *a* (Chl *a*) and chlorophyll *b* (Chl *b*) content; *b* – chlorophyll *a/b* (Chl *a/b*) ratio and carotenoid (Car) content according to traditional cultivation technology (UV-C seed treatment); $n = 20$

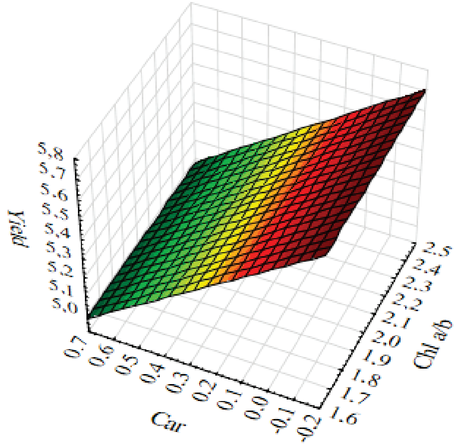
The application of different methods of pre-sowing seed treatment under organic farming technology also affected the chlorophyll and carotenoids' content. The seed treatment with "1r Seed Treatment" humic preparation caused some changes in the pigment composition of wheat plants: chlorophyll *a* content decreased by 2.4%, chlorophyll *b* content increased by 5.0%, and carotenoid content increased by 25.5% compared to the plants grown from the UV-C irradiated seeds. The yield as result of the UV-C seed treatment was 5.17 t/ha, and with "1r Seed Treatment" was 5.58 t/ha, i.e., the yield increase was ~8.0%.

Yield, t/ha = 4.2384+0.3119x+4.0208·10^{-9}y
$R^2 = 0.9999$



a

Yield, t/ha = 5.5463-6.2272·10^{-6}x-0.8134y+1.3442·10^{-6}x^2+
+2.8526·10^{-6}xy+1.4961·10^{-6}y^2
$R^2 = 1.0000$



b

Fig. 2. Graphs of linear regression (*a*) of emmer wheat yield from chlorophyll *a* (Chl *a*) and chlorophyll *b* (Chl *b*) content and quadratic regression (*b*) from chlorophyll *a/b* (Chl *a/b*) ratio and carotenoid (Car) content according to organic cultivation technology (UV-C seed treatment); $n = 20$

The correlation coefficients between chlorophyll *a* and chlorophyll *b* content and wheat yield under the organic technology with pre-sowing seed treatment by the "1r Seed Treatment" preparation are $r = 0.994$ and $r = 0.998$, respectively (Fig. 3a). This indicates a strong direct relationship. However, an inverse dependence between carotenoid content and yield with the correlation coefficient $r = 0.593$ was found for this cultivation technology (Fig. 3b).

Particularly important is the analysis of the chlorophyll a/b ratio, which is one of the main indicators of the carbon dioxide assimilation process in plants. Chlorophyll a/b ratio in the pigment's composition of emmer wheat plants under the organic farming is lower by 4.8% compared to traditional technology with the same method of seed preparation

(UV-C irradiation). Using "1r Seed Treatment" humic preparation in pre-sowing seed treatment under the organic farming technology, the chlorophyll a/b ratio is reduced by 11.2% compared to the traditional technology with UV-C seed irradiation.

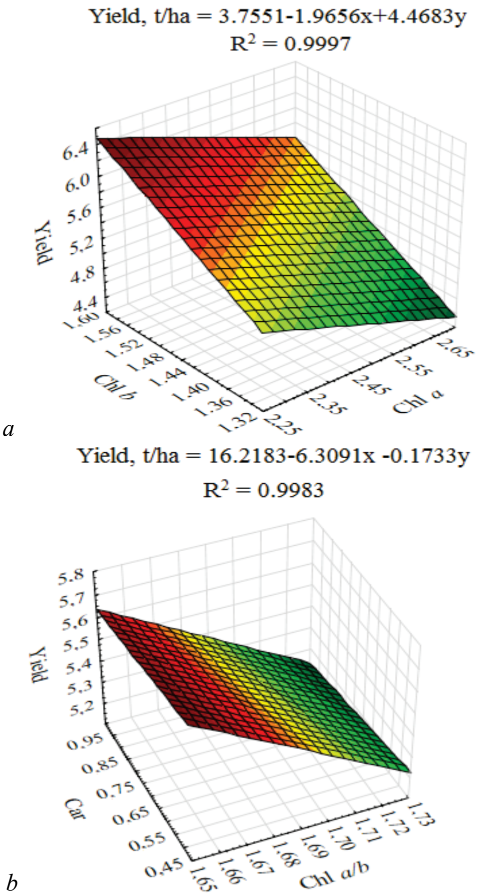


Fig. 3. Graphs of linear regression of emmer wheat yield from: *a* – chlorophyll *a* (Chl *a*) and chlorophyll *b* (Chl *b*) content; *b* – chlorophyll *a/b* (Chl *a/b*) ratio and carotenoid (Car) content under the organic farming technology ("1r Seed Treatment"); n = 20

This ratio decrease was caused by a successive increase in the chlorophyll *b* content by 14.5% (UV-C seed irradiation) and 20.0% ("1r Seed Treatment") i.e., chlorophyll *b* concentration in emmer wheat plants changed more than chlorophyll *a* concentration under the influence of pre-sowing seed treatment.

A reduction of the chlorophyll *a/b* ratio correlated with a significant increase in the emmer wheat yield. Under the traditional technology cultivation, this ratio was 1.88 (yield 4.26 t/ha), and under organic technology it decreased to 1.79 (i.e., by 4.8%) with the same method of pre-sowing seed treatment (UV-C) and the yield increased by 21.0%.

In the organic farming technology with pre-sowing seed preparation by "1r Seed Treatment", chlorophyll *a/b* ratio decreased to 1.67 (i.e., 11.2%), and the yield increased by 31.0% compared to the traditional one. The inverse relationship found between chlorophyll *a/b* ratio and the wheat yield was statistically confirmed by the correlation coefficients: under the traditional technology cultivation with UV-C seed irradiation – r = –0.028; under the organic technology with UV-C seed irradiation – r = 0.048; under the organic technology with "1r Seed Treatment" – r = –0.967.

Thus, the chlorophyll (*a* + *b*)/carotenoid ratio increased by 27.1% due to an increase in chlorophyll *b* concentration by 14.5% and a decrease in carotenoid concentration by 14.9% in the pigment composition of wheat plants grown under the organic farming technology in comparison with the plants grown at the traditional technology with the same method of pre-sowing seed treatment (UV-C).

However, when using various methods of pre-sowing seed treatment in organic farming technology, a decrease in chlorophyll (*a* + *b*) / carotenoid ratio by 20.2% was observed, mainly due to an increase in the chlorophyll *b* concentration by 4.8% and carotenoid concentration by 25.5% in the pigment composition of wheat plants grown from seeds treated with a humic preparation solution. Yields increased by ~8.0%.

The organic farming technology of emmer wheat cultivation in the proposed crop rotation included: winter rye – mustard – *T. dicoccum* wheat without fertilization and any chemical treatment.

1st year – cultivation of winter rye Synthetic cultivar Ukrainian selection for green manure, taking into account the requirements of organic farming. The main technological operations included: soil tillage (harrowing, cultivation), seed sowing at the rate of 250 kg/ha, treatment of crops with biopreparation "5r Soil Boost EA", cultivation of green manure. The production costs of cultivation were € 3,027.7. The structure of the main production costs is shown in Figure 4.

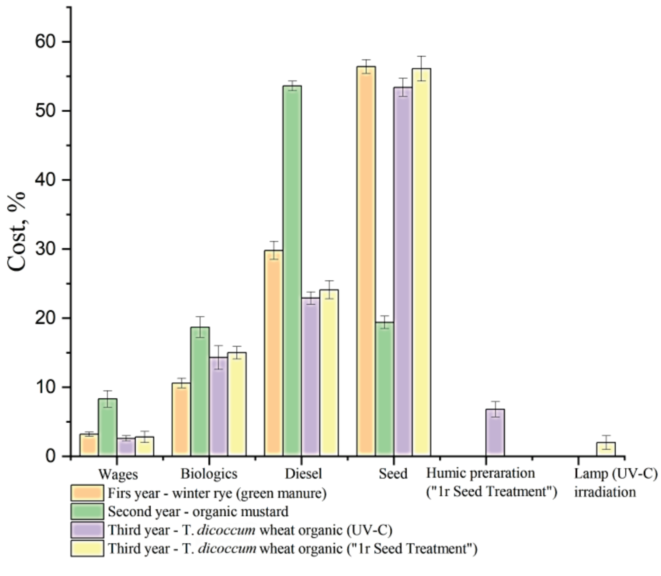


Fig. 4. The structure of emmer wheat production costs under the organic technology cultivation by the rotation: winter rye – mustard – *T. dicoccum* wheat

As can be seen, the largest expenses in the total production costs were for the seed purchase (€ 1.709, the domestic price of 1 ton of winter rye seed Synthetic cultivar was € 273.45) and diesel (€ 901, the domestic price of 1 liter was € 0.9). In total, the financial costs in the first year were € 3,614 (144.6 €/ha), including an unforeseen costs of 20.0%. As envisaged, the producer cannot make a profit in the first year, since the role of winter rye as a green manure crop is to improve soil structure and properties by accumulating basic nutrients in the system of the crop root canals, which will reduce tillage costs in the following year. 2nd year – cultivation of blue mustard Prima cultivar to improve the phytosanitary field condition and the soil organic matter indicators thanks to the involvement of a significant amount of crop residues into the soil-absorbing complex after crop cultivation. The main technological operations were adjusted to produce yields and included: soil tillage before seed sowing (cultivation, crops rolling), sowing mustard seed at the rate of 1.5 million pcs/ha (16 kg/ha), harrowing before shoots emergence, harrowing on shoots, treatment of crops with biological preparations and harvesting.

The structure of the main production costs for growing of blue mustard Prima cultivar by the organic technology is presented in Figure 4. The largest share of the costs is the diesel cost – € 923.3. The share of seed costs (the cost of 1 ton of mustard seed Prima cultivar on the domestic market is € 836.4) in the total production cost is 19.4% or € 334.6, which is almost 5 times lower than the winter rye seed cost because of the lower seeding rate. Cost of "5r Soil Boost EA" biopreparation for the mustard canopy treatment amount to € 438.9 (18.7%). Thus, the production costs for mustard cultivation amount to € 1,722.8, and considering unforeseen factors, the total costs are € 2,038.7 or 81.5 €/ha.

An important result of the introduced technology and justification of the production costs at end of the second year is a yield of up to 2.0 t/ha of organic mustard Prima cultivar. The producer will gain up to € 77,200, considering the domestic price of organic mustard seed (3.1 €/kg) and the yield of 25 ha (50 t/ha), and the sale of the product at a price of even 1.54 €/kg.

3rd year – cultivation of emmer wheat Holikovska cultivar. After harvesting mustard, the crop residues were processed, and disking of stubble was carried out. Emmer wheat Holikovska cultivar was sown at a rate of 4.5 million pcs/ha (200 kg/ha) into the soil prepared in this way. This was followed by harrowing and fertilizing with biopreparation twice: in autumn at the "tillering" stage and in spring at the "stem elongation" stage. The crop was harvested at the stage of "full grain ripening".

The main production costs for growing emmer wheat Holikovska cultivar by the organic technology according to different methods of pre-sowing seed treatment are shown in Fig. 4. Seed costs accounted for the biggest share – over 53.0% (€ 2,412.8) in the structure of costs, based on the seeding rate (200 kg/ha, the cost of 1 ton of emmer wheat seeds – € 482.5). The emmer wheat seeds costs on the domestic market at this seeding rate exceeded the cost of winter rye and mustard seed combined by 15.0%. The technological process of emmer wheat cultivation requires 1150 L of diesel which is slightly higher than the costs of winter rye (1000 L) and mustard (1025 L).

Considering the different methods of pre-sowing seed treatment, additional costs were made for: 4 lamps for UV-C irradiation at € 77.5 each – € 310; "1r Seed Treatment" humic preparation – € 86 for 16.5 L per 200 kg of seed. So, taking into account unforeseen cost (20.0%), the total production costs for growing emmer wheat by the organic technology were: with UV-C seed irradiation – € 5,426.4 (217 €/ha), with treatment by "1r Seed Treatment" humic preparation – € 5,157.6 (206 €/ha).

The potential yield of emmer wheat Holikovska cultivar is 5.00 t/ha. The traditional cultivation technology provided the yield of 4.26 t/ha. The introduction of the organic cultivation technology increased the yield to 5.17 t/ha (with UV-C pre-sowing seed treatment) and to 5.58 t/ha (with pre-sowing seed treatment by "1r Seed Treatment"). The price of organic emmer wheat on the domestic market varies between 8.4 €/kg. Assuming that an optimal price for the producer can be 3.3 €/kg, the profit from selling 100 tons of organic emmer wheat can reach € 426,000 if UV-C irradiation is included in the cultivation technology and € 460,000, if a humic preparation "1r Seed Treatment" is used for pre-sowing seed treatment.

To assess the efficiency of emmer wheat cultivation by the organic technology, we calculated the main economic indicators for three research years excluding tax payments, depreciation and rent, because they are individual and not subject to be averaged. The calculation results are given in Table 2. The presented calculations show that despite the lack of profit in the first year because of winter rye cultivation (green manure), i.e., creation of conditions to improve soil quality and enrich soil with nutrients to obtain a high yield of emmer wheat, the profit in the next two years fully covers the financial costs of the producer for three years. Thus, the net profit in the second year exceeds the costs by 29.6 times and in the third year by 71.2–80.6 times, depending on the method of pre-sowing seed treatment, indicating the rationality of growing emmer wheat by organic technology. Also, the financial safety margin of € 491,200–525,300 makes it possible to fully cover the fixed costs which we have not accounted (land and fixed asset rent, taxes, etc.).

Table 2
Economic efficiency indicators of emmer wheat cultivation in crop rotation: winter rye – mustard – *T. dicoccum* wheat under the organic technology

Income and expenditure forms	Firs year – winter rye (green manure)	Second year – organic mustard	Third year – *T. dicoccum* wheat organic
Full production cost, €	3,614.0	2,038.7	4,551.4
Payment for inspection and certification by the organic standards, €	482.6	482.6	482.6
Product price, €/t	–	1,544.2	3,345.7
Product Sales Revenues, €	–	77,208.6	334,570.8
Income or loss, €	–4,096.5	74,687.4	329,536.9

Note: "–" – an absence of profit because winter rye was used as a green manure crop.

In summary, it should be noted that on the European market, products from organic emmer wheat cost from about 10 €/kg, which creates prospects for the sale of organic raw materials for export.

Discussion

As is well known, the photosynthesis process mainly consists of three stages: the primary reaction, transport and photophosphorylation of photosynthetic electrons and carbon assimilation. Chlorophyll *a* and chlorophyll *b* are required for the primary reaction. The chlorophyll molecule in leaf chloroplasts of plants performs three important functions: it absorbs light energy selectively, stores it in the form of electron excitation energy and photochemically converts it into chemical energy of primary photoreduced and photo-oxidised compounds. Chlorophyll *b* and carotenoid act as additional and protective pigments that protect the photosynthetic apparatus from externally induced photooxidation and play a key role in the energy metabolism of wheat plants.

Today there is no consensus on the optimal chlorophyll amount in leaves and its effect on wheat productivity. Some researchers believe that chlorophyll levels should be low taking into account that a decrease in the light amount absorbed by the leaf prevents the photosynthetic apparatus from being destroyed by the absorbed energy excess. So, low chlorophyll content in leaves may ensure its more effective operation (Melis, 2009; Murchie et al., 2009). However, the authors of the study (Li et al., 2013) shown that under chlorophyll deficiency, photosynthetic activity is inhibited. Others, believe that plants with higher chlorophyll levels absorb more energy, making their photosynthesis more efficient (Luo & Ren, 2006), which results in high crop productivity (Sui et al., 2010).

In our studies, a higher (by 10.0%) content of chlorophyll ($a + b$) in the leaves of wheat grown under the organic technology in comparison with traditional and the same pre-sowing seed treatment (UV-C irradiation) was accompanied by an increase in yield by 21.4%. The obtained results agree with (Ghimire et al., 2015), which state that total chlorophyll content is significantly correlated with traits that determine yield structure, including grain yield. Gholamin & Khayatnezhad (2011) reported a similar positive correlation between leaf chlorophyll and maize yield ($r = 0.745$).

The photosynthesis process is significantly modified by the environmental factors. For example, a shortage of sufficient moisture reduces the photosynthesis rate, disrupts the transport and distribution of assimilates and causes lower crop yields (Możdżeń et al., 2015).

But, the photosynthetic apparatus of plants responds to the effect of any agronomic measures by changing not only in the total chlorophyll amount and carotenoids content, but also the changes in the ratio between chlorophyll *a* and chlorophyll *b*. I.e., more important than quantifying the content of photosynthetic pigments is analyzing their ratios (Gitelson, 2020; Zhang et al., 2020; Martins et al., 2021), including for yield prediction.

Chlorophyll *a* and chlorophyll *b* are known to absorb sunlight at different wavelengths (maximum absorption of chlorophyll a λ_{max} = 665 nm, and chlorophyll b λ_{max} = 649 nm), that is, the total chlorophyll amount in leaves chlorophyll (*a* + *b*) and the chlorophyll *a/b* ratio have a direct influence on the plant's photosynthetic capacity (Li et al., 2018). This assumption was proved using several plant species in the paper (Croft et al., 2017). Therefore, the chlorophyll *a/b* ratio may be one of the determinants of photosynthetic intensity and crop yield.

In our study, the decrease in the chlorophyll *a/b* ratio correlated with a significant yield increase under both emmer wheat growing technologies, regardless of the pre-sowing seed treatment method. Yan et al. (2021) also obtained the inverse correlation between chlorophyll *a/b* ratio and crop yield. The authors suggested that the lower chlorophyll *a/b* ratio could be used as a new indicator for selecting of the high yielding cultivars of grain crops. The higher grain yield obtained in the study resulted from a higher 1000-kernel weight, which explained by a longer photosynthetic duration, higher chlorophyll content, and lower chlorophyll *a/b* ratio.

The observed dependence may be associated with a change in the photosynthetic apparatus efficiency, since plants are very sensitive to changes in the environment and cultivation technologies and inevitably respond and regulate the chlorophyll content as evidenced by the research of Martins et al. (2022).

But not only changes in the chlorophyll *a/b* ratio, but also chlorophyll (*a* + *b*)/carotenoid can be an informative indicator of reorganization of light-harvesting plant photosystems complex under the influence of the technology cultivation (Ivanov et al., 2013). The total chlorophyll (*a* + *b*)/carotenoid ratio in plants is a sensitive indicator of photosynthetic activity and response to technological changes (Gitelson, 2020). The authors of this study observed decreased chlorophyll (*a* + *b*)/carotenoid, a result of faster degradation of total chlorophyll relative to carotenoid and reduced photosynthetic activity (Gamon et al., 2016).

In our research, a similar correlation in response to different wheat cultivation technologies, but with the same method of pre-sowing seed treatment (UV-C), was observed. A decrease in chlorophyll (*a* + *b*)/carotenoid ratio due to a decrease in total chlorophyll (*a* + *b*) in plants grown under the traditional technology in comparison with this indicator of plants cultivated under the organic farming technology was established. However, with the same cultivation technology but different methods of pre-sowing seed treatment, the decrease in chlorophyll (*a* + *b*)/carotenoid occurred due to an increase in the carotenoids content at the same content of total chlorophyll (*a* + *b*). Since carotenoids, in addition to their direct contribution to photosynthesis, are involved in a protective mechanism against oxidative stress (Campos et al., 2016), it can be assumed that emmer wheat plants grown from seed treated with "1r Seed Treatment" preparation will have increased protection of organic molecules against free radical damage in oxidation processes. Carotenoids act as a low-molecular antioxidant, whose biosynthesis in plants can increase in response to stress or technological change to reduce ROS production (Taran et al., 2017).

Thus, the obtained results display the transformation of the plants' pigment apparatus in the course of adaptation to different methods of pre-sowing seed treatment and cultivation technologies and can be used for yield prediction.

Conclusion

The different methods of pre-sowing seed treatment and cultivation technologies induced changes in the pigment composition of emmer wheat plants. An increase in the chlorophyll *a* and chlorophyll *b* content and a decrease in the carotenoid content in emmer wheat plants grown under organic farming technology in comparison with the traditional one with the same method of pre-sowing seed treatment (UV-C) was observed. Statistical analysis confirmed the presence of a direct correlation between the chlorophyll *a* content (r = 0.603), chlorophyll *b* content (r = 0.999) and the emmer wheat yield in organic cultivation technology. The most effective method of pre-sowing seed treatment was established by the analysis of the wheat plants pigment composition. The highest yield of emmer wheat was obtained under organic cultivation technology with pre-sowing seed treatment by "1r Seed Treatment" humic preparation. The yield increase under this cultivation technology was 31% compared to the traditional one. The evaluation of economic indicators of the emmer wheat cultivation in the rotation: winter rye-mustard-emmer wheat under organic farming technology proved its high profitability.

It would be promising to conduct further studies on the implementation of other physical methods of pre-sowing seed treatment for the organic cultivation technology of grain crops and obtaining profitable ecologically clean products.

The authors declare no conflict of interests.

References

Arzani, A., & Muhamad, A. (2017). Cultivated ancient wheats (*Triticum* spp.) and a potential source of health-beneficial food products. Food Science and Food Safety, 16, 477–488.

Cai, R.-G., Zhang, M., Yin, Y.-P., Wang, P., Zhang, T.-B., Gu, F., Dai, Z.-M., Liang, T.-B., Wu, Y.-H., & Wang, Z.-L. (2008). Photosynthetic characteristics and antioxidative metabolism of flag leaves in responses to nitrogen application during grain filling of field-grown wheat. Agricultural Sciences in China, 7, 157–167.

Campos, M. D., Nogales, A., Cardoso, H. G., Campos, C., Grzebelus, D., Velada, I., & Arnholdt-Schmitt, B. (2016). Carrot plastid terminal oxidase gene (DcPTOX) responds early to chilling and harbors intronic pre-mirnas related to plant disease defense. Plant Gene, 7, 21–25.

Chaika, T., Korotkova, I., Barabolia, O., Shokalo, N., Chetveryk, O., Bilenko, O., & Krykunova, V. (2021). Technological peculiarities of the mustang and *Triticum dicoccum* (Schrank) Schuebl wheat cultivation according to organic farming standards. International Journal of Botany Studies, 6, 205–210.

Cristache, S.-E., Vută, M., Marin, E., Cioacă, S.-I., & Vută, M. (2018). Organic versus conventional farming – a paradigm for the sustainable development of the European countries. Sustainability, 10, 4279.

Croft, H., Chen, J. M., Luo, X., Bartlett, P., Chen, B., & Staebler, R. M. (2017). Leaf chlorophyll content as a proxy for leaf photosynthetic capacity. Global Change Biology, 23, 3513–3524.

Crowder, D. W., & Reganold, J. P. (2015). Financial competitiveness of organic agriculture on a global scale. The Proceedings of the National Academy of Sciences, 112, 7611–7616.

Čurná, V., & Lacko-Bartošova, M. (2017). Chemical composition and nutritional value of emmer wheat (*Triticum diccoccon* Schrank): A review. Journal of Central European Agriculture, 18, 117–134.

Driever, S. M., Lawson, T., Andralojc, P. J., Raines, C. A., & Parry, M. A. J. (2014). Natural variation in photosynthetic capacity, growth, and yield in 64 field-grown wheat genotypes. Journal of Experimental Botany, 65, 4959–4973.

Forster, D., Andres, C., Verma, R., Zundel, C., Messmer, M. M., & Mäder, P. (2013). Yield and economic performance of organic and conventional cotton-based farming systems – results from a field trial in India. PLoS One, 8, e81039.

Gamon, J. A., Huemmrich, K. F., Wong, C. Y. S., Ensminger, I., Garrity, S., Hollinger, D. Y., Noormets, A., & Peñuelas, J. (2016). A remotely sensed pigment index reveals photosynthetic phenology in evergreen conifers. Proceedings of the National Academy of Sciences, 113, 13087–13092.

Ghimire, B., Timsina, D., & Nepal, J. (2015). Analysis of chlorophyll content and its correlation with yield attributing traits on early varieties of maize (*Zea mays* L.). Journal of Maize Research and Development, 1, 134–145.

Gholamin, R., & Khayatnezhad, M. (2011). The effect of end season drought stress on the chlorophyll content, chlorophyll fluorescence parameters and yield in maize cultivars. Scientific Research and Essays, 6, 5351–5357.

Gitelson, A. (2020). Towards a generic approach to remote non-invasive estimation of foliar carotenoid-tochlorophyll ratio. Journal of Plant Physiology, 252, 153227.

Gorban, V., Huslystyi, A., Recio Espejo, J. M., & Bilova, N. (2021). Prediction of SOC in calcic chernozem in the steppe zone of Ukraine using brightness and colour indicators. Ekológia (Bratislava), 40, 325–336.

Heckman, J. (2006). A history of organic farming: Transitions from Sir Albert Howard's war in the soil to USDA National Organic Program. Renewable Agriculture and Food Systems, 21, 143–150.

Ivanov, L. A., Ivanova, L. A., Ronzhina, D. A., & Yudina, P. K. (2013). Changes in the chlorophyll and carotenoid contents in the leaves of steppe plants along a latitudinal gradient in South Ural. Russian Journal of Plant Physiology, 60, 812–820.

Khalep, Y., & Moskalenko, A. (2020). Ecological and economic aspects of the efficiency of Polissia organic plant models. Agricultural and Resource Economics: International Scientific e-Journal, 6, 5–19.

Koutis, K. (2015). Selection and evaluation of emmer, einkorn and spelta germplasm in Greece for organic farming adaptability and bakery-nutritional quality. Acta Fytotechnnica et Zootechnica, 18, 81–82.

Lachman, J., Miholova, D., Pivec, V., Jiri, K., & Janovska, D. (2011). Content of phenolic antioxidants and selenium in grain of einkorn (*Triticum monococcum*), emmer (*Triticum diccoccum*) and spring wheat (*Triticum aestivum*) varieties. Plant, Soil and Environment, 57, 235–243.

Lacko-Bartošová, M., & Čurná, V. (2015a). Agronomic characteristics of emmer wheat varieties. Journal of Microbiology, Biotechnology and Food Sciences, 4, 91–94.

Lacko-Bartošová, M., & Čurná, V. (2015b). Nutritional characteristics of emmer wheat varieties. Journal of Microbiology, Biotechnology and Food Sciences, 4, 95–98.

Li, N., Jia, J., Xia, Ch., Liu, X., & Kong, X. (2013). Characterization and mapping of novel chlorophyll deficient mutant genes in durum wheat. Breeding Science, 63, 169–175.

Li, Y., He, N., Hou, J., Xu, L., Liu, C., Zhang, J., Wang, Q., Zhang, X., & Wu, X. (2018). Factors influencing leaf chlorophyll content in natural forests at the biome scale. Frontiers in Ecology and Evolution, 6, 64.

Lialina, N., & Matviienko-Biliaieva, G. (2019). Mechanism for providing the development of organic agricultural production in Ukraine. Agricultural and Resource Economics, 5, 121–140.

Long, S. P., Marshall, C. A., & Zhu, X. G. (2015). Meeting the global food demand of the future by engineering crop photosynthesis and yield potential. Cell, 161, 56–66.

Luo, P. G., & Ren, Z. L. (2006). Wheat leaf chlorosis controlled by a single recessive gene. Physiology and Molecular Biology of Plants, 32, 330–338.

Martins, J. P. R., de A. Rodrigues, L. C., dos Santos Silva, T., Rossini, F., Gontijo, A. B. P., & Falqueto, A. (2021). Morphophysiological responses of *Aechmea blanchetiana* (Bromeliaceae) to excess copper during *in vitro* culture. Plant Biosystems, 155, 447–456.

Martins, J. P. R., de Almeida Rodrigues, L. C., de Souza Braga, P. C., Falqueto, A. R., & Gontijo, A. B. P. L. (2022). Impacts of copper on photosynthetic pigments and anatomy of *Alcantarea imperialis* (Bromeliaceae) under *in vitro* conditions. Biotechnology, Agronomy, Society and Environment, 26, 78–87.

Melis, A. (2009). Solar energy convertion efficiencies in photosynthesis: Minimizing the chlorophyll antennae to maximize efficience. Plant Science, 17, 272–280.

Możdżeń, K., Bojarski, B., Rut, G., Migdałek, G., Repka, P., & Rzepka, A. (2015). Effect of drought stress induced by mannitol on physiological parameters of maize (*Zea mays* L.) seedlings and plants. Journal of Microbiology, Biotechnology and Food Sciences, 4, 86–91.

Murchie, E. H., Pinto, M., & Horton, P. (2009). Agriculture and the new challenges for photosynthesis research. New Phytologist, 181, 532–552.

Peng, J., Sun, D., & Nevo, E. (2011). Wild emmer wheat, *Triticum dicoccoides* occupies a pivotal position in wheat domestication process. Australian Journal of Crop Science, 5, 1127–1143.

Ren, B. Z., Cui, H. Y., Camberato, J. J., Dong, S. T., Liu, P., Zhao, B., & Zhang, J. W. (2016). Efects of shading on the photosynthetic characteristics and mesophyll cell ultrastructure of summer maize. The Science of Nature, 103, 1–12.

Riar, A., Mandloi, L. S., Poswal, R. S., Messmer, M. M., & Bhullar, G. S. (2017). A diagnosis of biophysical and socio-economic factors influencing farmers' choice to adopt organic or conventional farming systems for cotton production. Frontiers in Plant Science, 8, 1289.

Semenov, A., Korotkova, I., Sakhno, T., Marenych, M., Hanhur, V., Liashenko, V., Kaminsky, V. (2020). Effect of UV-C radiation on basic indices of growth process of winter wheat (*Triticum aestivum* L.) seeds in pre-sowing treatment. Acta Agriculturae Slovenica, 116(1), 49–58.

Suchowilska, E., Wiwart, M., Kandler, W., & Krska, R. (2012). A comparison of macro- and microelement concentrations in the whole grain of four *Triticum* species. Plant, Soil and Environment, 58, 141–147.

Sui, N., Li, M., Meng, Q.-W., Tian, J.-C., & Zhao, S.-J. (2010). Photosynthetic characteristics of a super high yield cultivar of winter wheat during late grown period. Agriculture Sciences in China, 9, 346–354.

Taran, N., Storozhenko, V., Svietlova, N., Batsmanova, L., Shvartau, V., & Kovalenko, M. (2017). Effect of zinc and copper nanoparticles on drought resistance of wheat seedlings. Nanoscale Research Letters, 12, 60.

Tkalich, Y., Tsyliuryk, O., Kozechko, V., Rudakov, Y., Tkalich, O., & Bagorka, M. (2020). Weed chemical control in the winter wheat planting after non fallow predecessors in the Northern Steppe of Ukraine. Scientific Papers, Series A – Agronomy, 63(1), 567–573.

Tsyliuryk, A. I., Tkalich, Y. I., Masliiov, S. V., & Kozechko, V. I. (2017). Impact of mulch tillage and fertilization on growth and development of winter wheat plants in clean fallow in Northern Steppe of Ukraine. Ukrainian Journal of Ecology, 7(4), 511–516.

Wellburn, A. R. (1994). The spectral determination of chlorophylls *a*, and *b*, as well as total carotenoids, using various solvents with spectrophotometers of different resolution. Journal of Plant Physiology, 144, 307–313.

Yan, Y., Hou, P., Duan, F., Niu, L., Dai, T., Wang, K., Zhao, M., Li S., & Zhou, W. (2021). Improving photosynthesis to increase grain yield potential: An analysis of maize hybrids released in diferent years in China. Photosynthesis Research, 150, 295–311.

Zhang, H., Li, X. Y., Chen, L., & Huang, Z. R. (2020). The photosynthetic performance of two *Citrus* species under long-term aluminum treatment. Photosynthetica, 58, 228–235.

Zhang, H., Zhao, Q., Wang, Z., Wang, L., Li, X., Fan, Z., Zhang, Y., Li, J., Gao, X., Shi, J., & Chen, F. (2021). Effects of nitrogen fertilizer on photosynthetic characteristics, biomass, and yield of wheat under different shading conditions. Agronomy, 11, 1989.