Anatomical and morphological features, and productivity of six perennial wheat varieties in the agroecological conditions of the Almaty region, Kazakhstan

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Abstract. Wheat plays a leading role among cultivated crops. However, some anatomical features of the perennial wheat leaf blade structure, cell development, and metameric stem segmentation remain poorly understood. The object of the present study was six varieties of perennial wheat cultivated in the Almaty region of Kazakhstan. During the study, metameric features of the growth and development of the perennial wheat stem internodes were analyzed. The stems consisted of four internodes and very rarely of five. The variety No. 701 had the longest stem (119 ± 4 cm), while the variety Sova had the shortest one (106 ± 4 cm). The variety No. 701 also had the largest leaf blade with a length of 42 cm ± 2 cm and a width of 1.6 ± 0.09 cm, while the variety No. 704 had the smallest leaf blade with a length of 27 ± 1 cm and a width of 1.2 ± 0.06 cm. The average biological productivity of the Sova variety was 10.49 centners per hectare. The varieties No. 703, No. 704, and No. 801 demonstrated high productivity ranging from 26.08 to 28.8 centners per hectare.

1 Introduction

Perennial crops contribute to the sustainable development of agriculture and can become an alternative to annual crops. The ability of perennial crops to grow year after year can significantly reduce the resources needed for planting and weed control and can improve soil health and biodiversity by reducing tillage [1]. As a result of various case studies, it was concluded that due to additional feed production, perennial wheat could be economically profitable, even with a grain yield down to 40% of that of the annual wheat for three consecutive years [2]. In addition to direct economic benefits, grazing and harvesting perennial crops for feed can contribute to pest control. Removal of vegetive parts by grazing or harvesting limits the production of weed seeds and reduces the abundance of weeds commonly found among cultivated crops [3,4].

Wheat plays a leading role among cultivated crops. To increase the yield of this crop, it is necessary to study the elements of photosynthetic activity at all levels of organization of

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the assimilation apparatus [5-7]. The crucial role of photosynthesis in crop formation is at the core of the theory of photosynthetic productivity. To further develop this theory, it is necessary to pay attention to the metameric principle of the plant shoot organization, since metamers can differ in structure and function [8-10]. To date, the cellular and tissue levels of organization of the photosynthetic apparatus of wheat remain insufficiently studied [11,12]. A detailed study of the photosynthetic apparatus organization is necessary for further development of a general theory of plant productivity and the use of the results obtained in the selection process [13].

The anatomy of the perennial wheat leaf blade, its structure, the development of individual cells, and metameric specificity remain poorly understood. Cereal plants have a well-defined metameric structure determined by the activity of the shoot apex. The difference between metamers manifests itself structurally in the development of their elements, as well as functionally in the implementation of individual physiological processes. In plant ontogenesis, there is a continuous re-adjustment of metamer relationships, where conducting tissues act as integral pathways that ensure their optimal level under the prevailing external conditions [14,15]. This property of conductive tissues is based on their ability to transport organic and inorganic substances, propagate action potentials and, possibly, serve, in the presence of concomitant sclerenchyma cells, as a light conductor [16]. The conductive tissues of wheat leaves, as a rule, relate to the fibers of sclerenchyma, which, considering various functions of sclerenchyma under consideration [17], is of interest to researchers.

The purpose of our work was to identify specific anatomical features of the perennial wheat leaf blade for the subsequent use of these data in the analysis of the breeding results, as well as for comparison with the hybrids already obtained.

2 Materials and Methods

2.1 Anatomical research Methods

The material was collected from 15 plants of each perennial wheat variety at different stages of development. In preparation for fixation, leaves were cut parallel to the center. For anatomical studies, a fixing mixture of alcohol, glycerol and water was used in a ratio of 1:1:1 according to the Strasburger-Flemming method [18]. The leaves were fixed in the phases of full tillering and stem elongation.

The anatomical preparations were made following the methods accepted in plant anatomy [19-22]. The leaf sections were obtained using an HS3345 automatic microtome. Microphotographs of anatomical sections were taken on an Escope trinocular microscope (Euromix, the Netherlands) with a high-speed camera CMEX-5 Pro 5.1 Megapixels.

3 Results and Discussion

The adaxial surface of a wheat leaf blade is characterized by wide ribs, especially noticeable in the region of the second-order bundles. The abaxial surface is almost smooth. The cells around the central conductive bundle are rounded. The epidermal cells are lignified, covered with a layer of cuticle on the outside. In the furrows of the adaxial side of the leaf blade, groups of 3-4 motor cells are located. The function of the motor (or bulliform) cells is to prevent water loss during stress and drought, by rolling the leaves. In the central vein, a large bundle is clearly visible, where the phloem is oriented towards the lower epidermis, and the xylem vessels are oriented towards the upper epidermis; the sclerenchyma is well developed under the phloem. Small conductive bundles are located parallel to the upper epidermis, under and above the lower epidermis. The mesophyll is spongy, the larger parenchymal cells are concentrated towards the center, with the smaller cells located at the edges. Morphometric indicators of the anatomical structure of perennial wheat varieties are shown in Table 1.

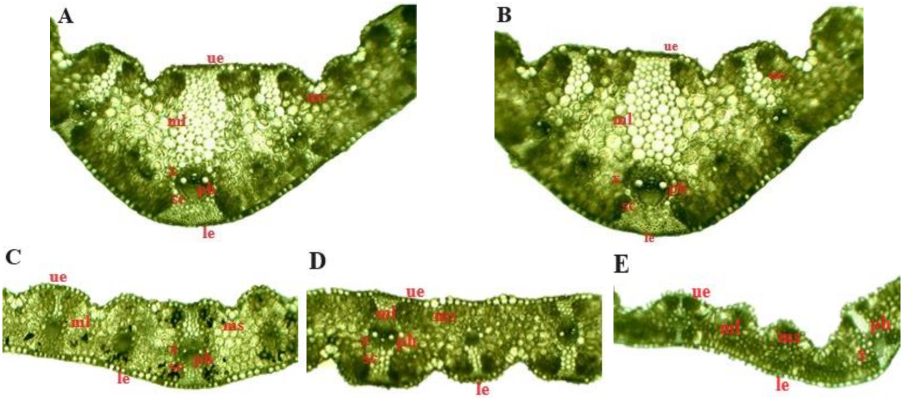

Fig. 1. Anatomical structure of perennial wheat leaf blades of five varieties: A) No. 701; B) No. 702; C) No. 703; D) No. 704; E) No. 801.

Table 1. Morphometric indicators of the perennial wheat anatomical structure.

Variety	Lower epidermis thickness, μm	Upper epidermis thickness, μm	Leaf blade thickness, μm	Mesophyll thickness, μm	Conductive bundle area, mm^2
№701	0.40±0.06	0.39±0.05	32. ±8.	12±2	37±6
№702	0.35±0.03	0.38±0.04	39±5	17±3	49±6
№703	0.40±0.07	0.42±0.06	19±3	6.5±0.9	48±5
№704	0.37±0.04	0.39±0.08	25±3	9±1	40±5
№801	0.38±0.05	0.40±0.09	19±3	6±2	46±8

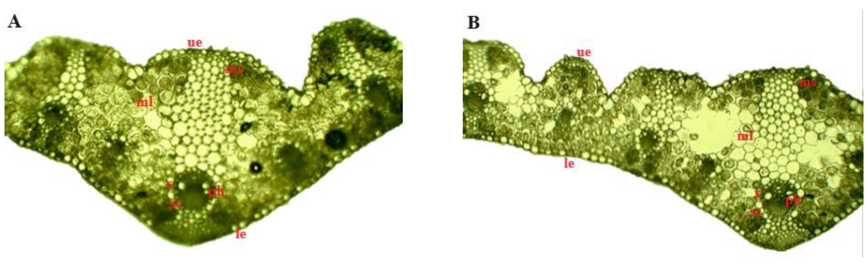

Fig. 2. Anatomical structure of a perennial wheat leave blade of the Sova variety, A) brown soil; B) chernozem.

Table 2. Morphometric indicators of the perennial wheat anatomical structures in different soil types.

Soil type	Lower epidermis thickness, µm	Upper epidermis thickness, µm	Leaf blade thickness, µm	Mesophyll thickness, µm	Conductive bundle area, mm^2
Chernozem	0.34±0.08	0.41±0.07	26±5	10±3	43±5
Brown soil	0.41±0.05	0.49±0.08	21±4	10±3	29±4

In the cross-section, trichomes are clearly visible on the upper epidermis; the leaves are slightly pubescent. Motor cells are visible in the upper and lower epidermis. Mechanical tissue is well developed above and below the conductive bundles. Morphometric indicators of the anatomical structures of perennial wheat growing in different soils are shown in Table 2.

In roots, the xylem is arranged as a single circle, and the number of vessels ranges from 10 to 12. The vessel thickness in the xylem is 52±2 µm. The total root thickness is 620±6 µm. The stem thickness reaches 1183 ±14 µm. In stems, numerous parallel closed bundles of 195-307 µm in length and 141-197 µm in width are observed.

According to the results of field studies conducted in 2021-2023, seed germination in the field averaged 70.55%. In the first year, perennial wheat competes with weeds, and in subsequent years it grows better and outcompetes weeds. In autumn, the optimal sowing period is the end of September - the beginning of October, and in spring, the middle of April and the end of April; the optimal distance between plants is up to 15 cm, and between rows, up to 30 cm. During the study, metameric features of the growth and development of the perennial wheat stem internodes were identified. The stems consisted of four internodes and very rarely of five. The analysis of the variety No. 701 showed that the average length of the first internode varied from 9.06 to 12.8 cm; of the second, from 16.17 to 21.46 cm; of the third, from 23.74 to 27.55 cm; and of the fourth, from 30.76 to 34.27 cm. The length of the rarely present fifth internode ranged from 33.52 to 42 cm. The height of the Sova variety was 106 ± 4 cm; the height of the variety No. 701 was 119 ± 4 cm; the height of the variety No. 702 was 110 ± 4 cm; the height of the variety No. 703 106 ± 2 cm, and the height of the variety No. 704 was 116 ± 3 cm. The height of the variety No. 801 was 118± 5 cm.

It was found that the intensity of tillering of perennial wheat was very high: in the tillering phase the number of stems reached 32, the number of productive shoots was on average 21, and the number of kernels per head ranged from 35 to 40. The kernel weight was 0.01-0.012 g. It is estimated that perennial wheat forms on average of 735 kernels per plant, which is more than twice the number of kernels formed by annual wheat.

According to all major environmental indicators, the natural resources of Kazakhstan are rapidly deteriorating. Almost a third of agricultural land is degraded or seriously threatened, and more than 10 million hectares of previously arable land are abandoned. Cultivation of perennial wheat is seen as an effective strategy to increase carbon uptake in agricultural fields [23].

In the global economy, perennial cereals are likely to become a sustainable alternative to annual crops. Annual crops make up a significant part of the food supply of Kazakhstan, although they have some drawbacks. Extensive cultivation of annual crops can have negative environmental impacts such as a decrease in soil fertility, water scarcity, increased emissions of toxic gases, and biodiversity loss. Perennial crops can yield for several consecutive years after sowing and contribute to alleviation of environmental problems.

Perennial crops improve soil quality by increasing organic matter and nutrients, increasing resilience, and reducing leaching, and can also help restore soils degraded by overcultivation.

4 Conclusion

We studied morphological and anatomical features of perennial wheat, and some features of crop formation, we also assessed the quality of perennial wheat kernel to estimate perennial wheat productivity. When studying the specifics of the anatomical structure of a three-year-old perennial wheat leaf, we found out that motor cells were in the upper and lower epidermis. Medium veins had large conductive bundles and were located close to the lower epidermis. The phloem was oriented towards the lower epidermis, and the xylem vessels were oriented towards the upper epidermis. Small conductive bundles were located parallel to the upper epidermis, under and above the lower epidermis. The mesophyll was spongy, with the larger parenchymal cells concentrated towards the center, and the smaller cells located at the edges. The average biological productivity of the varieties Sova, No. 701, No. 703, No. 704, and No. 801 were 10.49, 10.8, 26.08, 26.08, and 28.8 centners per hectare, respectively. The results of the study show that perennial wheat slows down the erosion of irrigated soils, preserves the initial agrophysical properties of soil, reduces the cost of growing crops, and creates new economic opportunities while improving the environment.

Authors' contribution

Conceptualization, M.S. and B.S.; Methodology, M.S.; Software, D.K.; Formal Analysis, B.S.; Investigation, A.K.; Resources, B.S.; Writing – Original Draft Preparation, D.K.; Writing – Review & Editing, M.S.; Visualization, N.Y.; Supervision, A.K.; Project Administration, M.S.; Funding Acquisition, M.S.”

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