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CROP PRODUCTION, PLANT PROTECTION AND BIOTECHNOLOGY

The Nutritive Value of Indian Dwarf Wheat Ears as Feed

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Abstract—There has been an increased interest in growing nontraditional cereal crops and studying the possibility of using them as raw material for feed preparation. Such promising crops include Indian dwarf wheat (*Triticum sphaerococcum* Percival). The aim of this study was to determine the nutritional value of Indian dwarf wheat ears in different phases of ripeness for use as raw material in feed production in comparison with soft wheat, and to determine the rational time frame of their harvesting for feed purposes. Harvesting was carried out by combing without threshing and separating grain heap in different phases of maturity. Feed was prepared from the grain heap. Chemical analysis of samples was carried out using standard methods. The mid-wax ripeness phase is the best time to harvest Indian dwarf wheat for preparing feed from its ears when they contain the maximum amount of essential amino acids and the minimum amount of fiber. The feed prepared from the ears of Indian dwarf wheat is of better quality than feed from soft wheat; in particular, it has an increased content of the sum of essential amino acids (by 1.06–2.23%) and individual amino acids (by 1–5%). This opens opportunities for using the crop in the preparation of feed in order to improve the quality of protein. The disadvantages of feed from Indian dwarf wheat include the increased (by 4– 10% compared to soft wheat) fiber content. The grain heap (ears) of Indian dwarf wheat harvested without threshing in the phase of early wax and mid-wax ripeness can be a source of raw materials that ensure an increase in the nutritional value of feed.

Keywords: Indian dwarf wheat, ear, grain heap, early stages of ripeness, protein, essential amino acids, feed

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INTRODUCTION

A low protein content, including essential amino acids, in the products of such traditional grain crops as soft wheat and barley is one of the problems of agriculture in Russia [1]. Therefore, there is increased interest in studying less common cereal crops and determining the possibility of using them as raw materials for the preparation of feed for farm animals and fish [2].

A group of rare wheats, such as Persian wheat (*Triticum persicum* Vavilov), Indian dwarf wheat (*Triticum sphaerococcum* Percival), and hulled wheat (*Triticum dicoccum* Schrank), etc., stands out among nontraditional grain crops [3]. These species were common in ancient times, but today they have been displaced from cultivation by more productive soft wheat (*Triticum aestivum* L.) [4]. At the same time, they have a number of useful properties, such as resistance to diseases and lodging, as well as a higher protein content, despite the lower yield [5].

According to breeders, the Indian dwarf wheat, which is resistant to lodging and early ripening despite its low yield, is the most suitable among the listed species of wheat for intensive cultivation technology [6]. In Russia, its breeding is carried out by the P.P. Lukyanenko National Grain Center, where varieties of winter Indian dwarf wheat suitable for cultivation in the south of Russia have been created [7].

Since Indian dwarf wheat is a relatively new crop for modern agriculture, there are only a few known results of studies of its nutritional value and digestibility as feed for farm animals and fish [8], which necessitates additional study of its nutritional value, not only at full maturity, but also in the early phases of ripeness, when it is possible and advisable to use not only the grain, but also the nongrain part of the ear to increase the nutritional value.

The aim of this study was to assess the nutritional value of Indian dwarf wheat ears in different phases of ripeness to determine the possibility of their use as raw

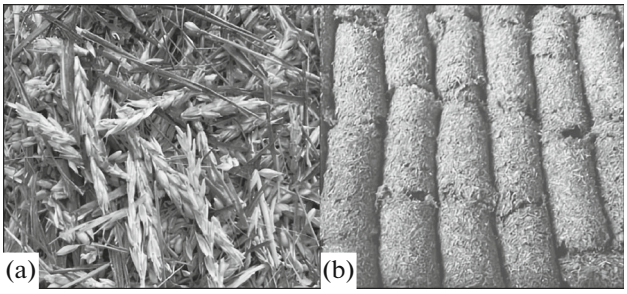

Fig. 1. Grain heap (a) and feed (b) from ears of soft wheat harvested at the phase of early wax ripeness.

materials in the production of feed in comparison with soft wheat and to establish rational harvesting times for feed purposes.

MATERIALS AND METHODS

The work was carried out in 2022–2023 in the south of the Rostov region. Winter soft wheat (*Triticum aestivum* L.) of the Ambar variety and winter Indian dwarf wheat (*Triticum sphaerococcum* Percival) of the Eremeevna variety were grown. Both crops were sown in the same field and grown using the same technology with the application of equal amounts of mineral fertilizers. The field experiment was two-factor (factor A is the crop, factor B is the grain ripening phase at harvesting) and was repeated three times. The area of the experimental plot was 60 m^2 and that of the accounting plot was 20 m^2.

Black fallow was a predecessor. Soil was ordinary carbonate heavy loamy chernozem, pH 7.0, humus content (according to Tyurin) 3.2%, total nitrogen (according to GOST R 58596-2019) 28.6 mg/kg, mobile phosphorus (according to Kirsanov) 20–25 mg/kg, and exchangeable potassium (according to Machigin) 300–350 mg/kg. A slight excess of precipitation (by 3%) and average air temperature (by 2°C) over the average long-term norm was observed during the vegetation period of 2022–2023.

Sowing was carried out with a SS-11 Alpha seeder. The seeding rate was 230 kg/ha (5.2 million viable seeds per 1 ha). Ammophos was applied simultaneously with sowing at a dose of 100 kg/ha. Two additional mineral fertilizer applications were then carried out (ammonium nitrate at a dose of 70 kg/ha) in the spring tillering and tube emergence phases.

Wheat was harvested by combing without threshing and separating the grain heap (grain and nongrain part of the ear) [9] with a stripper header at different times corresponding to specific grain ripening phases: 1, milk ripeness; 2, doughy ripeness; 3, early wax ripeness; 4, middle wax ripeness; 5, late wax ripeness; and 6, full ripeness.

Feed was prepared from the harvested grain heap for 2-year-old carp using a new technology, including the operations of expansion at a temperature of 35–40°C, drying to a moisture content of 14–18%, grinding in a crusher, and granulating in a granulator with a horizontal flat matrix (Fig. 1) [10].

Samples of the produced feed were taken in accordance with GOST ISO 6497–2014 and prepared for analysis in accordance with GOST ISO 6498–2014. Chemical analysis of the samples was carried out using standard methods to determine the content of protein, lipids, β-carotene, fiber, and ash. The content of essential amino acids in the feed was determined with a Kapel-104T device using capillary electrophoresis in accordance with GOST R 55569–2013, and the content of β-carotene was determined using the HPLC (thin layer chromatography) [11].

The statistical significance of the experimental results processing was determined by the method of variance analysis using the Student's criterion at a 5% significance level (Dospekhov B. A. Methodology of field experiment: (with the basics of statistical processing of research results). 6th ed. Moscow: Alliance, 2011. 350 p.).

The nutritional value indicators of feed from ears of Indian dwarf wheat harvested at different phases of ripeness established as a result of the analysis were compared with each other and with similar indicators of feed from soft wheat, which served as a control.

In addition, the amino acid score for limiting amino acids was calculated for feed from ears harvested at all phases of ripeness [12]. In this case, the content of essential amino acids in the feed was compared with their share in the "ideal" feed for 2-year-old carp [13].

RESULTS AND DISCUSSION

The change in protein content in the ears of the studied grain crops as they ripened occurred in different ways (Fig. 2). In the ears of soft wheat, the protein content from the beginning of ripening (12.91%) gradually increases significantly by 1.95%, reaching a maximum of 14.86% in the phase of mid-wax ripeness, and then it decreases sharply by 2.2% to a minimum of 12.66% in the phase of full ripeness. In contrast, the maximum protein content of 15.66% was observed in the feed from the ears of Indian dwarf wheat in the doughy ripeness phase, after which it significantly decreased by 2.65% to a minimum of 13.01% in the phase of full ripeness. The value of this indicator in the feed from the ears of both crops harvested at the phases of early and mid-wax ripeness was at approximately the same level.

The protein content in the feed from Indian dwarf wheat ears in the milk and doughy ripeness phases was higher than in the feed from soft wheat by 1.91–2.35%; the values of this indicator differed insignificantly in the phases of wax and full ripeness. As a result of chemical analysis of the feed from wheat ears, the

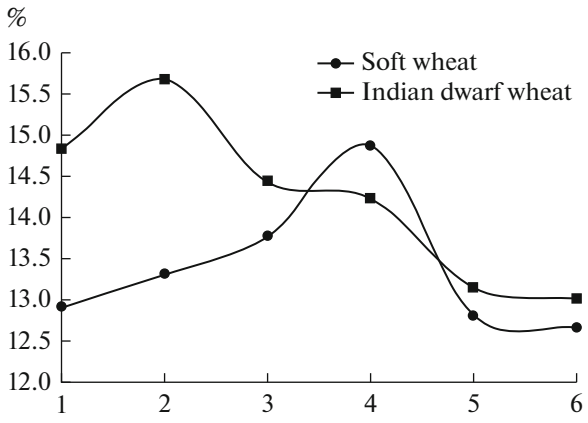

Fig. 2. Changes in protein content in feed from ears of wheat of different species during the ripening process (LSD_{05} for the crop factor, 0.83%; ripening phase, 0.75%): 1–6—grain ripening phases.

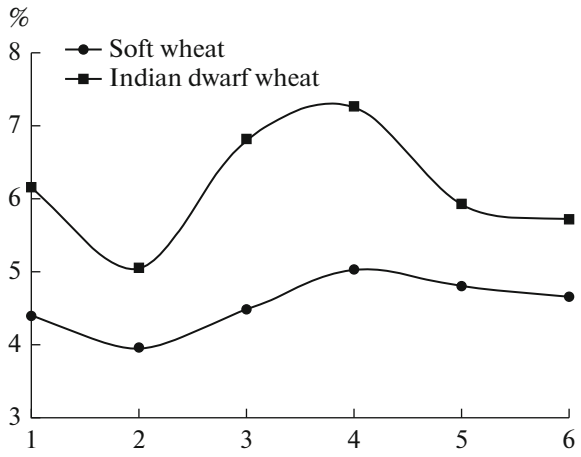

Fig. 3. The change in the total content of essential amino acids in feed from ears of wheat of different species during the process of ripening (LSD_{05} by crop factor, 1.6%; maturation phase, 1.35%): 1–6—grain maturation phases.

total content of essential amino acids was determined (Fig. 3). Unlike the protein content, the total amount of essential amino acids in the studied crops changed in a similar way as they ripened. It was the lowest in the doughy ripeness phase: 3.96% for soft wheat and 5.05% for Indian dwarf wheat. The value of this indicator then increased significantly by 1.07% and 2.21%, respectively, reaching a maximum (5.03% and 7.26%) in the phase of mid-wax ripeness and then it decreased significantly by 0.38% and 1.55% by the end of ripening (to 4.65 and 5.71%).

The content of essential amino acids in the feed from the ears of Indian dwarf wheat exceeds the value of this indicator in the product from the ears of soft wheat in all phases of ripeness by 1.06–2.23% (at LSD_{05} = 1.6% for the crop factor). The change in the content of individual essential amino acids in the feed from the ears of the studied crops mainly had the same patterns as their total amount (Table 1). At the same time, the values of these indicators in the feed from the ears of both wheat species, especially for lysine and the sum of amino acids, were lower than required in all phases of ripeness by 1.3–1.6% and 5–8%, respectively. Nevertheless, the product from Indian dwarf wheat significantly differed in an increased content of most essential amino acids and their sum, compared to the feed from soft wheat, by 1–2%.

Not only is the level of essential amino acids in the feed important for nutrition of fish, but also their ratio,

Table 1. The contents of essential amino acids in feed from ears of soft and Indian dwarf wheat at different phases of ripening, % of dried mass

Amino acid	Grain phase of ripening												LSD_{05}**	"Ideal" feed
	1		2		3		4		5		6			
	S*	I	S	I	S	I	S	I	S	I	S	I		
Arginine	0.70	0.71	0.67	0.55	0.76	0.66	0.77	0.58	0.80	0.57	0.70	0.56	0.13	1.90
Valine	0.48	0.80	0.43	0.59	0.47	0.58	0.53	0.76	0.52	0.66	0.48	0.66	0.12	1.48
Histidine	0.35	0.28	0.25	0.29	0.30	0.39	0.31	0.44	0.26	0.40	0.35	0.40	0.06	0.72
Lysine	0.45	0.62	0.38	0.48	0.48	0.57	0.51	0.62	0.47	0.44	0.45	0.40	0.07	2.00
Leucine + isoleucine	0.99	1.50	0.89	1.40	0.98	1.99	1.18	1.94	1.13	1.70	0.99	1.59	0.66	3.00
Methionine	0.22	0.43	0.24	0.24	0.26	0.33	0.30	0.34	0.25	0.26	0.22	0.23	0.06	0.70
Threonine	0.69	0.91	0.65	0.68	0.72	1.15	0.87	1.40	0.84	0.81	0.69	0.79	0.21	1.20
Tryptophan	0.11	0.40	0.10	0.38	0.12	0.48	0.14	0.50	0.12	0.44	0.11	0.43	0.32	0.60
Phenylalanine	0.41	0.50	0.35	0.44	0.40	0.66	0.42	0.68	0.41	0.65	0.41	0.65	0.20	1.40
Total	4.40	6.15	3.96	5.05	4.49	6.81	5.03	7.26	4.80	5.93	4.40	5.71	1.60	13.00

* S, feed from soft wheat; I, feed from round wheat;
** by crop factor.

Table 2. The amino acid score of feed from ears of wheat of different species harvested at different phases of grain ripening

Amino acid	Grain phase of ripening											
	1		2		3		4		5		6	
	S*	I	S	I	S	I	S	I	S	I	S	I
Arginine	0.37	0.37	0.35	0.29	0.40	0.35	0.41	0.31	0.42	0.30	0.37	0.29
Valine	0.24	0.40	0.22	0.30	0.24	0.29	0.36	0.51	0.26	0.33	0.24	0.33
Histidine	0.25	0.20	0.18	0.21	0.21	0.28	0.43	0.61	0.19	0.29	0.25	0.29
Lysine	0.63	0.86	0.53	0.67	0.67	0.79	0.26	0.31	0.65	0.61	0.63	0.56
Leucine + isoleucine	0.33	0.50	0.30	0.47	0.33	0.66	0.39	0.65	0.38	0.57	0.33	0.53
Methionine	0.31	0.61	0.34	0.34	0.37	0.47	0.43	0.49	0.36	0.37	0.31	0.33
Threonine	0.47	0.61	0.44	0.46	0.49	0.78	0.73	1.17	0.57	0.55	0.47	0.53
Tryptophan	0.09	0.33	0.08	0.32	0.10	0.40	0.23	0.83	0.10	0.37	0.09	0.36
Phenylalanine	0.68	0.83	0.58	0.73	0.67	1.10	0.30	0.49	0.68	1.08	0.68	1.08
Total	0.34	0.47	0.30	0.39	0.35	0.52	0.41	0.31	0.37	0.46	0.34	0.44

* S, feed from soft wheat; I, feed from round wheat.

Table 3. The results of chemical analysis of feed from ears of wheat of different species harvested at different phases of ripening

Grain phase of ripening	Lipids, %		Ash, %		Fiber, %		β–carotene, mg/kg	
	soft	Indian dwarf	soft	Indian dwarf	soft	Indian dwarf	soft	Indian dwarf
Milk	2.09	2.15	3.96	6.29	13.01	23.53	0.60	0.59
Doughy	2.29	2.81	4.02	6.40	13.31	20.50	0.62	0.62
Early wax	2.51	2.11	4.03	6.40	13.52	17.35	0.63	0.64
Mid-wax	2.23	2.17	4.25	6.06	11.88	18.65	0.78	0.81
Late wax	2.03	1.93	4.08	5.84	11.54	20.05	0.98	1.02
Full	2.02	1.89	4.07	5.81	11.50	20.78	0.61	0.65
LSD_{05} by factor A	0.02		2.07		7.68		0.02	
LSD_{05} by factor B	0.06		1.74		3.83		0.01	

i.e., the balance compared to the "ideal" feed expressed by the amino acid score. The amino acid score was calculated for feed from ears of all phases of ripeness (Table 2).

Feed from ears of Indian dwarf wheat has a more balanced amino acid composition with better score values for all amino acids, except for arginine, than soft wheat. The feed from ears of Indian dwarf wheat harvested in the phase of mid-wax ripeness has the best amino acid score. However, its values were insufficient for the majority of essential amino acids, with the exception of a satisfactory score for threonine and tryptophan. Arginine and lysine are the limiting essential amino acids for feed from ears of Indian dwarf wheat.

The results of chemical analysis of the feed from ears for other nutrients (Table 3) indicate that the product from Indian dwarf wheat has a significantly higher fiber content (by 4–10%) than the feed from soft wheat. Moreover, unlike the latter, it is minimal (17.35–18.65%) when harvesting ears in the early and mid-wax ripeness phases, after which it gradually increases by 3.43% to 20.78% in the full ripeness phase. Since fiber is poorly digested by fish, this is a negative factor that can be minimized by harvesting ears of Indian dwarf wheat in the early and mid-wax ripeness phases.

No significant differences were found in the lipid content of the feed from the ears of the studied crops. The content of mineral substances (ash) in the product from the ears of Indian dwarf wheat was higher than in the feed from soft wheat in all phases of ripening by 0.29–0.59%.

The content of β-carotene in the feed from the ears of all the studied crops increased from the beginning of grain formation, reaching a maximum of 0.98–1.02 mg/kg by the end of wax ripeness, after which it decreased upon reaching full ripeness to 0.61–0.65%. No significant differences were observed between these indicators depending on the species of wheat in all phases of ripeness.

CONCLUSIONS

The feed for carp from the ears of Indian dwarf wheat is not inferior to traditional feed from soft wheat in terms of protein, essential amino acids, lipids, ash, fiber, and β-carotene. At the same time, the content of lipids and β-carotene in feed from ears of soft and

Indian dwarf wheat harvested at all phases of ripeness does not differ significantly.

Rational time frames for harvesting ears of Indian dwarf wheat for feed purposes are the early and mid-wax ripeness, when the protein content in the feed made from them is satisfactory, the content of essential amino acids is maximal, and the fiber content is the lowest. Feed prepared from ears of Indian dwarf wheat harvested at rational time frames has a better amino acid profile and a 1.06–2.23% higher content of essential amino acids than feed from soft wheat, and therefore a better nutritional value. This allows the use of raw materials of an unconventional crop in the preparation of feed to improve the quality of protein. A fiber content of 4–10% higher than in the product from soft wheat is a disadvantage of feed from ears of Indian dwarf wheat.

The grain heap (ears) of Indian dwarf wheat harvested with tow without threshing at the early and mid-wax ripeness, can become a source of raw material that increases the nutritional value of feed, since it contains more essential amino acids than products from ears of soft wheat.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This work does not contain any studies involving human and animal subjects.

CONFLICT OF INTEREST

The author of this work declares that he has no conflicts of interest.

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