UDC 635.658:631.527:581.16

NUTRITIONAL PROPERTIES OF SEEDS OF RELATED SPECIES OF THE GENUS *PHASEOLUS* L.

https://doi.org/ 10.15673/fst.v18i3.3020

O. Bezuhla[1], Candidate of Agricultural Sciences, Senior Researcher
L. Kobyzeva[2], Doctor of Agricultural Sciences, NAAS Corresponding Member
S. Sylenko [5], Candidate of Agricultural Sciences, Senior Researcher
V. Pozdniakov[3], Candidate of Biological Sciences
T. Sheliakina [4]**,** Researcher
[1] Laboratory of Genetic Resources of Cereals, Grain Legumes and Groats Crops
[2] Department of Theoretical Studies in Plant Production and Genetic Resources
[3] Laboratory of Plant Physiology and Biochemistry
[4] Laboratory of Immunity, Biotechnology and Quality
Yuriev Plant Production Institute of NAAS
142, Heroiv Kharkova Avenue, Kharkiv, 61060, Ukraine
[5] Ustymivka Experimental Station of Plant Production of the Yuriev Plant Production Institute of NAAS, 15, Akademika Vavilova Str., Ustymivka Village, Kremenchutskyi District, Poltavska Oblast, 39074

Correspondence:

O. Bezuhla
E-mail: olgabezuglaya61@gmail.com

Cite as Vancouver style citation

Bezuhla O, Kobyzeva L, Sylenko S, Pozdniakov V, Sheliakina T. Nutritional properties of seeds of related species of the genus *Phaseolus* L. Food science and technology. 2024;18(3):14-22. https://doi.org/10.15673/fst.v18i3.3020

Цитування згідно ДСТУ 8302:2015

Nutritional properties of seeds of related species of the genus *Phaseolus* L / Bezuhla O. et al // Food science and technology. 2024. Vol. 18, Issue 3. P. 14-22. https://doi.org/ 10.15673/fst.v18i3.3020

Abstract. The nutritional properties of three related bean species – *Phaseolus multiflorus* Lam., *P. acutifolius* A. Gray, and *P. lunatus* L. – from the core collection of beans of the National Centre for Plant Genetic Resources of Ukraine were studied. The related species under investigation were ranked in descending order according to their nutritional value as follows: *P. multiflorus* Lam., *P. lunatus* L., *P. acutifolius* A. Gray. *P. multiflorus* Lam. accessions had the highest content of proteins (the mean protein content in dry matter was 25.10%) and the highest antioxidant activity (6.09–6.16 mg chlorogenic acid equivalent (CAE) /g of seeds). The *P. lunatus* L. accessions were significantly inferior to the scarlet bean accessions in terms of protein content in seeds (the mean protein content was 19.39 %), while the antioxidant activity in *P. lunatus* L. was similar to that in the scarlet beans with the same color of the seed coat (1.05–2.34 mg CAE/g of seeds). The *P. acutifolius* A. Gray accessions had the lowest protein content (the mean protein content was 17.43%). The antioxidant activity in this species was 1.27–1.62 mg CAE/g of seeds. Analysis of cooking time of seeds of the related bean species showed that they were ranked in ascending order according to their cooking time as follows: *P. acutifolius* A. Gray, *P. lunatus* L., *P. multiflorus* Lam. It was found that the cooking time of mature seeds was negatively correlated with their nutritional properties in the studied related bean species. Analysis of path coefficients showed that seed coat thickness had a direct positive effect on antioxidant activity, while protein content in dry seeds had a direct negative effect on antioxidant activity. Protein content in seeds had a direct positive effect on cooking time of seeds.

Key words: *Phaseolus multiflorus* Lam., *P. acutifolius* A. Gray, *P. lunatus* L., nutrition, cooking time, protein content, antioxidant activity

Introduction. Formulation of the problem

Beans are a food crop. They have been used for human nutrition since ancient times. Seeds of this crop are found in pharaohs' tombs, they were grown in ancient Russia, Greece, Italy, and in Asian and American ancient countries – wherever there was a developed civilization. At present, the nutritional properties of common beans are well studied; however, related bean species (scarlet bean, lima bean, tepary bean) are not inferior in nutritional and gustatory properties to the more common species *Phaseolus vulgaris* L.

Analysis of recent research and publications

The protein content in bean seeds can amount to 30%, which is twice as much as in meat and 60–75% of bean proteins are digested in the human body [1]. At the same time, beans contain no cholesterol and low in fat. High contents of phenols, starch, vitamins (A, C, E, B1, B2, B3, B6, PP), mineral salts, micronutrients (K, Mg, Ca, Na, Fe, I) and fructooligosaccharides determine a high nutritional value of beans, which is reflected through protection of the human body against stresses [2-4]. The energy value of beans is about 339 kcal; the digestibility is 86% [5].

Among legumes, beans stand out due to the amino acid composition of their proteins, which consist mainly of globulins and albumins. According to Marquez U.M. and Lajolo F.M. [6], in *Phaseolus* L. globulins account for 52.3% of the total nitrogen, while albumins, prolamins, and glutenins account for only 31.5%. As to amino acid composition, low levels of sulfur-containing amino acids and tryptophan limit bean protein quality, but bean proteins contain a lot of essential amino acids (lysine, isoleucine, valine) and nonessential amino acids (glycine and glutamic acid). The total content of free amino acids in bean seeds varies from 0.15 g to 0.36 g [5].

Bean seeds contain a lot of carbohydrates (the amount of carbohydrates in 100 g is 17.1% of the daily intake). The major carbohydrates are fiber (the mean fiber content in 100 g is 22.6 g or 90.2% of the daily intake) and starch (the mean starch content in 100 g is 43.8 g); the contents of sucrose (1.44 g in 100 g), galactose (0.34 g), and pectin (9% of the daily intake in 100 g) are also rather high. Bean seeds are noticeable for high levels of phytosterols (230.9% of the daily intake in 100 g), with beta-sitosterol being the major phytosterol (179.8%) [5]. Guzmán-Uriarte M. L., Sánchez-Magaña L. M., Angulo-Meza G. Y. et al. [7] recommended using bean flour in food production technologies to increase the energy value of products, prevent stress-induced diseases in humans. Gómez-Favela M. A., Reyes-Moreno C., Milán-Carrillo J. Et al. [8] offered corn and tepary mixtures with a lower nutritional load and higher energy content as an alternative to commercial snacks.

Antioxidants consumed with vegetable food help a person gain control over his/her body and resist the aggressive influence of not only psychological factors but also the environment [9, 10]. Mature seeds of legumes, among which beans established themselves as a leading choice, are a potent source of antioxidants [11,12].

Broeck H.C., Londono D.M., Timmer R. et al. [13] believed that the conditions of plant vegetation were the main factor affecting antioxidant activity. Li X.P., Li M.Y., Ling A.J. et al. [14] considered the genotype as a basis, without ruling out effects of growing conditions. Thus, antioxidant levels are an important aspect in breeding to develop healthy foods.

Cooking time of seeds is a significant factor that determines consumers' demand for a particular genotype [15]. This parameter is sure to be influenced by weather during the crop cultivation and reproduction year. Nevertheless, *Phaseolus* L. species are phylogenetically younger and belong to the macrobiotic group, which is characterized by the ability to preserve properties of their seeds for a long period of time [16]. This is due to the facts that the contents of albumins, globulins, and glutelins in bean seeds hardly change during storage for up to 16 years and enzymatic activity in seeds remains high.

It was found that substances in bean seeds varied in different cultivars [17], therefore we assumed that the nutritional properties of related species of the genus *Phaseolus* L. would also differ.

Thus, we set **the purpose** to evaluate the nutritional properties of related bean species and to determine their features depending on the species and morphological characteristics of seeds. The following study **objectives** were pursued:

– to determine the protein content, antioxidant activity, cooking time, and palatability of mature seeds of scarlet bean, lima bean, and tepary bean;
– to calculate correlations between nutritional indicators of seeds;
– to calculate correlations between nutritional indicators and morphological characteristics of seeds.

Research materials and methods

The National Center for Genetic Resources of Ukraine keeps a collection of related bean species: *Phaseolus multiflorus* Lam. (scarlet bean; 202 accessions), *P. acutifolius* A. Gray (tepary bean; 53 accessions, and *P. lunatus* L. (lima bean; 16 accessions). For this study, a sample of accessions that differed in morphological characteristics (seed coat color, plant shape) and origins (5 scarlet bean accessions from Ukraine, Poland, and Germany; 4 lima bean acessions from the USA, Hungary, and Russia; 6 tepary bean accessions from Ukraine, USA, and Mexico) was formed.

The collection accessions were studied in the field: in special crop rotation No. 1 of the experimental field of the Yuriev Plant Production Institute of NAAS (Elitne Village, Kharkivskyi District, Kharkivska Oblast; location 49°59′02 N, 36°27′51 E, 195 m above sea level). The plants were grown on potent weakly leached black soil. The forecrop was winter wheat. The farming techniques were traditional for the forest-steppe of Ukraine. Beans were sown with manual planters without replications within optimal timeframes. The sowing arrangement was as follows: tepary bean – 30 cm / 10 cm; lima bean – 30 cm / 20 cm; scarlet bean – 30 cm / 30 cm; the record area was 1 m^2.

The study was carried out in 2016–2023; these years differed in temperature and precipitation: dry – 2017 (HTC = 0.23), 2018 (0.35), 2019 (0.44), and 2021 (0.80); water-logged – 2016 (1.33), 2020 (1.18), and 2023 (1.18) (Fig. 1).

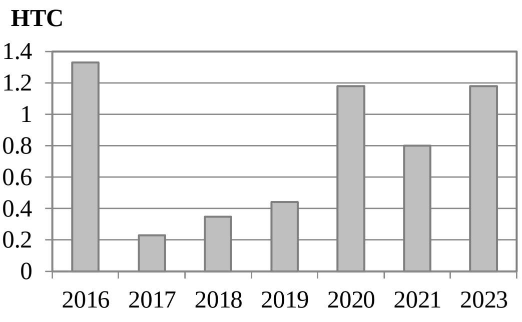

Fig. 1. Hydrothermal coefficient during the bean growing period, 2016–2023

The weather was almost optimal for the growth and development of beans in three years: 2020, 2021, and 2023, which were characterized by torrential precipitation. In 2020 and 2023, th precipitation fell during the crucial phases of bean plant development: generative organ formation and seed setting and filling; in 2021 – the temperature rose and the precipitation stopped.

To analyze the weather conditions, we calculated the hydrothermal coefficient using the following formula:

$$\mathrm{HTC} = \frac{\sum \mathrm{r}}{0{,}1\ \times \sum \mathrm{t°C}}$$

where: $\sum$ r – precipitation amount during the vegetation period, mm;

$\sum$ t°C − sum of temperatures above 10°C during the same period;

0.1 – coefficient.

The biochemical analyzes were carried out in the Laboratory of Immunity, Biotechnology and Quality of the Yuriev Plant Production Institute of NAAS. The protein content in bean seeds was determined by Kjeldahl digestion [18, 19]. The antioxidant activity was determined using a stable radical (DPPH•) by S. Arabshahi and A. Urooj's method [20] with some modifications [21, 22, 23] along 4 parallels. The results of this analysis are expressed as the standard antioxidant (chlorogenic acid) equivalent (CAE) in mg of CAE per 1 g of seeds, with adjustment for dilution using a calibration graph.

The cooking time of bean seeds was determined in compliance with methods of the qualification examination of plant varieties for suitability for dissemination in Ukraine [24]. The palatability was determined organoleptically. The seed coat thickness was measured with a micrometer. The economic and morphological characteristics of beans were described in accordance with the Extended Harmonized Classifier of Ukraine for the genus *Phaseolus* L. (2004) and using the technique for studying genetic resources of legumes [25]. Path analysis for estimating the direct and indirect effects of other traits on cooking time was performed using the formula given by Dewey and Lu [26]. Data were statistically processed in MS Excel.

Results of the research and their discussion

The nutritional properties of beans are determined not only by their excellent gustatory qualities but also by their high nutritional value, which is attributed to the presence of alkali-soluble globulins and water-soluble albumins [27], which is an indication of digestibility [1], and antioxidants (ascorbic acid, tocopherol, β-carotene, polyphenols, tannins, anthocyanins) [28], which have a positive effect on human health [29]. We compared the nutritional value of accessions of the related species (*Phaseolus multiflorus* Lam., *P. acutifolius* A. Gray, and *P. lunatus* L.) using the following parameters: antioxidant activity (AOA), protein content, cooking time and palatability of seeds in combination with additional morphological characteristics such as seed size, color and thickness of the seed coat.

Antioxidant levels have been often assessed in vegetables, fruits, and beverages [30, 31]; however, this parameters is not enough studied dry grain of agricultural crops, especially in seeds of related bean species. Our analysis of AOA showed that scarlet bean seeds with pigmented seed coats had the highest AOA, even within one accession. For example, local Ukrainian accession 'UD0300900' has both white and pigmented seed coats in different colors. It was found that the AOA in seeds with white seed coats was 1.18 mg of CAE/g of seeds (17.62% AOA); in seeds with purple coats with a dotted black pattern, it was 6.09 mg of CAE/g of seeds (91.10% AOA); in seeds with isabelline coats, it was 6.10 mg of CAE/g of seeds (91.25% AOA); in seeds with brown coats, it was 6.16 mg of CAE/g of seeds (92.03% AOA) (Table 1).

The AOA in white seeds of accessions 'Eryka', 'Blanka', and 'Obroshynska Mistseva' ranged within 0.95–1.11 mg of CAE/g of seed, which corresponded to 14.30%–16.69% AOA. Accession 'Preisgewinner' has black seeds with an AOA of 1.15 mg of CAE/g of seeds (91.96% AOA).

We observed a similar trend in lima beans. The pigmentation of their seed coats was not as diverse as that in scarlet beans, but the AOA varied depending on color. Cultivar (Cv.) 'Henderson' with white seeds had an AOA of 1.05 mg of CAE/g of seeds (15.75% AOA); Cv. 'Tree Color Pole' with white seeds and a large fuzzy wine-red spot had an AOA of 1.67 mg of CAE/g of seeds (23.96% AOA); Cv. 'Geszentye Bab' with white seeds with a motley wine-red pattern had an AOA of 2.27 mg of CAE/g of seeds (33.09% AOA); and Cv. 'Pyostropalevaya' with gray seeds with a motley pattern had an AOA of 2.34 mg of CAE/g of seeds (33.0% AOA). There was a noticeable rise in the AOA with an increase in the wine-red color area on the seed coat. Gray seeds had the highest AOA in lima beans.

When screening tepary beans for AOA, we also noted a relationship between AOA and the seed coat pigmentation. Accessions with white seeds ('PI 477038' and 'PI 440795') had an AOA of 1.28 and 1.27 mg of CAE/g of seeds (19.16% and 19.01% AOA, respectively); accessions with brown seeds ('A. gr' and 'PI 477032)' had an AOA of 1.32 and 1.34 mg of CAE/g of seeds (19.16% and 19.01% AOA, respectively); accessions with ocherous seeds ('PI 321637'and 'PI 406633') had an AOA of 1.60 and 1.62 mg of CAE/g of seeds (23.93% and 24.22% AOA, respectively). It should be noted that the AOA in tepary bean seeds was slightly different compared to scarlet bean and lima bean seeds. Thus, scarlet bean and lima bean accessions with white plain seeds had an AOA of 0.95–1.11 mg of CAE/g of seeds, while tepary bean accessions with white seeds had an AOA of 1.27–1.28 mg of CAE/g of seeds. The scarlet bean accession with brown seeds had an AOA of 6.16 mg of CAE/g of seeds, while in the tepary bean accessions with brown seeds the AOA ranged within 1.32–1.34 mg of CAE/g of seeds. That is, the differences in the AOA levels between the variants of the seed coat pigmentation were smaller in tepary beans.

Hence, seeds with brown or black coats of scarlet bean showed the highest AOA. These results confirm the previous information on AOA changes depending on pigments in the seed coat [29,30]. This conclusion was drawn in our studies of AOA in common bean [32] and other authors' studies [29,33] of AOA in lima bean [27,34], chickpea [35], lentil, dolichos bean [36], and barley [37,38].

In solving the problem of vegetable protein in the human diet, a vital role is assigned to legumes, especially to beans, as a food crop with excellent gustatory properties. The nutritional value of beans is attributed to high content of protein in seeds and bean proteins are noticeable for containing essential alkaline and water-soluble amino acids [27,39]. We analyzed the protein content in seeds of the related bean species and found that scarlet bean seeds had the highest protein content in 2016–2023 (the mean protein content was 25.1% of dry matter, ranging 22.05% to 29.30% of dry matter). The lima bean accessions had 19.39% of protein in dry matter (range 15.37–23.87% of dry matter) and the tepary bean accessions had 17.47% of protein in dry matter (range 13.15-23.15% of dry matter). Within one species, the accessions did not differ significantly from one another, except for tepary beans, since the tepary bean accessions with white seeds ('PI 477038' and 'PI 440795') had higher protein content (19.07% and 18.13% of dry matter, respectively) than the accessions with brown or ocherous seed coats (Table 2).

However, López-Ibarra S., Ruiz-López F. de J., Bautista-Villarreal M. et al. [40] claimed that the nutrition value of tepary beans was similar to that of common beans and the technological properties of tepary bean flour were superior to those of flour from other legumes.

In a study by Heredia-Rodríguez L., Gaytán-Martínez M., Morales-Sánchez E. et al. [41], significant differences in their technological properties between bean species, especially for tepary beans, were demonstrated. Based on our assessment of palatability, the related species were ranked as follows: the *Phaseolus multiflorus* Lam. and *Phaseolus lunatus* L. accessions had very high scores (9 points), while the *Phaseolus acutifolius* A. Gray accessions had mostly medium scores (5 points). Nevertheless, taking into account the high nutritional value of bean species, including tepary beans, several authors recommended using them in new food recipe with improved benefits for human health [8,42].

Table 1 – Antioxidant activity in seeds of the related bean species, 2016–2023

ID in the National Catalog of Ukraine	Name	Country of origin	Color of the seed coat	Antioxidant activity	
				Mg of chlorogenic acid equivalent/ g of seeds	AOA, %
Phaseolus multiflorus Lam.					
UD0300900	-	Ukraine	White	1.18	17.62
			Purple with a dotted black pattern	6.09	91.10
			Isabelline	6.10	91.25
			Brown	6.16	92.03
UD0304009	Eryka	Poland	White	0.95	14.30
UD0303446	Blanka	Poland	White	1.11	16.69
UD0303904	Obroshynska Mistseva	Ukraine	White	1.01	15.15
UD0300440	Preisgewinner	Germany	Black	6.15	91.96
			Mean	3.46	53.76
Phaseolus lunatus L.					
UD0303246	Geszentye Bab	Hungary	White with a wine-red motley pattern	2.27	33.09
UD0303348	Henderson	USA	White	1.05	15.75
UD0303247	Tree Color Pole	USA	White with a large wine-red spot and a motley pattern	1.67	23.96
UD0302220	Pyostropalevaya	Russian Federation	Gray with a motley pattern	2.34	34.11
			Mean	1.82	26.73
Phaseolus acutifolius A. Grey					
UD0303771	A.gr	Ukraine	Brown	1.32	19.77
UD0300133	PI 477032	USA	Brown	1.34	19.96
UD0300126	PI 477038	USA	White	1.28	19.16
UD0300204	PI 440795	Mexico	White	1.27	19.01
UD0300128	PI 321637	Mexico	Ocherous	1.60	23.93
UD0300129	PI 406633	Mexico	Ocherous	1.62	24.22
			Mean	1.40	21.01
			LSD_{005}	0.059	0.853

Table 2 – Protein content in seeds and palatability of the related bean species, 2016–2023

ID in the National Catalog of Ukraine	Name	Country of origin	Palatability score*	Protein content in seeds, % of dry matter	
				$\bar{x}$	*lim*
Phaseolus multiflorus Lam.					
UD0300900	-	Ukraine	9	24.47	22.34–25.56
UD0304009	Eryka	Poland	9	25.62	23.87–28.50
UD0303446	Blanka	Poland	9	25.68	24.02–28.85
UD0303904	Obroshynska Mistseva	Ukraine	9	25.71	24.37–29.30
UD0300440	Preisgewinner	Germany	9	24.03	22.05–26.58
		Mean	9	25.10	
Phaseolus lunatus L.					
UD0303246	Geszentye Bab	Hungary	9	18.88	15.37–21.53
UD0303348	Henderson	USA	9	19.31	17.68–23.20
UD0303247	Tree Color Pole	USA	9	19.68	17.37–23.87
UD0302220	Pyostropalevaya	Russian Federation	9	19.68	17.38–22.94
		Mean	9	19.39	
Phaseolus acutifolius A. Grey					
UD0303771	A.gr	Ukraine	7	17.43	15.35–19.15
UD0300133	PI 477032	USA	5	17.03	15.69–18.98
UD0300126	PI 477038	USA	7	19.07	15.98–23.15
UD0300204	PI 440795	Mexico	5	18.13	16.35–20.56
UD0300128	PI 321637	Mexico	5	16.55	13.15–19.37
UD0300129	PI 406633	Mexico	5	16.56	14.45–18.87
		Mean	5	17.43	
* 9 points – excellent, 7 points – good, 5 points – satisfactory					

The technological properties of the crop cannot be investigated without analyzing the time of its seeds. This parameter is an important characteristic for determining food quality because it is associated with levels of compounds with anti-nutritive properties. In addition, long cooking time destroys important nutrients in seeds. Thus, beans with a shorter cooking time retain more minerals and proteins for human nutrition [43].

We ranked the related bean species by cooking time of dry seeds follows: the lima beans, with a 0.149 mm thick seed coat and thousand seeds weight of 627 g, took the shortest time to be cooked (the mean cooking time was 129 minutes); the tepary beans, with a 0.073 mm thick seed coat and thousand seed weight of 136 g, were cooked on average for 145 minutes; the scarlet beans, with a 0.220 mm thick seed coat and thousand seed weight of 1,689 g, took the longest to be cooked (the mean cooking time was 214 minutes) (Table 3).

The cooking time of seeds varied between accessions within one species, depending on seed coat thickness, which in turn depends on seed coat color. For example, in the *Phaseolus multiflorus* Lam. accessions with white seeds (‘Blanka’, ‘Eryka’, and ‘Obroshynska Mistseva’), the seed coat thickness was 0.196 mm, 0.197 mm, 0.211 mm, respectively, and, accordingly, the cooking time of seeds was 206 minutes, 212 minutes, and 211 minutes, respectively. The accessions with pigmented seeds (‘Preisgewinner’ and ‘UD0300900’) had thicker seed coats (0.241 mm and 0.255 mm, respectively) and their seeds took a longer time to be cooked (221 and 220 minutes, respectively). In *Phaseolus lunatus* L., the accession with white plain seeds (‘Henderson’) had a seed coat of 0.093 mm thick and its seeds took 125 minutes to be cooked. The accessions with patterned seeds had thicker seed coats: ‘Geszentye Bab’ – 0.179 mm, ‘Pyostropalevaya’ – 0.181 mm, ‘Tree Color Pole’ – 0.182 mm, but the cooking time of their seeds was not much longer (134 minutes, 128 minutes, and 129 minutes, respectively). In *Phaseolus acutifolius* A. Gray, the accessions with white seeds (‘PI 477038’ and ‘PI 440795’) had thinner seed coats (0.058 mm and 0.060 mm, respectively) and the cooking time of their seeds was 145 and 141 minutes, respectively. However, there were some deviations from this trend in the accessions with pigmented seeds. The accessions with ocherous seed coats (‘PI 321637’ and ‘PI 406633’) had seed coats of 0.075 mm and 0.076 mm thick and their seeds took a longer time to be cooked (154 and 161 minutes, respectively) than the accessions with brown seed coats (‘A. gr’ and ‘PI 477032)’, which had seed coats of 0.082 mm and 0.088 mm thick, respectively, and the cooking time of seeds of these accessions was 147 and 148 minutes, respectively.

Seed size did not affect cooking time. Thus, small tepary beans (the mean thousand seed weight was 136 g) were cooked longer (the mean cooking time was 145 minutes) than large lima beans (the mean thousand seed weight was 627 g; boiling time, the mean cooking time was 129 minutes). Scarlet bean has very large seeds (the mean thousand seed weight was 1,689 g) and its seeds were coked longer than seeds of the other related species (the mean cooking time was 214 minutes), but the seed coat in scarlet beans was significantly thicker than in the other species (0.220 mm).

Table 3 – Cooking time of seeds, seed coat thickness, and thousand seed weight in the related bean species, 2016–2023

ID in the National Catalog of Ukraine	Name	Country of origin	Thousand seed weight, g	Seed coat thickness, mm	Cooking of seeds	
					Coefficient	Time, min
Phaseolus multiflorus Lam.						
UD0300900	-	Ukraine	1626	0.255	1.52	220
UD0304009	Eryka	Poland	840	0.197	1.36	212
UD0303446	Blanka	Poland	839	0.196	1.64	206
UD0303904	Obroshynska Mistseva	Ukraine	2370	0.211	1.60	211
UD0300440	Preisgewinner	Germany	1000	0.241	1.51	221
		Mean	1689	0.220	1.57	214
Phaseolus lunatus L.						
UD0303246	Geszentye Bab	Hungary	1011	0.179	2.22	134
UD0303348	Henderson	USA	404	0.093	2.29	125
UD0303247	Tree Color Pole	USA	550	0.182	2.26	129
UD0302220	Pyostropalevaya	Russian Federation	542	0.181	2.27	128
		Mean	627	0.149	2.26	129
Phaseolus acutifolius A. Grey						
UD0303771	A.gr	Ukraine	141	0.082	2.11	147
UD0300133	PI 477032	USA	145	0.088	2.10	148
UD0300126	PI 477038	USA	110	0.058	2.14	135
UD0300204	PI 440795	Mexico	130	0.060	2.16	141
UD0300128	PI 321637	Mexico	140	0.075	2.06	154
UD0300129	PI 406633	Mexico	152	0.076	2.00	161
		Mean	136	0.073	2.10	145

Correlation analysis showed that all parameters of the nutritional properties of seeds of the related bean species were positively correlated. The following pairs of parameters showed had the highest correlation coefficients: protein content in seeds – seed coat thickness (0.87); protein content in seeds – cooking time (0.87); seed size – seed coat thickness (0.86); seed size – protein content in seeds (0.83); cooking time – seed coat thickness (0.80) (Table 4).

Path analysis allowed us to evaluate the relationships between the parameters of the bean nutritional properties. Based on its results, we could determine the biological value of a specific characteristic of beans for the intended purpose [44,45]. Thus, in the related bean species, the seed coat thickness exerted a direct, high, positive effect on the AOA (1.45) through indirect, positive effects of the protein content (1.26), thousand seed weight (1.25), and cooking time of seeds (1.16). In addition, the protein content in dry seeds exerted a direct, negative effect on the AOA (-0.73) through the seed coat thickness (-0.63), cooking time (-0.63), thousand seed weight (0.60) (Table 5).

Of the technological properties of beans, the cooking time of dry seeds is the most important one [16]. Path analysis of the relationships between the nutritional properties showed the only direct, positive relationship: effect of the cooking time of dry seeds on the protein content (0.66) through indirect, positive effects of the seed coat thickness (0.58) and thousand seed weight (0.55) (Table 6).

This interaction is explained by protein denaturation, leading to molecule aggregation and having a great impact on the stability of food properties [46].

Table 4 – Correlations between the nutritional value parameters in the related bean species

Parameter	Seed coat thickness	Seed size	AOA	Cooking time	Protein content
Seed coat thickness	-	0.86*	0.68*	0.80*	0.87*
Seed size	0.86*	-	0.47	0.77*	0.83*
AOA	0.68*	0.47	-	0.56*	0.41
Cooking time	0.80*	0.77*	0.56*	-	0.87*
Protein content	0.87*	0.83*	0.41	0.87*	-
n=15, *p<0.05					

Table 5 – Path coefficients of the relationships between the AOA and the seed quality parameters in the related bean species

Parameter	SCT	TSW	CT	PC
SCT	1.45	-0.07	0.10	-0.63
TSW	1.25	-0.08	0.10	-0.60
CT	1.16	-0.06	0.13	-0.63
PC	1.26	-0.07	0.11	-0.73
SCT – seed coat thickness, TSW – thousand seed weight, CT – cooking time of seeds, PC – protein content in dry seeds				

Table 6 – Path coefficients of the relationships between the cooking time and the seed quality parameters in the related bean species

Parameter	SCT	TSW	AOA	PC
SCT	0.14	-0.18	0.24	0.58
TSW	0.12	-0.19	0.28	0.55
AOA	0.09	0.02	0.13	0.28
PC	0.12	-0.16	0.23	0.66
SCT – seed coat thickness, TSW – thousand seed weight, AOA – antioxidant activity in seeds, PC – protein content in dry seeds				

Conclusion

Analysis of the nutritional properties of the related bean species showed that they were ranked in descending order according to their nutritional value as follows: scarlet beans, lima beans, tepary beans. The scarlet bean accessions had the highest protein content (the mean protein content was 25.10% of dry matter) and pigmented seeds showed the highest AOA (6.09–6.16 mg CAE/g of seeds). The lima bean accessions were significantly inferior to the scarlet bean accessions in terms of protein content in seeds (the mean protein content was 19.39% of dry matter), while the lima bean AOA was similar to that in the scarlet beans with the same color of the seed coat (1.05–2.34 mg CAE/g of seeds). The gustatory properties of scarlet beans and lima beans were excellent (9 points). The protein content in tepary beans was lower than that in lima beans (the mean protein content in dry matter was 17.43%), although the accessions with white seed coats had a protein content similar to that in lima beans (19.07% and 18.13% of dry matter). The AOA in this species varied slightly (1.27–1.62 mg CAE/g of seeds). The palatability of tepary beans was mostly medium (5 points). The evaluation of the cooking time of seeds of the related bean species demonstrated that they were ranked in ascending order according to their cooking time as follows: tepary beans, lima beans, scarlet beans. Thus, the cooking time was negatively correlated with the nutritional properties of the related bean species. Path analysis revealed that the seed coat thickness had a direct positive effect on the AOA and the protein content in dry seeds had a direct negative effect on the AOA. The protein content in seeds exerted a direct positive effect on the cooking time of seeds.

References

1. The Labyrinth of Mandrake [electronic source]: http://mag.org.ua/rast/trava668.html
2. Câmara CRS, Urrea CA, Schlegel V, Pinto Beans (*Phaseolus vulgaris* L.) as a Functional Food: Implications on Human Health. Agriculture. 2013;3:90-111. https://doi.org/10.3390/agriculture3010090
3. Tsuda T, Osawa T, Nakayama S, Awakishi S, Ohshima K. Antioxidant activity of pea bean (*Phaseolus vulgaris* L.) extract. Journal of the American Oil Chemists' Society. 1993;70:910-913. https://doi.org//10.1007/bf02545353
4. Onyeneho SN, Hettiarachchy NS, Effect of navy bean hull extract on the oxidative stability of soy and sunflower oils. Journal of Agricultural and Food Chemistry. 2005;39(10):1701-1704 https://doi.org/10.1021/jf00010a600
5. Website of Prof. Konovalova OYu [electronic source]: http://www.pharmacognosy.com.ua/index.php/vashe-zdorovoye-pitanije/zlakovyje-i-bobovyje/fasol UM, Lajolo FM. Composition and digestibility of albumin, globulins, and glutelins from Phaseolus vulgaris Agric Food Chem. 1981 Sep-Oct;29(5):1068-74. https://doi.org/10.1021/jf00107a043
6. Guzmán-Uriarte ML, Sánchez-Magaña LM, Angulo-Meza GY, Cuevas-Rodríguez EO, Gutiérrez-Dorado R, Mora-Rochín S, Milán-Carrillo J, Valdez-Ortiz A, Reyes-Moreno C. Solid State Bioconversion for Producing Common Bean (*Phaseolus vulgaris* L.) Functional Flour with High Antioxidant Activity and Antihypertensive Potential. Food and Nutrition Sciences. 2013;4:480-490. https://doi.org/10.4236/fns.2013.44061
7. Gómez-Favela MA, Reyes-Moreno C, Milán-Carrillo J, Partida-Preciado RA, Espinoza-Moreno RJ, Preciado-Ortiz R, Gutiérrez-Dorado R. Botana saludable libre de gluten con alto valor nutricional y nutracéutico elaborada con una mezcla de granos extrudidos subutilizados (maíz de calidad proteínica/frijol tépari). Acta Universitaria. México. 2021;31.
8. Lin J-Y. Tang C-Y. Determination of total phenolic and flavonoid contents in selected fruits and vegetables, as well as their stimulatory effects on mouse splenocyte proliferation. Food Chemistry. 2007;101(1):140-147. https://doi.org/10.1016/j.foodchem.2006.01.014
9. Nijveldt RJ, van Nood E, van Hoorn DEC, Boelens PG, van Norren K, van Leeuwen PAM. Flavonoids: a review of probable mechanisms of action and potential applications. The American Journal of Clinical Nutrition. 2001;74 (4):418-425.h ttps://doi.org/10.1093/ajcn/74.4.418
10. Tsuda T, Osawa T, Nakayama S, Awakishi S, Ohshima K. Antioxidant activity of pea bean (*Phaseolus vulgaris* L.) extract. Journal of the American Oil Chemists' Society. 1993;70:910-913. https://doi.org/10.1007/bf02545353 ·
11. Onyeneho SN, Hettiarachchy NS, Effect of navy bean hull extract on the oxidative stability of soy and sunflower oils. Journal of Agricultural and Food Chemistry. 1991;39:1701-1704. https://doi.org/10.1021/jf00010a600
12. Broeck HC, Londono DM, Timmer R, Smulders MJM, Gilissen LJW, Meer IM. Profiling of nutritional and health-related compounds in oat varieties. Foods. 2016;5(2):2-11.https://doi.org/10.3390/foods5010002
13. Li XP, Li MY, Ling AJ, Hu XZ, Ma Z, Liu L, Li YX. Effects of genotype and environment on avenanthramides and antioxidant activity of oats grown in northwestern China. Journal Cereal Science. 2017; 73:130-137. https://doi.org/10.1016/j.jcs.2016.12.005
14. Dos Santos GG, Ribeiro ND, Masiero SM. Evaluation of common bean morphological traits identifies grain thickness directly correlated with cooking time. Scientific Articles. Pesquiisa Agropecuaria Tropical. 2016;46 (1):35-42. https://doi.org//10.1590/1983-40632016v4638191
15. Ewart A.J. 0n the Lovgevity of Seeds. Proceedings Rogal Sosietg Victoria. 1908;21(1):1-210.
16. https://ia601605.us.archive.org/27/items/proceedingsofroy21roya/proceedingsofroy21roya.pdf
17. Gouveia CSS, Freitas G, de Brito JH, Slaski JJ, de Carvalho MÂAP. Nutritional and Mineral Variability in 52 Accessions of Common Bean Varieties (Phaseolus vulgaris L.) from Madeira Island. Agricultural Sciences. 2014;5:317-329. https://doi.org/10.4236/as.2014.54034

18. S´aez-plaza P, Michałowski T, Navas MJ, Asuero AG, Wybraniec S. An overview of the Kjeldahl method of nitrogen determination. Part I. Early history, chemistry of the procedure, and titrimetric finish. Critical Reviews in Analytical Chemistry. 2013;43(4):178-223. https://doi.org/10.1080/10408347.2012.751786.
19. S´aez-plaza P, Navas MJ, Wybraniec S, Michałowski T, Asuero AG. An overview of the Kjeldahl method of nitrogen determination. Part II. Sample preparation, working scale, instrumental finish, and quality control. Critical Reviews in Analytical Chemistry. 2013;43(4):224-272. https://doi.org/10.1080/10408347.2012.751787
20. Arabshahi S, Urooj A. Antioxidant Properties of Various Solvent Extracts of Mulberry morusindica L. Leaves. Food Chemical. 2007;102:1233-1240. https://doi.org/10.1016/j.foodchem.2006.07.013
21. Bonoli M, Verardo V, Marconi E, Caboni MF. Antioxidant phenols in barley (*Hordeum vulgare* L.) flour: comparative spectrophotometric study among extraction methods of free and bound phenolic compounds/ Journal Aagricultural Food Chemical. 2004;52:5195-200. https://doi.org/10.1021/jf040075c
22. Zhou K, Yu L. Effects of extraction solvent on wheat bran antioxidant activity estimation. Lebensm.-Wiss. u.-Technol. 2004;37:717-721. https://doi.org/10.1016/j.lwt.2004.02.008
23. Pozdnyakov VV, Vasilenko AO. Use of test systems to assess the total antioxidant activity in seeds. Selektsiia i Nasinnytstvo. 2017;112:153-163. https://doi.org/10.30835/2413-7510.2017.120443
24. Methods of qualification examination of plant varieties for suitability for dissemination in Ukraine. Methods for determining plant product quality parameters. 2016:58-62. https://sops.gov.ua/uploads/page/5a5f41997447d.pdf [in Ukrainian]
25. Methodological guidelines for studying genetic resources of legumes. L.N. Kobyzeva, O.M. Bezuhla, S.I. Sylenko, et al. NAAS, Plant Production Institute named after V.Ya. Yuriev. Kharkiv: Stil-Izdat. 2016:84 [in Ukrainian]
26. Dewey D.R., Lu K.H. A correlation and pathcoefficient analysis of components of crested wheatgrass seed Production. Agron Journal. 1959;51(9),515-518. https://doi.org/10.2134/agronj1959.00021962005100090002x
27. Palupi HT, Estiasih T, Yunianta, Sutrisno A. Physicochemical and protein characterization of lima bean (Phaseolus lunatus L) seed. Food Research. 2022;6 (1):168-177. https://doi.org/10.26656/fr.2017.6(1).107
28. Chávez-Servia JL, Heredia-García E, Mayek-Pérez N, Aquino-Bolaños EN, Hernández-Delgado S, Carrillo-Rodríguez JC, Gill-Langarica HR, Vera-Guzmán AM. Diversity of Common Bean (*Phaseolus vulgaris* L.) Landraces and the Nutritional Value of their Grains. Grain legumes. 2016. https://doi.org/10.5772/63439
29. Nyau V, Prakash S, Rodrigues J, Farrant J. Screening Different Zambian Market Classes of Common Beans (*Phaseolus vulgaris)* for Antioxidant Properties and Total Phenolic Profiles. Journal of Food and Nutrition Research. 2016;4 (4):230-236. https://doi.org/10.12691/jfnr-4-4-6
30. Dykes L., Rooney LW. Phenolic Compounds in Cereal Grains and Their Health Benefits. Cereal Foods World. 2007;32(3):105-111. https://nulifemarket.com/wp-content/uploads/2016/02/CFWPhenolicCompoundsCerealGrainsTheirHealthBenefits.pdf
31. Mattila P, Pihlava JM, Hellstrom J. Contens of phenolic acids, alkyl and alkenylresorcinols, and avenanthramides in commercial grain products. Journal of Agricultural and Food Chemistry. 2005;5:8290. https://doi.org/10.1021/jf051437z
32. Bezugla O.N., Pozdniakov V.V., Kobyzeva L.N., Boguslavskiy R.L., Antsyferova O.V. «Antioxidant activity of *Phaseolus* L. species seeds with different coat color». Žemės ūkio mokslai. Agricultural Sciences. 2018;25(3):117-124. https://doi.org/10.6001/zemesukiomokslai.v25i3.3794
33. Oomah BD, Corbe´ AL, Balasubramanian P. Antioxidant and Antiinflammatory Activities of Bean *(Phaseolus vulgaris* L.) Hulls. Journal of Agricultural and Food Chemistry. 2010;58: 8225-8230. https://doi.org/10.1021/jf1011193
34. Funome H, Pangastuti A, Setyaningsih R. The effect of heat treatment on antioxidant activity of ethyl acetate extracts Arbila beans from Kapan, East Nusa Tenggara. IOP Conference Series: Materials Science and Engineering. 4th International Conference on Advanced Material for Better Future 2019 (ICAMBF 2019) Surakarta, Indonesia. 2019;858:012028. https://doi.org/10.1088/1757-899X/858/1/012028
35. Vus NO, Kobyzeva LN, Pozdniakov VV, Antsyferova OV. Antioxidant activity in chickpea accessions in the Eastern Forest-Steppe of Ukraine. International Scientific and Practical Conference "State-of-the-Art Technologies to Enhance the Genetic Potentials of Plants" Kharkiv, July 4–5, 2018:171-172. [in Ukrainian]
36. Silva-Cristobal L, Osorio-Díaz P, Tovar J, Bello-Pérez LA. Chemical composition, carbohydrate digestibility, and antioxidant capacity of cooked black bean, chickpea, and lentil Mexican varieties Composición química, digestibilidad de carbohidratos, y capacidad antioxidante de variedades mexicanas cocidas de frijol negro, garbanzo, y lenteja, CyTA. Journal of Food. 2010;8:1:7-14. https://doi.org/10.1080/19476330903119218
37. Lee C, Han D, Kim B, Baek N, Baik BK. Antioxidant and antihypertensive activity of anthocyanin-rich extracts from hulless pigmented barley cultivars. International Journal of Food Science @ Technology. 2013;48(5):984-991. https://doi.org/10.1111/ijfs.12050
38. Gong LX, Jin C, Wu LJ, Wu XQ, Zhang Y. Tibetan hull-less Barley (*Hordeum vulgare* L.) as a potential source of antioxidants. Cereal Chem. 2012;89(6):290-295 https://doi.org/10.1094/cchem-03-12-0029-r
39. Garcés-Rimón M; Morales D, Miguel-Castro M. Potential Role of Bioactive Proteins and Peptides Derived from Legumes towards Metabolic Syndrome. Nutrients. 2022;14:5271. https://doi.org/10.3390/nu1424527
40. Heredia-Rodríguez L, Gaytán-Martínez M, Morales-Sánchez E, Garza-Juárez AdeJ, Urias-Orona V, González-Martínez BE, López-Cabanillas Lomelí M, Vázquez-Rodríguez JA. Nutritional and technological properties of Tepary bean (*Phaseolus acutifolius*) cultivated in Mexican Northeast. Czech Journal of Food Sciences. 2019;37(1):62-68. https://doi.org/10.17221/331/2017-CJFS
41. López-Ibarra C, de Jesús Ruiz-López F, Bautista-Villarreal M, Báez-González JG, Romero BAR, González-Martínez BE, Lomelí ML-C, Vázquez-Rodríguez JA. Protein Concentrates on Tepary Bean (*Phaseolus acutifolius* Gray) as a Functional Ingredient: *In silico* Docking of Tepary Bean Lectin to Peroxisome Proliferator-Activated Receptor Gamma. Frontiens in Nutrion. 2021;8:661463. https://doi.org/10.3389/fnut.2021.661463
42. Osuna-Gallardo EI, Cuevas-Rodríguez EO, Sepúlveda-García CI, Reyes-Moreno C, León-López L, Han R, Hernández-Álvarez AJ. Impact of Cooking and Extrusion Processing on Nutritional, Antinutritional, and Techno-Functional Characteristics of Indigenous Bean (Phaseolus coccineus). Food Science Technology. 2023;3:1835-1853. https://doi.org/10.1021/acsfoodscitech.2c00416
43. Adriana C, Madoșă E, Sorina P, Giancarla V, Sărac I, Ciulca S. Genetic parameters, correlation and path coefficient analysis for cooking quality and its attributing traits in dry bean. Journal of Horticulture, Forestry and Biotechnology. 2022;26(2):93-97. www.journal-hfb.usab-tm.ro
44. Önder M, Kahraman A, Ceyhan E. Correlation and Path Analysis for Yield and Yield Components in Common Bean Genotypes (*Phaseolus vulgaris* L.). Ratarstvo i povrtarstvo. 2013;50(2):14-19. https://doi.org/10.5937/ratpov50-3958
45. Abd E, Jasim Al-h, Esho KB. Correlation and Path Coefficient Analysis in Some Varieties of Phaseolus (Phaseolus vulgaris L.). International Journal of Science and Research. 2020;9(8):948-952. https://doi.org/10.21275/SR20812140529
46. Prudencio S, Christ D, Sampaio SC, Coelho SRM. Storage-induced changes in protein interactions and protein solubility in common beans. Journal of Food Agriculture and Environment. 2011;10(2):44-48.

НУТРІТИВНІ ВЛАСТИВОСТІ НАСІННЯ СПОРІДНЕНИХ ВИДІВ *PHASEOLUS* L.

О. Безугла [1], кандидат с.-г. наук, старший науковий співробітник, *E-mail*: olgabezuglaya61@gmail.com
Л. Кобизєва [2], доктор с.-г. наук, член-кореспондент НААН, *E-mail*: l.n.kobyzeva@gmail.com
С. Силенко [5], кандидат с.-г. наук, старший науковий співробітник, *E-mail*: udsr@ukr.net
В. Поздняков [3], кандидат біол. наук, *E-mail*: vladimyr.pozdnyakov@gmail.com
Т. Шелякіна [4]**,** науковий співробітник, *E-mail*:masovianalizy@gmail.com
[1] Лабораторія генетичних ресурсів зернових, зернобобових і круп'яних культур
[2] Відділ теоретичних досліджень в рослинництві та генетичних ресурсів рослин
[3] Лабораторія фізіології та біохімії рослин
[4] Лабораторія імунітету, біотехнології і якості
Інститут рослинництва ім. В.Я. Юр'єва НААН, 142, проспект Героїв Харкова, м. Харків, Україна 61060
[5] Устимівська дослідна станція рослинництва Інституту рослинництва ім. В.Я. Юр'єва НААН
15, вул. Академіка Вавилова, с. Устимівка, Кременчуцький район, Полтавська область, 39074

Анотація. Досліджено нутрітивні властивості споріднених видів квасолі *Phaseolus multiflorus* Lam., *P. acutifolius* A. Grey та *P. lunatus* L. з базової колекції квасолі Національного центру генетичних ресурсів рослин України. Встановлено, що вивчені споріднені види розподілилися за зниженням їх рівня поживності: *P. multiflorus* Lam., *P. lunatus* L., *P. acutifolius* A. Grey. Зразки *P. multiflorus* Lam. мали найбільший вміст білка (в середньому 25,10% на суху речовину) та найбільшу антиоксидантну активність (6,09–6,16 еквівалент хлорогенової кислоти мг/г насіння). Зразки *P. lunatus* L. значно поступаються за вмістом білка в насінні (в середньому 19,39 %) квасолі багатоквітковій, а антиоксидантна активність подібна до багатоквіткової з однаковим забарвленням насіннєвої оболонки (1,05–2,34). За вмістом білка в насінні зразки *P. acutifolius* A. Grey мають найменший вміст (в середньому 17,43%). Антиоксидантна активність цього виду варіює на рівні 1,27–1,62 еквіваленту хлорогенової кислоти мг/г насіння. Аналіз розварювання насіння зразків споріднених видів квасолі показав, що вони розподілилися за зростанням часу розварювання: *P. acutifolius* A. Grey, *P. lunatus* L., *P. multiflorus* Lam. Установлено, що швидкість розварювання зрілого насіння має від'ємну кореляційну залежність від поживних властивостей споріднених видів квасолі. Аналіз коефіцієнтів шляху визначив, що на антиоксидантну активність мають прямий позитивний вплив товщина насіннєвої оболонки та прямий негативний вплив вміст білка в сухому насінні. На час розварювання насіння прямий позитивний вплив має вміст білка в ньому.

Ключові слова: *Phaseolus multiflorus* Lam., *P. acutifolius* A. Grey, *P. lunatus* L., поживність, розварюваність, вміст білка, антиоксидантна активність.