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SOYBEAN GERMPLASM EVALUATION FOR PROTEIN AND OIL CONTENT PLANTED AS A REPEAT CROP IN UZBEKISTAN

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SUMMARY

Soybean (*Glycine max* L.) is a globally recognized food crop for its high nutritional value, primarily due to its excellent protein and oil content. Its grains are also abundant in essential amino acids, polyunsaturated fatty acids, B vitamins, fiber, calcium, folic acid, and selenium. Additionally, soybean grains provide vital minerals such as magnesium, manganese, iron, and zinc. The unique biochemical composition of soybeans comprises proteins (49%) and fats (30%). The following research examined the seed oil and protein content of the exotic and local soybean cultivars cultivated as a recurrent crop in Uzbekistan. The study material included three each of the exotic Sparta and Selekta-201 (Russian selection), Nena (Kazakh selection), and local cultivars Ustoz-MMan-60, Toʻmaris-MMan-60, and Oyjamol, planted as repeated crops in 2020–2022 in the Samarkand and Navoi regions. In the environmental conditions of Uzbekistan, the highest seed oil and fat content were evident by sowing soybean as the main crop. However, as a repeated crop, the seed protein content was higher than the main crop.

Keywords: Soybean (*G. max* L.), exotic and local cultivars, repeated crop, grain yield, seed oil, proteins, carbohydrates

Key findings: The highest seed oil content resulted in the soybean (*G. max* L.) exotic cultivar Nena and local cultivar Oyjamol, planted as a repeated crop under the environmental conditions of Uzbekistan.

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INTRODUCTION

Leguminous crops are significantly important in the global agricultural economy, supplying essential raw materials to satisfy the world's growing demand for proteins, oils, carbohydrates, and vital micronutrients (Abzalov *et al*., 2018; Hakimov *et al*., 2023; Azimov *et al*., 2024). Soybean (*Glycine max* L.), a key member of the Fabaceae (Leguminosae) family, belongs to the Papilionoideae subfamily and the *Glycine* genus. This crop stands out for its protein content, which is nutritionally comparable to animal-derived proteins (Singh, 2010). Soybeans also offer an array of biologically active compounds, vitamins, and valuable trace elements, while being naturally free from lactose and cholesterol.

The main processed products of soybeans include oil and soy flour. Soybeans contain approximately 49% protein and about 26% high-quality oil, with soybean oil contributing around 40% to global vegetable oil production (Sattarov, 2019). A yield of 100 kg of soybean grains can provide roughly 140 feed units. Additionally, the grain, husks, and stems serve as economical, nutrient-rich feed for livestock—especially poultry—facilitating rapid weight gain. Moreover, soybeans enhance soil fertility through biological nitrogen fixation, adding approximately 60–100 kg of nitrogen per hectare after cultivation (Abzalov *et al*., 2006; Kholikova and Matniyazova, 2023).

Soybean is the world's most valuable oilseed crop, accounting for approximately 56% of global oilseed production. The leading producers are the United States (33%), Brazil (28%), and Argentina (21%), followed by China, India, and several other countries. Currently, soybean cultivation occurs on about 90.5 million hectares worldwide, with a total production volume of 220 million tons (Kholikova and Matniyazova, 2023). As an annual plant, primary soybean growing prevails in the Far East, Moldova, Georgia, and Ukraine, with its origin tracing back to East Asia. Numerous soybean cultivars succeeded in cultivation across China, India, Japan, Australia, North America, and the Far East (Board and Kahlon, 2010). In China, certain soybean species can grow as tall as 2.8 meters and flower throughout the year. The country has developed a substantial soybean milk industry and manufactures various other food products. Soybean oil remains the most widely produced liquid vegetable oil in the world.

The soil and climatic conditions in Uzbekistan are favorable for soybean cultivation, both as a main and repeated crop. Soybean cultivation can provide high-quality oil and proteins for the population while also offering nutritious feed for livestock and poultry (Abzalov *et al.,* 2018). Soybeans play a crucial, unique role in the food industry and livestock production globally, being rich in proteins, high in calories, and a contributor to soil fertility (Matniyazova *et al.,* 2023). Legumes, as a whole, are a significant source of protein, providing more than half of the protein consumed worldwide (Kholikova *et al.,* 2024). Soybean grains contain 2.5 times more proteins than wheat grains and 3.5 times more than corn grains, and soybean proteins comprise over 10 amino acids (Kholikova and Matniyazova, 2022).

Repetitive crops are those planted a second time after the main crop has completed its harvest, producing another yield within the same year (Ataboeva, 2004). This practice allows for more efficient land use and maximizes agricultural output per unit area. After the winter wheat harvest, common repetitive crops include corn, oats, and legumes (Mirkhamidova *et al.,* 2002). Repetitive crops, particularly legumes, offer significant benefits for the land, such as addressing the soil nitrogen deficiency by growing legumes as a second crop on land previously occupied by grain crops (Idrisov *et al.,* 2017; Abdurazakova *et al.,* 2020). These practices enhance soil cultivation, reduce the need for industrially produced nitrogen, and help prevent harmful effects of nitrogen runoff into water bodies, which can negatively impact human health (Hoshimov and Khudoyberdiyeva, 2023). Additionally, repetitive crops continuously improve soil fertility, enriching it with organic matter,

Table 1. Chemical composition of soybean seeds.

Water	Protein	Oil	Carbohydrates	Ash
Up to 12%	Up to 50%	Up to 25%	Up to 17%	Up to 4.0%

boosting biological processes, and generating extra income for the farming community. Most importantly, soybeans ensure a year-round supply of products rich in proteins, fats, and vitamins (Nazirova and Khamrakulova*,* 2021a and b).

Soybean (*Glycine max* L.) grains vary in size, depending on the cultivar, typically measuring 7.0–8.5 mm in length, 5.8–7.1 mm in width, and 4.2–5.8 mm in thickness. On a dry matter basis, the seeds contain 13.5%–25.4% fat, 29.0%–60.3% total protein (calculated as nitrogen × 6.25), 2.8%–6.8% crude fiber, 3.3%–6.4% ash, and 14.1%–33.0% nitrogen-free extractives (Table 1). Notably, the lysine content in soybean flour is 10 to 20 times higher than that of wheat flour. When incorporating 50% of soybean flour into dough, the lysine content nearly doubles (Kholikova *et al*., 2022). Furthermore, soybean flour contains significantly more vitamins than wheat flour. With its rich nutritional profile, soybeans often entail a recommendation to be processed under mild conditions, being regarded as a valuable source of plant-based protein (Ataboeva, 2004).

Soybeans are rich in nutrients, containing 40%–45% protein, 22%–25% vegetable oil, and 12 essential vitamins for the human body (Kholikova and Matniyazova*,* 2023). Yormatova and Tolibaev (2018) have studied the importance of biological nitrogen fixation in soybean roots and grains for the food industry. Schakowsky was also the first to document the method of making artificial milk from soybeans in his research (Matniyazova *et al.,* 2023). Soybean oil constitutes more than 50% of the vegetable oil produced worldwide (Idrisov *et al.,* 2017). It contains 30%–40% protein, 20% oil, and 9%–12% total sugars. The food industry makes a cultivar of products from soybeans, including milk, cottage cheese, yogurt, egg powders, flour, and oil (Matniyazova *et al.,* 2023).

In addition to essential amino acids, soybeans contain 13%–24% oil, 25% carbohydrates, 4.5%–5.5% cellulose, and 7% minerals, including calcium, phosphorus, sodium, iodine, molybdenum, and nickel. Soybeans also contain 2% phosphatides and vitamins, such as E, B1, B2, and B6, pantothenic acid, niacin, choline, folic acid, and biotin (Kurbanbaev *et al*., 2023). Vegetable oils, including soybean oil, consist of both saturated and unsaturated fatty acids, such as oleic, linoleic, and linolenic acids. The chemical composition of vegetable oils primarily comprises glycerides (95%–98%), free fatty acids (1%–2%), phosphatides (1%–2%), sterols (0.3%–0.5%), vitamins, and carotenoids. Oil and fatty substances in plants are abundant and have the unique property of not dissolving in water (Matniyazova *et al*., 2019). The following study aimed to examine the seed oil and protein content of the exotic and local soybean cultivars cultivated as a recurrent crop in Uzbekistan.

MATERIALS AND METHODS

The research material included three 50-grain samples each of the exotic Sparta and Selekta-201 (Russian selection), Nena (Kazakh selection), and local soybean (*Glycine max* L.) cultivars Ustoz-MMan-60, To'maris-MMan-60, and Oyjamol. The grains' weight and mass determination transpired before being ground into flour using a porcelain mortar. The measurement of flour from each sample had one gram of flour weighed into three separate filter paper bags. The degreasing process proceeded using an extractor apparatus, first with acetone and then with ethyl ether. After the defatting process, drying the samples followed, with the masses of the flour and filter paper measured. The differences in mass before and after the defatting process served to determine the fat content (%) in the soybean grains (Yuldashov *et al.,* 2021).

The degreasing procedure followed these steps: placing 8–10 grams of ground soybean in a filter paper bag before putting it in an extractor that was connected to a cooler; a flask containing solvent incurred heating in a water bath at 40 °C–55 °C; the solvent vapors passed through the extractor tube, condensed in the cooler, and returned to the extractor. The extraction process lasted for 6–8 hours, with the solvent being rotated 8–15 times per hour. After the extraction, the sample entailed drying in a brick oven at 60 °C until achieving a constant mass. The fat content, as calculated, used the formula:

$$x = (M_1\text{-}M_2)100/P(100\text{-}W)\times 100$$

Where M1 = the mass of the sample package before extraction in grams (g); M2 = the mass of the sample package after extraction in grams (g); P = the mass of the sample in grams (g); and W = the moisture content of the product in grams (g) (Sox, 1983).

Field experiments commenced from 2020 to 2022 at two locations: the Sharofiddin Memorial Field in the District Pakhtachi, Samarkand, and the Lochin Farms, District Karmana, Navoi, Uzbekistan. The experimental field at Samarkand has a location 124 km east of the regional center at coordinates 39°18' North latitude and 65°51' East longitude, at an altitude of 413 m. The experimental field at Navoi sits 17 km east of the regional center at coordinates 40°33' North latitude and 65°23' East longitude, at an altitude of 396 m (Kholikova and Matniyazova, 2023).

In both experimental fields, the soil was medium humus, typical irrigated light-colored gray soil, with a sandy texture. The terrain was slightly sloping and non-saline, with deep groundwater (7–8 m). The climate was highly variable, with hot summers (June, July, and August) and moderately cold winters (December and January). The region experiences 175–185 sunny days, and the cold-free period lasts 200–210 days. Rainfall primarily occurs in the autumn, winter, and spring, with dry summers (Sattarov, 2019).

In District Pakhtachi, the Zarafshan River flows through the northern part of the territory; however, the river water is seldom used for irrigation due to its lower bed elevation. Crops receive irrigation mostly through the Narpay Canal. The climate was sharply continental, with summer temperatures reaching 42 °C–45 °C, and the average temperature in July was 28 °C. Annual rainfall was 230–250 mm, with soils mainly gray or saline, sandy loam, and clayey gray in some areas. The experimental area sits on irrigated meadow soils in the lower reaches of the Zarafshan River (Karakhanov *et al*., 2018).

The location of the Karmana District of the Navoi Region is along the banks of the Zarafshan River. It has the Navbahor and Konimekh districts bordering it to the north, the Kyziltepa district to the west, and the Samarkand Region to the east and south. The district's terrain primarily consists of low-lying plains, with freshwater reserves found between ancient dry riverbeds and hills within the Zarafshan River valley. The climate is sharply continental, characterized by hot, dry summers and cold winters. The average annual temperature is approximately 15 °C, with average temperatures of 0.4 °C in January and 28.9 °C in July. Annual precipitation ranges from 100 to 200 mm. Irrigation comes from the Zarafshan River, the Navoi branch of the Amu-Bukhara Canal, and the Narpay Canal. The experimental fields sit on irrigated grassy, gray soils (Matniyazova *et al*., 2023).

RESULTS

In the presented experiments, the oil and protein contents of the local and exotic soybean (*Glycine max* L.) cultivars planted as repeated crops in the Samarkand and Navoi regions, Uzbekistan, received evaluation in 2020–2022. Based on the results, the significant variations were notable among the local and exotic soybean cultivars for oil and protein contents. It was evident that soybean cultivars Nena and Oyjamol had higher values (22% and 28%, respectively) than the control variant (Table 1). It was apparent that the oil content in the seeds was relatively low in the soybean cultivars Selekta-201 (control), Sparta, and Tomaris-MMAn-60.

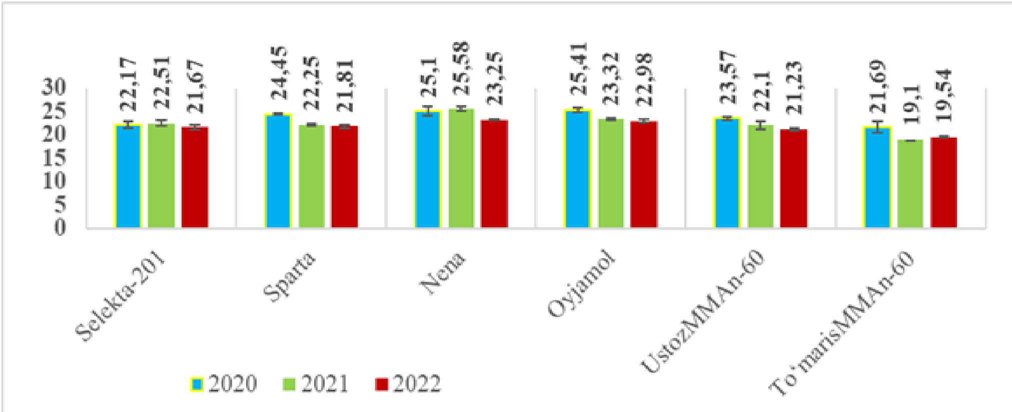

Figure 1. Total oil content in the grains of soybean cultivars planted as a repeated crop under the environmental conditions of Samarkand Region, Uzbekistan, compared to dry mass (%).

Figure 2. Total oil content in the grains of soybean cultivars planted as a repeated crop under the environmental conditions of Navoi Region, Uzbekistan, compared to dry mass (%).

According to results, in the conditions of the Samarkand region during 2020–2022, the grain oil content in the soybean cultivars planted as a repeated crop after the grain oil harvest ranged from 19.1% ± 0.2% to 25.4% ± 1.6% (Figure 1). In the local soybean cultivars, the highest index of seed oil content resulted in the cultivar Oyjamol (25.4% ± 0.8%, 23.3% ± 0.9%, and 22.98% ± 1.5%), and a relatively low index in cultivar Tomaris-MMAn-60 (21.7% ± 1.7%, 19.1% ± 0.3%, and 19.5% ± 0.8%). From the findings, under Navoi region conditions in 2020–2022, the grain oil content in soybean cultivars grown as a repeat crop after grain oil harvest has ranged from 19.8% ± 0.2% to 25.8% ± 1.2% (Figure 2). In local soybean cultivars, the highest index of grain oil content appeared in the cultivar Oyjamol (25.8% ± 1.3%, 24% ± 0.4%, and 23.1% ± 0.5%), and a relatively low index occurred in the cultivar Tomaris-MMAn-60 (22.8% ± 1.6%, 20% ± 1.2%, and 19.7% ± 0.2%).

In the soybean exotic cultivars, a high indicator for grain oil content emerged in the cultivar Nena belonging to the Kazakhstan selection in 2020–2022 (ranging from 23.2% ± 0.7% to 25.1% ± 1.6%) (Figure 1). However, the relatively low seed oil indicator was noticeable in the cultivar Selekta-201 during 2020 to 2022 (ranging from 21.7% ± 1.1% to 22.2% ± 1.3%). According to the results, the grain oil content in the soybean cultivars planted in the Navoi region in 2020–2022 ranged from 21.5% ± 0.5% to 25.8% ± 0.9%. In the local and exotic soybean cultivars, the highest index of grain oil content was remarkable in the cultivars Oyjamol and Nena, with relatively low indicators recorded in the To'maris cultivar in all years (Figures 1 and 2).

Several reasons surfaced why soy protein is more promising than other proteins. First, large-scale production of protein products from soybean meal, isolate, texture, and concentrates has succeeded in establishing itself in the economically developed countries. Second, soybeans are a unique source of various vegetable protein raw materials due to their high protein content. Thirdly, soybean is a known crop from the past thousand years of experience in producing various food products, and in human nutrition, many protein products came from soybean seeds. Fourth, soy proteins are distinguished by the highest biological values. Fifth, soy proteins, along with other plant proteins, have clinically proven hypocholesterolological effects (Nazirova and Khamrakulova, 2021a and b).

In the experiment, the total seed proteins in local and foreign soybean cultivars in the Samarkand and Navoi regions also attained studies. The total proteins in domestic and exotic soybean cultivars range from 27% to 36%. The higher seed protein content than the control cultivar in both regions was evident in the soybean cultivar To'maris-MMAn-60 (34%–36 %), while the lowest indicator appeared in the cultivar Nena (27%–28%).

In the field experiments conducted in the Samarkand region in 2020–2022, the grain protein content in soybean control cultivar Selekta-201 in 2020 was 30.06%. The lower indicator compared to the control cultivar manifested in the cultivar Nena (28.44%). However, the highest indicator resulted in the local soybean cultivar To'maris-MMAn-60 (34.41%). Similarly, for seed protein content, the varied values were noteworthy in the cultivars Sparta (33.03%), Oyjamol (31.47%), and Ustoz-MMAn-60 (32.11%). In the experiments during 2021, the grain protein content in the control cultivar was 30.08%, while the highest indicator was 35.41% in the cultivar To'maris-MMAn-60 in comparison with the control cultivar. The lowest indicator was evident in the exotic cultivar Nena (29.44%). The grain protein content in the local Oyjamol and Ustoz-MMAn-60 and exotic cultivars Sparta were 31.47%, 32.12%, and 34.64%, respectively (Figure 3). In the experiments conducted in 2022, the highest protein content in comparison with the control cultivar emerged from the soybean cultivar To'maris-MMAn-60 (34.73%), with the lowest protein content observed in the cultivar Nena (28.89%).

In the experiments conducted in the Navoi region in 2020–2022, the grain protein content in the soybean control cultivar Selekta-201 in 2020 was 30.89% (Figure 4). The lower indicator compared to the control cultivar resulted in the exotic cultivar Nena (28.89%). The highest indicator manifested in the local cultivar To'maris-MMAn-60 (34.73%). Similarly, varied values of the grain protein content were evident in the soybean cultivars Sparta (33.03%), Oyjamol (30.34%), and Ustoz-MMAn-60 (32.59%). The experiment conducted in 2021 showed the seed protein content in the control cultivar was 29.19%, while the highest indicator versus the control cultivar was notable in the cultivar To'maris-MMAn-60 (36.55%). Meanwhile, the lowest indicator was in the exotic cultivar Nena (29.83%). In the experiment conducted in 2022, the highest protein content materialized in the cultivar To'maris-MMAn-60 (34.21%) compared with the control cultivar, and the lowest protein content occurred in the cultivar Nena (27.07%). Thus, in both regions over the years, the highest grain protein content was remarkable in the soybean cultivar To'maris, while the lowest was in the exotic cultivar Nena.

In the Samarkand region, soybean cultivars, such as Nena and Oyjamol, exhibited higher oil contents, ranging from 22% to 28%. The results suggested these cultivars were particularly suitable for oil extraction, as their oil content surpasses the control cultivar Selekta-201 and other cultivars like Sparta and Tomaris-MMAn-60. Similar trends were

Figure 3. Total protein content in the grains of soybean cultivars planted as a repeated crop under the environmental conditions of Samarkand Region, Uzbekistan, relative to dry mass (%).

Figure 4. Total protein content in the grains of soybean cultivars planted as a repeated crop under the environmental conditions of Navoi Region, Uzbekistan, relative to dry mass (%).

prevalent in the Navoi region, where the cultivar Nena showed a consistently higher oil content in 2020–2022, ranging from 22.1% to 25.3%. Conversely, the cultivar Sparta during these three years displayed relatively low oil content, ranging from 19.4% to 25.5%. These findings underline the complexity of genotype-by-environment interactions, which play a key role in determining seed composition traits such as oil and protein contents.

DISCUSSION

In the years 2020–2022, the oil and protein content of seeds from local and foreign soybean varieties grown as a repeated crop in the Samarkand and Navoi regions underwent assessment. The results indicated that for oil content, the foreign variety Nena (22.1%–25.3%) and the local variety Oyjamol (24.5%–25.85%) showed the highest values. Although the local variety Tomaris-MMAn-60 exhibited lower oil content (19.7%) in some years, its protein content remained consistently high, reaching 36.55% in 2021. This variety was the leader in protein content across all years.

On protein content, the Nena variety showed lower values (27%–28%), indicating that it is rich in oil but has relatively low protein content. The Selecta-201 variety, used as a control, gave average results (29%–

30%). Similarly, the Sparta, Oyjamol, and Ustoz-MMAn-60 varieties demonstrated stable, high protein levels. Overall, the oil content of the seeds in all studied varieties ranged from 19% to 28%, and the protein content ranged from 27% to 36%. The Tomaris-MMAn-60 variety proved superior, consistently producing high protein content results every year. The findings revealed the oil and protein content in soybean varieties is significantly dependent on both the variety and growing region. These variations occur through the genotype-by-environment interaction. The high protein content in the Tomaris-MMAn-60 variety and the high oil content in the Nena variety confirm this relationship.

The accumulation of oil in seeds acquires primary influences from environmental factors, such as temperature, light duration, and humidity, during the seed-filling stage (Jin *et al*., 2023a and b). The consistently warm temperatures and extended sunny days in the Samarkand and Navoi regions during this period may have contributed to the elevated oil content observed, particularly in the Nena and Oyjamol cultivars. Conversely, the high-protein content recorded in the Tomaris-MMAn-60 variety can be due to a corresponding decrease in oil content. This inverse relationship has received highlights in several scientific studies, which emphasize the negative correlation between oil and protein accumulation in soybean seeds (Wilson, 2004; Rotundo and Westgate, 2009). Supporting this, Karr-Lilienthal *et al*. (2004) demonstrated that carbon and nitrogen compounds compete during seed development, often resulting in an increase in one component at the expense of the other.

Additionally, the high and stable protein content in the Tomaris-MMAn-60 variety year after year is an important trait for breeding programs. Li *et al*. (2021a and b) have pointed out the link of protein content to genotype, nitrogen content in the soil, and post-anthesis temperature. This study's results support this finding, as protein content increased in 2021 when precipitation was higher. From a nutritional perspective, the high-protein seeds of the Tomaris-MMAn-60 variety stood out due to their nutritional value and technological potential. The complete amino acid composition of soybean, especially the high-lysine content, makes it superior to other plant proteins (Nazirova and Xamrakulova, 2021). Furthermore, soybean proteins have been proven through experimental and clinical studies to be beneficial for the cardiovascular system, having properties that help lower cholesterol levels (Anderson *et al*., 1995).

From an agronomic perspective, cultivating soybeans as a repeated crop significantly enhances soil fertility, particularly by improving nitrogen balance through biological nitrogen fixation. Research conducted by Caliskan *et al*. (2007) and Mourtzinis *et al*. (2014) has highlighted that sowing soybeans after wheat supports sustainable agricultural practices, as well as helps maintain high yield and favorable biochemical composition. Consequently, the high-protein content observed in the Tomaris-MMAn-60 variety and the high-oil content in the Nena variety suggest selecting these genotypes strategically according to specific breeding objectives.

CONCLUSIONS

In soybeans (*Glycine max* L.), grain oil content incurred influences, to a certain degree, from environmental factors. For the Samarkand region, higher oil content was evident in the exotic cultivar Nena and the local genotype To'maris-MMAn-60, both cultivated as repeated crops following winter cereals. In contrast, lower oil content was notable in the exotic cultivar Sparta and the local cultivar Oyjamol. In the Navoi region of Uzbekistan, the trend differed; the highest oil content resulted in the exotic cultivar Nena and the local cultivar Oyjamol, while the lowest oil content appeared in the local genotype To'maris-MMAn-60 when grown as a repeated crop. This highlights the role of the genotype-environment interaction in determining oil accumulation in soybean grains.

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