

Dynamics and Volatility of Organic Oil Plants Production in World and Serbia

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ABSTRACT

Areas produced under organic oil plants, 2015-2024, displays a strong growth trend with notable yearly fluctuations. About 8% of all oilseeds produced worldwide are sunflowers, with significant concentration among a small number of European nations. Over 74% of Europe's total production of organic sunflower seeds comes from Romania and France. With 41.41% of overall production, Romania is in the lead, followed by France with 32.76%. With a share of 11.29%, Serbia comes in third, other nations make smaller contributions. The overall area of oil crops was 1,256.73 ha of Serbia's organically grown industrial oil plants in 2024. In 2024, sunflower accounted for 1,014.86 ha (80.8%), followed by soy (7%), flax (5.5%) and other crops (hemp 3.5%, oilseed rape 1.9%, mustard 1%, pumpkin 0.2%, poppy 0.01%, etc.). Vojvodina leads with 1,188.13 ha (≈95%), according to regional study. The majority of the industry has certified organic status, 1,007.24 ha are already certified and 249.49 ha are currently undergoing conversion. An examination of the base and chain indices for Serbia's entire organic industrial plant area, 2015-2024 exhibits noticeable swings and production instability. The significant annual fluctuations are further shown by chain indices (Ci), which show a nearly 1.6-fold increase in area in 2021 compared to 2020 and a sharp fall in 2020 (Ci = 58.05) compared to the previous year. These variations highlight the need for more stable planning and a long-term strategy in order to lower volatility and increase the sector's sustainability, as the production of organic industrial plants in Serbia depends on climatic, market, and economic factors in addition to state support.

Keywords: area, oil plants, organic production, base and chain indices.

INTRODUCTION

Oil crops are vital to the world economy and are mostly utilised in the manufacturing of food, feed, equipment, metallurgy, soap, paint, rubber, plastics, and pharmaceuticals.

Sunflowers (*Helianthus annuus*) are an oilseed crop native to North America that is grown all over the world for food or animal feed. Sunflower is one of the three main oilseed crops - soybean, rapeseed, and sunflower - and is known to be a significant source of high-quality edible oil that is crucial for cooking (Pal et al., 2015; Popović D. et al., 2024). It is an important source of dietary fibre and high-quality oil for human health. Sunflowers' ability to adapt to various

soil and climate conditions has improved its production as an oilseed crop globally (Forleo et al., 2018). As a source of high-quality oil and dietary fibre that greatly improves human health, sunflower is one of the major oilseed crops cultivated worldwide (Khan et al., 2015). Sunflower is also one of the most important oil crops in the European organic farming sector, with Romania representing a major producer in terms of organically cultivated area (Brumă et al., 2021). The need for edible sunflower seeds, oil, and by-products has grown along with the human population, and in order to meet this demand, efforts to enhance sunflower output must be intensified (Taher et al., 2017). Sunflowers, soybeans, rapeseed, peanuts, cottonseed etc. dominate the global oilseed market.

Legumes are proposed as one of the tools that could mitigate ecosystem deficiencies and lessen nutrient imbalances in stockless organic farming systems; nonetheless, a decline in legume cropping areas has been noted in most European farms with no clear explanation (Magrini et al., 2016). The notion of introducing soybeans [*Glycine max* (L.) Merr.] into conventional organic farming systems is encouraged in Europe due to the ongoing climate change and the increasing demand for domestic non-GMO soybean markets (Nemecek et al., 2008). In addition to adjusting nutrient cycles (Möller, 2018), promoting environmental biodiversity (Put et al., 2018; Popović V. et al., 2013; 2015), increasing organic crop output (Toleikienė et al., 2019), and mitigating pathogen-related issues (Nemecek et al., 2008), soybeans can become productive enough to compete with other potentially better adapted species (Toleikienė et al., 2019; Ilin et al., 2025).

Flax (*Linum usitatissimum* L.) to be significant both economically and agronomically because it can be used to produce both fibre and seed (oil). One of the first cultivated crops, flax (*Linum usitatissimum* L.) dates back to the Neolithic era (~8000-9000 years ago) in the Fertile Crescent. Early applications included the manufacture of fibre in ancient Egypt and the usage of oilseeds in Asia; diversity throughout Europe resulted in the formation of unique flax seed and fibre varieties that were climate-adapted (Dash et al., 2017; Duk et al., 2021). Flax's importance in human nutrition, diverse and sustainable agriculture, and bio-based industrial applications has sparked a resurgence of interest in the plant in recent years. The translation of experimental results into solid, environment-specific crop management advice is hampered by the fragmentation of agronomic knowledge on flax across settings, production goals, and management techniques, despite increased research efforts. Therefore, combining optimised agronomic techniques with breeding strategies that take advantage of current genetic variety to enhance yield stability, quality, and resilience under growing climate variability will be necessary for the sustainable intensification of flax

production (Nožinić et al., 2022; Popović D. et al., 2026; Popović M. et al., 2026b).

The popularity of hemp, or *Cannabis sativa* L., has significantly increased. Hemp seeds have recently drawn more attention as a key component for obtaining premium foods and dietary supplements because of their outstanding nutritional content. High-quality proteins like edestin and albumin, as well as healthy fats with a high concentration of polyunsaturated fatty acids like linoleic acid (omega-6), alpha-linolenic acid (omega-3), and several vitamins (vitamins E, D, and A), are what make hemp seeds unique. Particularly found in hemp seeds, polyphenols and terpenoids have antibacterial, antioxidant, and anti-inflammatory qualities (Tănase-Apetroaei et al., 2024).

The pumpkin is a member of the Cucurbitaceae family, and economically important species are *Cucurbita moschata* Duch., *Cucurbita maxima*, *Cucurbita ficifolia*, *Cucurbita pepo* L., *Cucurbita mixta* and *Telfairia occidentalis* (Taylor et al., 2002), which includes a number of economically and agronomically significant species. Every portion of the pumpkin is edible and packed with healthy nutraceutical chemicals. Pumpkin seeds are an important source of protein that can aid in the eradication of protein deficiency. Lipids, which are high in polyunsaturated fatty acids (PUFAs), contain both essential and non-essential fatty acids that protect against a number of illnesses, including cancer and other cardiovascular disorders. Pumpkin seeds can be utilised as an amazing dietary supplement that helps treat a variety of deficiency illnesses since they are rich in macro (magnesium, phosphorous, potassium, sodium, and calcium) and microminerals (iron, copper, manganese, zinc, and selenium) (Singh and Vivek, 2024).

In food preparation, sunflower seeds are a prospective source of protein that can be used in place of soybeans, whose supply is limited (de Moraes Oliveira et al., 2016). As seeds, processed or extracted, or as composite goods, sunflowers have been used to make a variety of delicacies (Adesina, 2018). As composite functional meals, sunflower seeds

can be roasted, baked, boiled, or processed into flour (Grasso et al., 2019). Humans can still obtain nutritious nourishment from sunflowers. A number of phytochemicals, including antioxidants, flavonols, phenolic acids, procyanidins, phytosterols, amino acids, dietary fibre, potassium, arginine monounsaturated, and polyunsaturated fatty acids, have been found to be abundant in sunflower seeds, according to studies (Alagawany et al., 2015; Islam et al., 2016).

Sunflower seeds are a valuable food product that is widely used in the processing industry. Rich in oil, it is used for food and other purposes, and the oil from the seeds represents the most efficient way of storing reserve substances and has the highest energy value. Sunflower oil continues to occupy a significant position among vegetable oils in the world: world production of sunflower oil accounts for approximately 9% of total global vegetable oil production, making it the fourth most abundant oil by volume of production behind palm, soybean and canola oils (USDA, 2022). Global production of sunflower oil in the 2025/26 season is estimated at about 21.9 million tonnes, marking a significant increase over previous years and reflecting recovery in key production regions, including Ukraine, the European Union and Russia (USDA 2025). In the Republic of Serbia, the demand for health-safe food is growing more and more, which has encouraged many conventional farms to switch to organic production. This transition significantly contributes to the overall sustainability of agriculture, as organic production encourages the conservation of natural resources and the reduction of negative environmental impact. Between 2010 and 2015, the area under organic crops in Serbia almost tripled, from 5,855 hectares to 15,298 hectares, which shows the rapid development of this sector (Simić, 2017). Agro-ecological parameters, regional climate, genotype and nutrition influence the yield of plants (Kosev et al., 2024, 2025, 2026; Georgieva et al., 2025; Aćimić-Remiković et al., 2026; Mihailović et al., 2026; Ninova et al., 2026; Popović M. et al., 2026a). The organization of agricultural production in Serbia is determined by both economic and agroecological conditions, as

well as the specificities of rural areas (Milunović et al., 2022). When looking at the structure of organic production, arable crops have the largest share, including pastures and meadows, which make up 68.7% of the total area. Cereals follow with 31.7%, while the production of fruit and other crops appears in smaller forms. This distribution shows that the main pillars of organic agriculture in Serbia are arable crops and animal husbandry, while fruits and vegetables develop more slowly (Golijan et al., 2017; Golijan-Pantović, 2025a, b). The increasing share of organic production shows the growing interest of consumers in healthy and ecological food, but its yields still lag behind conventional agriculture (Babec et al., 2019). Sunflower is one of the most important organic oil crops on a global level, with a share of about 17% in the total area under organic oil crops, but it still participates with only about 1% in the total world area under sunflower (Report Linker Research, 2023).

The annual plant *Sinapis alba* L., commonly called Brassica hirta or white or yellow mustard, is a member of the Brassicaceae family and is native to the Mediterranean region. White mustard (*Sinapis alba* L.) seed oil is used in biodiesel manufacturing, cooking, food preservation, body and hair revitalisation, and as an alternative biofuel and diesel fuel additive. White mustard seed pretreatments (shelling, preheating, and grinding) and processing methods for oil recovery (pressing, solvent extraction, and steam distillation) from whole seeds, ground seed or kernels, and press cake come next. Additionally included are cutting-edge technologies including aqueous, enzyme-assisted aqueous, supercritical CO₂, and ultrasound-assisted solvent extraction. The generation of biodiesel from white mustard seed oil, including fuel characteristics and performance, marks the grown trend. Risks and toxicological effects of producing and using biodiesel derived from white mustard on the economy, ecology, society, and human health are being observed more and more in the world (Katepa-Mupondwa et al., 2005).

The aim of this study was to examine organic oil crops production: sunflower,

soybean, flax, hemp, pumpkin, oilseed rape, poppy, and mustard, in Serbia and in the world, due to the growing interest in healthy and organic food.

MATERIAL AND METHODS

In this study, the organic production of oil crops in our country and in the world was examined (Faostat, 2026). Official databases of the Ministry of Agriculture, Forestry and Water Management of the Republic of Serbia were used as the primary data sources. The study applied a combined methodological approach. To describe and analyze the collected data, standard descriptive statistical methods were employed, including tabular and graphical presentation of data, as well as the calculation of measures of central tendency and measures of variability. In order to examine the dynamics of changes over time, chain indices and base indices were calculated, enabling the analysis of year-to-year changes as well as comparisons with the selected base year. In addition to quantitative methods, qualitative methods were applied namely content analysis, synthesis, and comparative analysis, which contributed to a more comprehensive interpretation of the research results.

RESULTS AND DISCUSSION

Analysis of areas under organic crop production in the period 2015-2024 shows a pronounced growth trend with significant annual oscillations (Figure 1a). In the period 2015-2017 a decrease was recorded from 15,298 ha to 13,423 ha (-12.3%), which can be attributed to the adaptation of producers to organic production standards and unfavorable climatic or economic conditions. Since 2018, the surface area has recorded a continuous increase, with 19,255 ha (+43.4% compared to 2017) and a peak of 29,002 ha in 2023, which reflects the increased interest in organic production, support through subsidy programs and favorable market trends. In 2024, a slight decrease was registered to 27,550 ha (-5.1%), which may be a consequence of climatic events, market fluctuations or crop rotation. The average area in the analysed period is approximately 21,370 ha, while the coefficient of variation of about 27% indicates significant annual variability, which emphasizes that organic plant production still remains sensitive to external factors, emphasizing the need for long-term planning and stabilization of the sector.

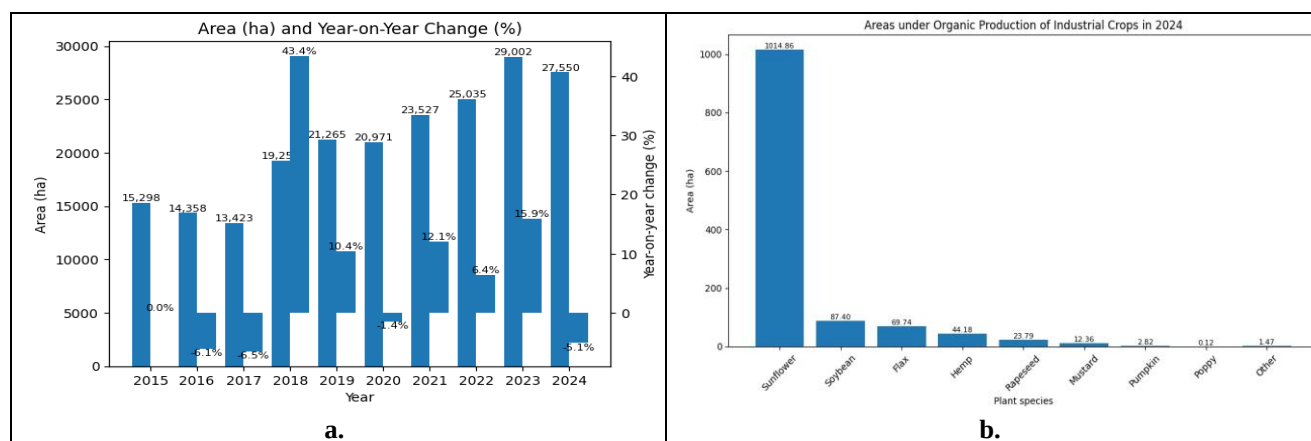


Figure 1. Total areas under organic crop production in Serbia and year on year change, %, (a) and areas under organic production of individual industrial crop species in 2024 and their percentage share (b)

The analysis of the areas of organically grown industrial plants in Serbia during 2024 (Figure 1b) determined that the total area of these crops was 1,256.73 ha. The dominant crop was sunflower, with an area of 1,014.86

ha, which represents 80.8% of the total industrial plants. The second largest was soy, with 87.40 ha (7%), while flax represented 69.74 ha (5.5%). Other crops occupy a much smaller share, with hemp amounting to 44.18

ha (3.5%), oilseed rape 23.79 ha (1.9%), mustard 12.36 ha (1%), pumpkin 2.82 ha (0.2%), poppy 0.115 ha (0.01%), while other crops together make up 1.47 ha (0.1%). The results show that sunflower dominates the structure of organic production of industrial plants in Serbia, making up the majority of the total area, while other crops represent secondary segments, mainly intended for production diversification and specialized markets. The dominance of sunflower clearly reflects its agronomic and market importance in organic sector of industrial crops.

The base index of total organic crop production (2015 = 100) indicates a pronounced long-term growth of the sector

during the observed period 2015–2024 (Figure 2a). After a slight decline in the initial years, where the base index values in 2016 and 2017 were 93.86 and 87.74, an intense upward trend began in 2018, with the base index rising to 125.86. The growth continues in the following years, with the base index reaching its maximum value in 2023 (189.58), which means that the total area under organic crop production was almost 90% higher compared to the base year 2015. Although a decline was recorded in 2024 (180.09), the value of the base index still remains significantly above the initial level, confirming the stable long-term growth of the organic sector.

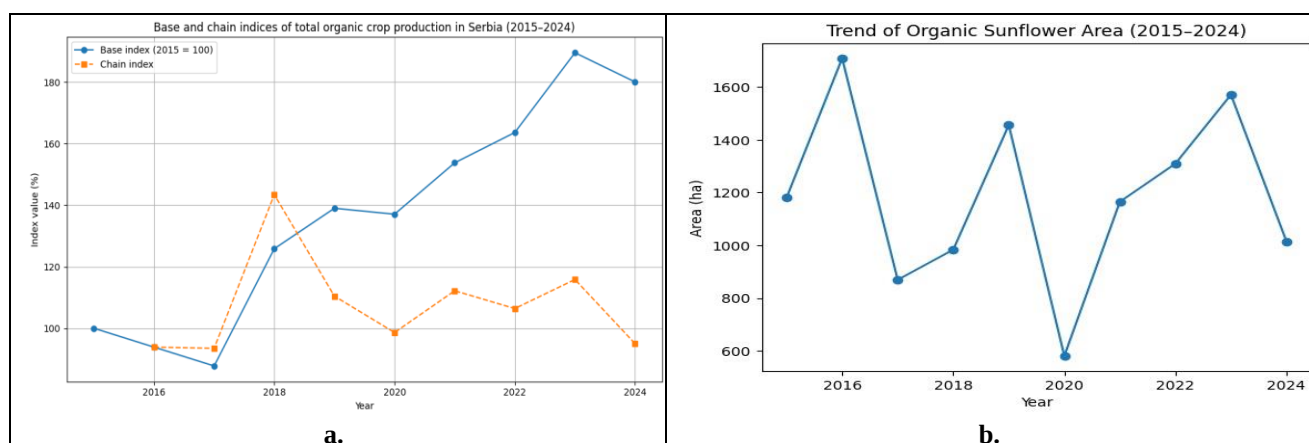


Figure 2. Base and chain indices of total organic crop production in Serbia (a), trend of organic sunflower area (2015–2024) (b)

Chain indexes additionally shed light on the dynamics of inter-annual changes. The period 2016–2017 is characterized by a moderate decline in production, with chain indices below 100, which indicates a decrease in area compared to previous years. On the contrary, 2018 stands out as a turning point, with an extremely high chain index (143.44), which indicates a strong expansion of organic areas compared to 2017. In the period 2019–2023 chain indices generally move above 100, which confirms continuous annual growth, although with certain oscillations, especially during 2020, when there is a slight stagnation of growth (98.61). In 2024, the chain index falls below 100 again (94.99), which indicates a decrease in areas compared to the previous year, but without disrupting the overall positive long-term trend.

Areas under organic sunflower in the period 2015–2024 (Figure 2b) showed pronounced inter-annual variability, ranging from 581.38 ha (2020) to 1708.06 ha (2016). The average value of the area was 1183.87 ha, with a standard deviation of 340.66 ha, while the coefficient of variation reached 28.78%, which indicates a high degree of production instability. In the initial part of the observed period, the area increased from 1180.96 ha in 2015 to a maximum of 1708.06 ha in 2016, followed by a significant decrease to 869.56 ha in 2017. In the following years, the areas showed an oscillatory character, with a moderate recovery in 2018 (983.63 ha) and a more pronounced growth in 2019 (1455.43 ha). The most pronounced decrease was recorded in 2020, when the areas were reduced to 581.38 ha, which represents a

decrease of approximately 51% compared to the multi-year average. In the post-pandemic period, a gradual recovery was recorded, with an increase in areas to 1165.08 ha in 2021, 1309.35 ha in 2022 and 1570.38 ha in 2023, while in 2024 a decrease was again registered to 1014.86 ha. The absence of a stable growing trend during the observed period indicates a pronounced sensitivity of organic sunflower production to agro-climatic conditions, economic factors and changes in the incentive system, which is in accordance with the findings of other authors who

indicate a high variability of areas in organic field production.

Table 1 shows the regional distribution of areas under organic industrial plants in Serbia in 2024. The most dominant crop was sunflower with 1,014.86 ha (80.8%), mainly in Vojvodina (1,000.80 ha), with smaller areas in Šumadija and Western Serbia (12.74 ha) and Southern and Eastern Serbia (1.32 ha); of the total sunflower area, 158.83 ha were in conversion, while 856.03 ha were already certified.

Table 1. Organic production of industrial plants in Serbia in 2024 - regional distribution

Crops	Belgrade	Šumadija and Western Serbia	Southern and Eastern Serbia	Vojvodina	Conversion period	Organic status	Total (ha)
Sunflower	0.00	12.74	1.32	1,000.80	158.83	856.03	1,014.86
Soybean	0.37	0.00	0.00	87.03	19.75	67.65	87.40
Flax	0.00	0.00	0.00	69.74	1.73	68.02	69.74
Hemp	0.00	0.00	39.06	5.12	44.18	0.00	44.18
Rapeseed	0.00	0.00	0.00	23.79	23.79	0.00	23.79
Mustard	0.00	12.30	0.00	0.06	0.00	12.36	12.36
Pumpkin	0.00	0.00	2.82	0.00	0.00	2.82	2.82
Poppy	0.00	0.00	0.00	0.12	0.00	0.12	0.12
Other	0.00	0.00	0.00	1.47	1.22	0.25	1.47
Total	0.37	25.04	43.19	1,188.13	249.49	1,007.24	1,256.73

The second largest crop was soy (87.40 ha; 7%), mainly in Vojvodina, with 19.75 ha in conversion and 67.65 ha of certified areas, while flax had 69.74 ha (5.5%), also predominantly in Vojvodina. Other crops, including hemp (44.18 ha; 3.5%), oilseed rape (23.79 ha; 1.9%), mustard (12.36 ha; 1%), pumpkin (2.82 ha; 0.2%), poppy (0.12 ha; 0.01%) and other crops (1.47 ha; 0.1%), occupy a much smaller share and mainly contribute to production diversification. Regional analysis shows that Vojvodina dominates with 1,188.13 ha ($\approx 95\%$), representing the center for all dominant crops and the majority of areas in conversion and certified, while Southern and Eastern Serbia have a total of 43.19 ha, mainly hemp and smaller areas of pumpkin, Šumadija and Western Serbia 25.04 ha, mainly sunflower and scallion, while Belgrade contributes a minimum of 0.37 ha, mainly soybeans. In total, 249.49 ha of industrial plants are in the process of conversion, and 1,007.24 ha are already certified, which shows that although

most of the sector has certified organic status, there is considerable room for expansion of certified areas in the coming years.

Analysis of base and chain indices of areas under organic sunflower in Serbia in the period 2015-2024 shows pronounced instability of production and significant annual oscillations (Table 2). The base indices (Ib), which compare the areas with the base year 2015, show that the area in 2016 increased by 44.6% (Ib = 144.63), while in 2017 there was a sharp drop to 73.63%, which means that the area fell below the level of the base year. The period from 2018 to 2019 is characterized by the growth of areas, with Ib values of 83.29 and 123.24, while the year 2020 represents the lowest value in the period (Ib = 49.23), which shows that the area has decreased by more than half compared to 2015. After that, there is a recovery in 2021 and 2022 (Ib = 98.66 and 110.87), with a peak in 2023 (Ib = 132.97), while 2024 records a slight decline to 85.94.

Chain indices (Ci), which show changes compared to the previous year, further highlight the extreme oscillations of production. The highest growth was recorded in 2021 (Ci = 200.40), when the area almost doubled compared to 2020, while the biggest decrease was registered in 2020 (Ci = 39.95), which means that the area decreased by about 60% compared to 2019. Other years also show significant fluctuations, including 2017 (Ci = 50.91) and 2024 (Ci = 64.63).

The analysis of base and chain indices for the total area under organic industrial crops in Serbia during 2015-2024 reveals pronounced year-to-year fluctuations and considerable variability in the cultivated area (Table 3). The base indices (Ib) show that the areas increased in 2016 by 9.1% compared to

the base year 2015, followed by a decrease in 2017 and 2018, while the year 2020 recorded the lowest value (Ib = 48.39), which means that the areas decreased by more than half compared to the initial year. Areas recovered in the period 2021–2023, only to record a new decline in 2024 (Ib = 46.99). Chain indices (Ci) further highlight the extreme annual changes, including a nearly 1.6-fold increase in area in 2021 compared to 2020, and a sharp decline in 2020 (Ci = 58.05) compared to the previous year. These fluctuations indicate that the production of organic industrial plants in Serbia depends on climatic, market and economic factors, as well as on state support, which emphasizes the need for more stable planning and a long-term strategy in order to reduce volatility and increase the sustainability of the sector.

Table 2. Base and chain indices of areas under organic sunflower cultivation in Serbia (2015 = 100)

Year	Areas (ha)	Base index (Ib)	Chain index (Ci)
2015	1,180.96	100.00	–
2016	1,708.06	144.63	144.63
2017	869.56	73.63	50.91
2018	983.63	83.29	113.12
2019	1,455.43	123.24	147.97
2020	581.38	49.23	39.95
2021	1,165.08	98.66	200.40
2022	1,309.35	110.87	112.38
2023	1,570.38	132.97	119.94
2024	1,014.86	85.94	64.63

Table 3. Base and chain indices of the total area of organic industrial crops in Serbia (2015 = 100)

Year	Areas (ha)	Base index (Ib)	Chain index (Ci)
2015	2,674.38	100.00	–
2016	2,918.34	109.12	109.12
2017	2,290.46	85.64	78.49
2018	1,961.81	73.36	85.65
2019	2,229.56	83.37	113.65
2020	1,294.23	48.39	58.05
2021	2,121.61	79.33	163.93
2022	2,075.73	77.62	97.84
2023	2,286.22	85.49	110.14
2024	1,256.73	46.99	54.97

According to the data of the Report Linker Research platform (2026), the European production of organic sunflower seeds is characterized by pronounced spatial concentration and uneven growth dynamics among countries (Table 4).

In 2023, Romania was the leading producer, with a production of 163.08 thousand metric tons, followed by France and Serbia. Although it is not among the largest producers in terms of absolute volume of production, Serbia stands out for its

extremely high annual growth rate, which was 76.33%, which represents the highest value among the analyzed countries. In contrast, Slovakia and Lithuania recorded a decline in production, which indicates marked differences in the development of this sector. Observed over a period of several years, Romania, France and Slovenia recorded

a stable and significant growth in organic sunflower production, which can be linked to favorable agro-ecological conditions and the strengthening of policies and incentives for organic agriculture, Table 4. On the other hand, smaller producers, such as Ireland and Lithuania, experience stagnation or decline in production.

Table 4. Top countries in organic sunflower seed production by country

Rank	Country	Production (metric tons)	Year	Year-on-year change (%)	5-year CAGR (%)
1	Romania	163,080	2023	+20.19	+28.34
2	France	129,030	2023	+11.17	+22.84
3	Serbia	44,460	2023	+58.35	+76.33
4	Hungary	13,030	2023	+5.95	+4.35
5	Bulgaria	11,790	2023	+13.87	+2.13
6	Croatia	11,550	2023	+11.49	+13.82
7	Spain	5,420	2023	-25.57	+1.14
8	Slovakia	4,480	2023	+3.08	-1.86
9	Greece	2,930	2023	+2.91	+10.66
10	Czech Republic	1,250	2023	+12.26	+50.21

Source: Report Linker Research (2023)

The distribution of organic sunflower seed production shares in 2023 indicates a strong concentration among a limited number of European countries (Figure 3). Romania holds the dominant position with 41.41% of total production, followed by France with 32.76%. Together, these two countries account for more than 74% of overall organic sunflower seed production in Europe. Serbia

ranks third with a share of 11.29%, clearly distinguishing itself from the remaining producers and highlighting its growing importance in the sector. Other countries, including Hungary, Bulgaria, and Croatia, contribute more modest shares, each below 4%, while Spain, Slovakia, Greece, and the Czech Republic have relatively minor roles (Report Linker Research, 2026).

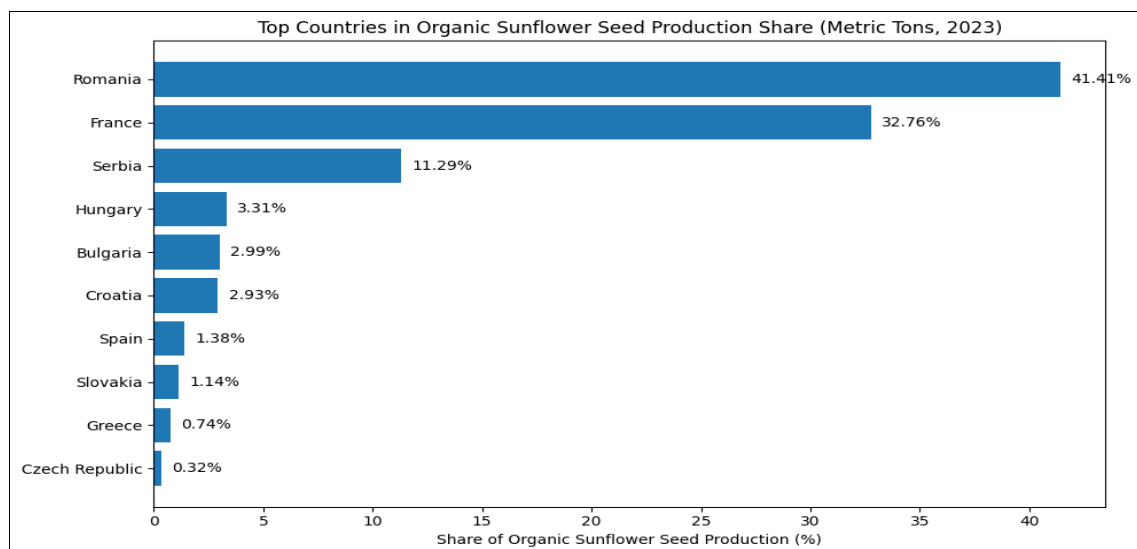


Figure 3. Top countries in organic sunflower seed production share by country (metric tons)

Global sunflower production in the 2025/26 marketing year is expected to be 56.2 million tons, which represents an increase of 4.3 million tons compared to the previous year when production was 51.9 million tons, Table 5. The largest producers remain Russia (~18.3 million tons), Ukraine (~14.5 million tons) and the EU 27 (~9.4 million tons), while Turkey and Argentina contribute with 0.8 and 4.7 million tons, respectively. The increase in production in Ukraine (+14%) and the EU 27 (+6%) offsets the slight decrease in Russia (−4%), while other countries recorded a moderate growth of around 11%. Sunflower accounts for approximately 8% of the total global production of oilseeds, and higher production

contributes to the growth of oil and seed processing and trade, thereby ensuring market stability and meeting growing global demand.

The World and the Republic of Serbia planted sunflower on an average of 27.42 mill. ha (219,868 ha) throughout the test period. The average yield of grain was 1.88 t ha^{−1} / 2.97 t ha^{−1}, and the production was 50,850,021 t / 652,238 t. The exceptional soil and agro-ecological conditions in Serbia, along with the indigenous high yielding genotypes-of which the assortment of the Institute of Field and Vegetable Crops from Novi Sad dominates-make it an ideal place to produce sunflowers (Popović D. et al., 2024).

Table 5. Global sunflower production

Country/Region	Sunflower production in 2024/2025 (million t)	Sunflower production in MY 2025/2026 (million t)	Change (%)
Rusia	~19.0	~18.3	−4 ¹
Ukraine	~12.7	~14.5	+14 ¹
EU-27	~8.9	~9.4	+6 ¹
Turkey	~0.54 ¹	~0.80	+48 ¹
Argentina	~5.0 ¹	~4.7	−6 ¹
Other countries	~6.3 ¹	~7.0 ¹	+11 ¹
Total	~52.4	~55.3-56.6 ⁺	+5-8 ⁺

Notes (sources): ¹USDA/IGC estimates for 2025/26 based on the latest agricultural sources and sunflower market analysis.

⁺Different sources (IGC and USDA) give slightly different total global production estimates between 55.3 and 56.6 mill.t in MY 2025/26.

The introduction of soybeans in states with cool climates, like Germany, Sweden, Denmark, and Norway, has been the subject of recent studies. Growing soybeans is not common in the Baltic states. In order to learn about the best soybean opportunities at high latitudes, research on soybean growth, development, and environmental circumstances is necessary. Because of the shifting climatic and environmental factors, the potential yield of soybeans varies geographically (Van Roekel et al., 2015). According to a number of studies, one of the most important factors influencing soybean growth, development, and productivity is the weather (Cerezini et al., 2016). In new areas, soybean development and productivity can be influenced by temperature and moisture (Hartman et al., 2011). Establishing a successful rhizobial symbiosis

is essential for both soil fertility and soybean yield in organic farming (Herridge and Rose, 2000). In most European soils, which lack rhizobia specific to soybeans, legume inoculation using *Rhizobium* strains is an essential agricultural practice (Albareda et al., 2009). To maintain nitrogen fixing effectiveness, certain *Bradyrhizobium japonicum* strains should nodulate soybean plants (Coskan et al., 2003). Grain yield, protein content, and protein yield are all increased by effective inoculation with *Bradyrhizobium* strains (Zimmer et al., 2016). The rhizobia genome, environmental variables, and various farming methods can all affect how well nitrogen is fixed in a given area (Coskan et al., 2003).

Flax is grown for two different purposes: either as fibre flax for stem biomass and bast fibre characteristics, or as seed flax for oil

production and seed quality. Furthermore, flax can be cultivated using either spring-based or winter-based cropping systems, which have significant effects on seed and fibre performance due to differences in growth duration, yield stability, and susceptibility to abiotic stressors. Flax is highly responsive to agronomic management in all of these production systems, and successful cultivation depends on combining genotype selection with decisions specific to the environment and management, such as sowing date and density, soil fertility management (especially nitrogen and phosphorus), and techniques that promote stand uniformity and lower lodging risk. Global flax output, including seed flax (referred to as "linseed") and fibre flax, significantly decreased between 2022 and 2023, according to Food and Agriculture Organization (FAO) figures. This decline was mostly caused by reductions in harvested land. The amount of seed flax produced worldwide shrank by more than 1.4 million hectares, from almost 4.0 million t in 2022 to 2.6 million t in 2023. Similar trends were seen in the output of fibre flax, which decreased from roughly 0.88 million t to 0.71 million t over that time. These declining trends most likely result from a mix of unfavourable weather, changes in farming systems and land-use objectives, and limitations imposed by the economy or policy that influence producer choices (Popović D. et al., 2026; Popović M. et al., 2026b; Santos et al., 2026). In order to reduce climate-related risks in flax production, adaptive agronomic techniques such as modifying sowing dates, enhancing soil water management, and choosing cultivars more suited to regional climates are becoming more and more relevant (Barbaś et al., 2025; Stavropoulos et al., 2025). Innovation in breeding is essential to making flax producing systems more resilient (Wang et al., 2025). The use of multi-omics methods and genomics-assisted selection are becoming more and more important in current research. These methods, which integrate transcriptomic, proteomic, metabolomic, and genomic data, enhance comprehension of the genetic pathways underpinning stress responses, make biomarker identification easier, and aid

in the creation of more precise genomic selection models (Yadav et al., 2022). Since modern flax cultivars frequently come from very small breeding pools, broadening the genetic foundation of flax is still crucial. The genetic foundation of breeding programs may be expanded by incorporating wild cousins like *Linum bienne* together with landraces and other varied genetic resources. This could improve the stability of fibre properties under changing environmental conditions and increase stress tolerance (Yadav et al., 2022). In addition to genetic enhancement, new technologies and crop management advancements are being investigated to lower climate-related risks and promote more reliable flax production systems. In flax production systems, precision agricultural technology may present potential opportunities to maximise crop management and enhance resource efficiency. Drone-based monitoring systems, remote sensing platforms, and soil moisture sensors are some of the tools that could help detect crop stress earlier and regulate irrigation more precisely. Variable-rate fertilization systems with GPS-guided equipment can provide more focused nutrient administration, maintaining consistent fibre development while lowering input losses and environmental effects. Adaptive crop management under more changeable climatic conditions may be further supported by the integration of digital agriculture technologies, crop simulation models, and decision-support systems (Pyne et al., 2024). Further research is needed to better understand genotype $\times$ environment $\times$ management interactions, improve water and nutrient use efficiency under variable climatic conditions, and develop effective strategies that combine breeding innovations with adaptive agronomic practices (Lafond et al., 2008). Addressing these challenges will require integrated approaches that combine advances in plant breeding, agronomic management, and digital technologies. Particular priorities include developing stress-tolerant cultivars, improving agronomic recommendations for different production systems, and better integrating digital agriculture tools into flax management. The long-term sustainability of flax cultivation

will depend on the effective integration of breeding innovation, climate-adapted agronomic practices, and emerging technological tools that improve productivity while maintaining resource-use efficiency and environmental sustainability (Popović D. et al., 2026; Popović M. et al., 2026b). Significant justifications for introducing soybeans in northern regions above the traditional soybean distribution area in Europe include climate change, new varieties, improved technological capabilities, and greater demand for local resources. Later planting dates and a wide 50-cm row spacing greatly improved the number of pods per plant by 28%, aboveground dry biomass by two times, and seed production by 36% plant⁻¹ in the dry 2015 year. When infected soybeans were sown earlier with 50-cm row spacing in the wet 2016, yield components reached their maximum values of 16.8 g dry biomass, 19.9 pods plant⁻¹, and 7.9 g seeds plant⁻¹. The fat percentage ranged from 17.4 to 21.5% and the protein level from 27.4 to 35.3%. Organically managed areas above the current northern soybean distributional region could sustain regular soybean development; however, management approaches have a major impact on soybean development, productivity, and output quality (Toleikiene et al., 2021).

Soybean and wheat were the two main plant-based protein sources in 2020, accounting for 57.6% and 36.8% of the overall food market, respectively (Sim et al., 2021). These two sources, which are essential for human nutrition, are becoming more frequently linked to allergic reactions (Rizzo et al., 2023). Ninety percent of all known food allergic reactions are caused by soy and wheat, which are both among the top eight food allergens (Remington et al., 2013; Burton et al., 2022). Wheat exacerbates the issue, which is a major concern for over 109 million people globally, or 1.4% of the world's population, who suffer from coeliac disease, an autoimmune condition associated with gluten consumption. The use of vegan and vegetarian products, which are seen as sustainable lifestyle choices (Promhuad et al., 2022), has significantly increased as a result of this progression.

Due to its economic significance, pumpkin is a major crop farmed around the world in both tropical and temperate climates (Zanish et al., 2013). With an aggregate production of 5.1 million MT, or 18.32% of global production, India is the second-largest producer of pumpkins (Faostat, 2020). China leads the world in pumpkin production with 7.4 million MT (26.63%). About 4.0%-4.5% of pumpkin is produced in Russia and Ukraine, with the United States coming in second at 3.76%. With a production of 2.78%, Spain overtakes Mexico to take fourth place. Other nations, such as Bangladesh, Turkey, and Italy, report producing between 2.0% and 2.5% of different types of pumpkin. Pumpkin seeds are a profitable raw material for the food and pharmaceutical sectors because they contain a variety of bioactive chemicals, including polyphenols, flavonoids, phytosterols, and squalene. Pumpkin seeds primarily aid in the treatment of benign prostatic hyperplasia (BHP) and have antidepressant properties. Consuming pumpkin seeds on a daily basis can lower the risk of Parkinson's and Alzheimer's disease. Because pumpkin seeds are high in tocopherols, they can be used to extract edible oil and incorporate it into other food compositions for later use (Singh and Vivek, 2024). Because flax, pumpkin and industrial hemp (*Cannabis sativa* L.) do not cause food allergies and are acceptable for those with coeliac disease (Mamone et al., 2019), they become appealing sources of plant protein (Sim et al., 2021). Hemp is unique in that it is a renewable resource (Burton et al., 2022), grows quickly (Galic et al., 2019), requires little initial investment (Oomah et al., 2002), and has a favourable effect on the environment (Promhuad et al., 2022). The textile industry was the main application for industrial hemp. The hemp plant has substantial nutritional, economic, and social value, according to recent studies (Galic et al., 2019).

CONCLUSIONS

An analysis of organic oil production during 2015-2024 demonstrates that the sector in Serbia has significant development

potential, but its expansion has been accompanied by pronounced year-to-year fluctuations. Sunflowers account for around 8% of all oilseeds produced globally, and more production promotes the growth of oil and seed processing and commerce, ensuring market stability and meeting growing demand. The distribution of organic sunflower seed production shares in 2023 reveals a strong concentration among a few European countries. Romania was the leading producer, according for 41.41% of total European production, followed by France with 32.76%. Together, Romania and France accounted for more than 74% of European organic sunflower seed production. Serbia ranked third, with a share of 11.29%, confirming its increasing importance in the European organic sunflower sector.

The overall area of these crops was 1,256.73 hectares, according to a survey of Serbia's organically grown industrial plants in 2024. With an area of 1,014.86 ha (80.8%) of all industrial plants, followed by soybean with 87.40 ha (7%), and flax with 69.74 ha (5.5%). Hemp occupied 44.1 ha (3.5%), oilseed rape 23.79 ha (1.9%), mustard 12.36 ha (1%), pumpkin 2.82 ha (0.2%), and poppies 0.115 ha (0.01%), while other crops accounted for 1.47 ha (0.1%). The findings indicate that the organic output of industrial plants in Serbia is dominated by sunflowers, which account for the bulk of the total area. Other crops are secondary segments, mostly used for specialised markets and production diversification.

The overall area of these crops was 1,256.73 ha, according to an examination of Serbia's organically grown industrial oil plants in 2024. In 2024, sunflower accounted for 1,014.86 ha (80.8%), followed by soy (87.40 ha; 7%), and flax (69.74 ha; 5.5%). Vojvodina leads with 1,188.13 ha ($\approx 95\%$), according to regional study. Although the majority of the industry has certified organic status, there is still significant space for the expansion of certified areas in the upcoming years, as evidenced by the fact that 1,007.24 ha are already certified and 249.49 ha of industrial plants are currently undergoing conversion. The analysis of base and chain

indices for the total area under organic industrial crops during 2015-2024 revealed pronounced year-to-year fluctuations and considerable variability in cultivated area. The most substantial decline occurred in 2020, when the chain index reached 58.05, whereas a strong recovery was recorded in 2021, when the cultivated area increased by approximately 64% compared with 2020 ($C_i = 163.93$). In 2024, the chain index declined to 54.97, indicating a substantial reduction in the cultivated area compared with the previous year. These fluctuations suggest that the development of organic industrial crop production in Serbia is influenced by a combination of agro-climatic, economic, market and policy-related factors. The significance of ongoing developments in crop management and genetic improvement is underscored by the likelihood that climate change and rising climatic variability will exacerbate current output limits. Future research should therefore focus on improving the resilience, productivity and stability of these crops through the development of adapted genotypes, improved crop management practices and sustainable production technologies.

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