Journal of Elementology ISSN 1644-2296

Šević, B., Dolijanović, Ž., Terzić, D., Rajičić, V., Vasileva, V., Bajagić, M., Cvijanović, V. and Stojiljković, J. (2026)
'Dietary fiber profile and ß-carotene content of corn kernels with specific traits under sustainable cultivation',
Journal of Elementology, 31(3), 585-599,
available: https://doi.org/10.5601/jelem.2026.31.1.3785

RECEIVED: 9 February 2026
ACCEPTED: 29 June 2026

ORIGINAL PAPER

Dietary fiber profile and *β*-carotene content of corn kernels with specific traits under sustainable cultivation*

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Abstract

A two-year study was conducted with the aim of evaluating the impact of growing cover crops and the application of microbiological fertilizers on the nutritional value of sweet corn hybrid kernels grown in the experimental field of the Maize Institute Zemun Polje, Serbia. The experimental design was a randomized split plot with four replications, and the factors of year (A), cover crop (B) – 4 plant species and 2 mixtures and microbiological fertilizer (C) were observed. A sweet corn hybrid (ZPSC 421su, FAO group 400) was grown as the main crop. The research results show significant variations in the content of *β*-carotene (7.08-8.47 μg g^{-1}), total dietary fiber (2.79-3.74%), soluble dietary fiber (0.27-0.56%) and insoluble dietary fiber (2.22-3.30%) depending on the treatment, cover crops and annual meteorological conditions. Cover crops, especially mixtures of winter fodder peas and winter oats, with the application of microbiological fertilizers, increased the content of *β*-carotene to 8.47 μg g^{-1}, while total dietary fibers reached 3.74% in the second year of the research, which was more favorable in terms of meteorological conditions. The unfavorable weather in the first year of the research reduced the nutritional value of the kernel. The results indicate that the integrated application of cover crops and microbial fertilizers has the potential to enhance resilience to adverse weather conditions while improving the nutritional value of hybrid sweet corn kernels.

Keywords: quality, kernel, cover crops, production

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* This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-136/2025-03/200216).

INTRODUCTION

Due to climate extremes, the nutritional quality of food depends on a shift from short-term productive conventional farming to long-term sustainable ecological practices (Jug et al. 2025). Degradation of agroecosystems due to climate change and intensive cultivation leads to nutritional depletion of food (Dolijanović et al. 2022), which directly contributes to an increase of chronic diseases in humans (Dragičević et al. 2021). The integration of cover crops and microbiological fertilizers revitalizes the soil as a key medium for stable production (Terzić et al. 2025). Mixtures of grasses and legumes show better adaptability than pure crops (Vasileva and Vasilev, 2011), whereby legumes promote nitrogen fixation. At the same time, microbiological fertilizers with proteolytic and cellulolytic bacteria accelerate biomass decomposition and reduce the consequences of climate change (Bajagić et al. 2025).

As the most active provitamin A, β-carotene is crucial for the prevention of ophthalmic diseases and protection against oxidative stress (Farasati Far et al. 2023). At the same time, the profile of dietary fiber which includes soluble (pectins) and insoluble fractions (cellulose, lignin) plays a crucial role in the regulation of glycemia, the health of the digestive tract and the prevention of cardiovascular diseases (Alahmari et al. 2024, Wang et al. 2024). However, considering that climatic extremes, such as high temperatures and drought, can drastically reduce the content of these bioactive components, it is necessary to investigate to what extent sustainable cultivation systems can preserve and improve the specific nutritional profile of kernels (Stojiljković et al. 2025*a*, *b*).

The aim of the study was to examine the influence of different cover crops and microbiological fertilizers on the nutritional quality of sweet corn hybrid kernels, with the focus on the content of β-carotene and dietary fiber, in variable meteorological conditions. The novelty of the study lies in the integration of cover crops and microbiological fertilizer as sustainable measures to improve the nutritional quality of sweet corn while simultaneously mitigating the negative effects of weather variability on crop quality. A particular contribution of this research is the evaluation of combinations of leguminous and non-leguminous cover crops with microbiological fertilizer under the specific agroecological conditions of Serbia. Working hypothesis: The application of cover crops and microbiological fertilizer significantly increases the content of β-carotene and fiber in sweet corn kernels, which positively affects nutritional quality.

MATERIALS AND METHODS

Experimental design and location

The research was conducted during the 2014-2015 and 2015-2016 seasons (factor A) on an experimental field (Figure 1) of the Maize Institute

a *b*

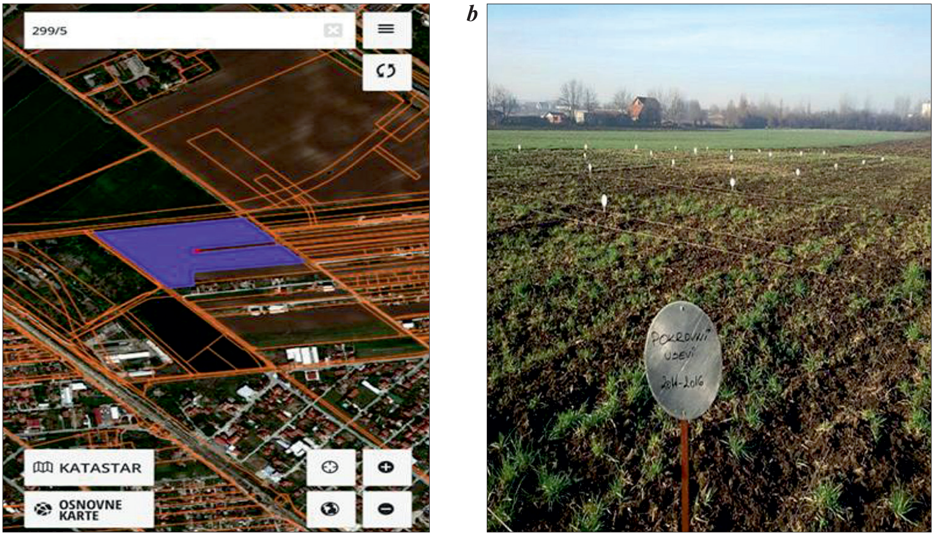

Fig. 1. Location of the experiment: *a* – Zemun Polje, Serbia on cadastral plot number 299/5 (Source: https://a3.geosrbija.rs/), *b* – Experimental field with winter cover crops

Zemun Polje, in Zemun Polje, Serbia (44°52′ N, 20°20′ E, 110 m altitude). The experiment was designed to examine the effects of growing cover crops and applying microbiological fertilizers on the chemical properties of hybrid sweet corn (ZPSC 421su, FAO group 400). The experimental design was a randomized split plot with four replications.

Cover crops

Four types of cover plants (factor B) were grown in the following variants: 1 – common vetch (*Vicia sativa* L.), 2 – winter oats (*Avena sativa* L.), 3 – winter fodder kale (*Brassica oleracea* L. convar. *acephala*), 4 – mixture: winter fodder peas + winter oats, 5 – mixture: common vetch + winter oats, 6 – winter fodder pea (*Pisum sativum* L.) and 7 – control variant, which was not covered with plants. Cover crops were sown by hand in the first half of November in both years, with seeding rates adapted to the species: 120 kg ha^{-1} for common vetch, 160 kg ha^{-1} for winter oats, 15 kg ha^{-1} for winter forage kale and 150 kg ha^{-1} for winter forage peas. The area of each basic plot was 17.5 m^2.

Fertilization

Monopotassium phosphate (MKP 0:52:34) was applied in the autumn to supply phosphorus and potassium, while nitrogen was added in the spring in the form of urea (120 kg ha^{-1} N for oats and control, 80 kg ha^{-1} N for legumes, 90 kg ha^{-1} N for other variants). After plowing the cover crops in the spring before sowing the main crop, liquid microbiological fertilizer UNIKER (factor C) was applied in the amount of 10 l ha^{-1}, which contains *Bacillus megaterium*, *Bacillus licheniformis* and *Bacillus pumilus* (min. 10 l cm^{-3} by strain).

Sowing and harvesting

Sweet corn was sown in the second half of May in both years, with a density of 65.000 plants per ha (distance between rows 70 cm, between plants in a row 22 cm). The kernels were manually separated after harvest, dried at 60 °C and ground to a particle size of <500 μm.

Analyses

Total, soluble and insoluble fibers were analyzed according to the method of Prosky et al. (1992). β-carotene was determined by extraction with n-butanol and expressed as μg β-carotene equivalent (bCE) g^{-1} of dry matter (Vančetović et al. 2014).

Meteorological conditions

In April 2015, precipitation was below the long-term average, amounting to 30.7 mm (Figure 2). In contrast, precipitation in April 2016 (53.9 mm) was close to the long-term average, although air temperature was slightly higher. The sowing period in May of both years was characterized by favorable rainfall amounts, close to the average, which ensured optimal crop emergence. June 2015 was marked by a spell of dry weather, with only 38.6 mm of precipitation, which negatively affected the development of biomass. In contrast, June 2016 was exceptionally wet, with 152.2 mm of precipitation, which was 60.2 mm above the long-term average. July 2015 was extremely unfavorable, with temperatures of 26.8°C, which is 3°C above the long-term average, and only 10.6 mm of precipitation. High temp. (26°C) and moisture deficit continued in August 2015. In the months of 2016, conditions were more moderate, with lower temp. (by about 4°C) and precipitation closer to the multi-year average. Comparative analysis confirms that the growing season of 2015 was extremely unfavorable for the cultivation of sweet corn due to a combination of high temperatures and rainfall deficit, while the year 2016 was meteorologically much more favorable.

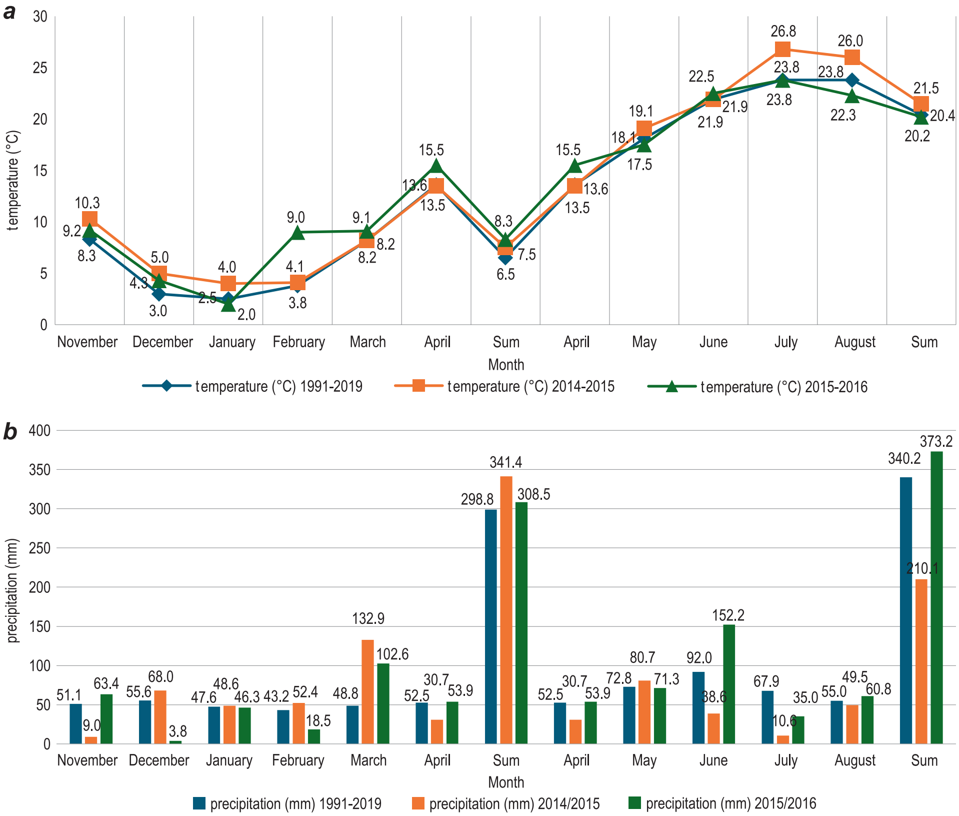

Fig. 2. Average monthly air temperatures (ºC) – *a* and the distribution precipitation (mm) – *b* during the experimental periods (2014-2016) and multi-year averages (1991-2019) in Zemun Polje (Serbia) location

Soil characteristics

The experimental field of the Zemun Polje Maize Institute, where the experiments were carried out, is located in northeastern Srem. Owing to very high quality soil, it creates favorable conditions for growing field crops. Available nitrogen was determined according to the method of Scharpf & Wehrmann (1975). Available phosphorus was determined by the method of Olsen et al. (1954), and accessible potassium was assessed in the same solution (alkaline $NaHCO_3$) with an ion-selective electrode. K content was also determined by ICP-OS (EPA Method 200.7, Martin et al. 1994).

The soil pH was neutral to weakly alkaline, with pH increasing with soil depth (pH H_2O 7.05; pH KCl 7.04) – Table 1. The total nitrogen content was 44.37 kg ha^{-1} in the 0-20 cm layer and 21.66 kg ha^{-1} in the 20-40 cm layer, indicating a moderate nitrogen supply. The soil was also characterized by a high supply of plant-available phosphorus (29.73 and 38.01 mg kg^{-1}) and a very high potassium concentration (150.75 and 160.45 mg kg^{-1}).

Table 1

Basic agrochemical properties of soil on the experimental plot at different profile depths

Depth (cm)	N total (kg ha^{-1})	NH_4 (kg ha^{-1})	NO_3 (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})	pH H_2O	pH nKCl
0-20	44.37	1.82	42.55	25.96	280.42	29.73	150.75	7.05	7.04
20-40	21.66	0.70	20.96	33.19	298.47	38.01	160.45	-	-

Statistical data processing

Statistical data analysis was carried out in IBM SPSS Statistics software, version 26.0. The first factor was the year of production (A), the second factor was cover crops (B), while the third factor was treatment – microbiological fertilizer (C). To compare mean values between treatments, the Tukey's test (HSD – Honestly Significant Difference) was performed. Minitab software (Trial version) was used to develop an Interval Plot showing the average values of the parameters for each treatment combination with a confidence interval of 95%, an Interaction Plot for visualizing the relative importance of different factors affecting the variables and their interactions, a Pareto Chart showing the importance of the observed factors, and a Multi-Vari Chart.

RESULTS AND DISCUSSION

***β*-carotene**

Figure 3*a* shows that *β*-carotene levels vary by cover crop and year across both fertilization treatments. Annual averages are represented by blue (first year) and red (second year) lines, with confidence intervals indicating significant differences between the factors. During the first year, the application of microbiological fertilizer resulted in the highest values of beta-carotene, especially in winter fodder kale (7.76 µg g^{-1}) and a mixture of fodder peas and winter oats (7.08 µg g^{-1}). More favorable meteorological conditions in the second year enabled the production of greater biomass of cover crops, whose plowing increased the content of organic matter and available nitrogen. This improvement in soil fertility directly stimulated the accumulation of *β*-carotene, whose values in the second year were between 8.34 and 8.47 µg g^{-1}. This trend is consistent with research, which indicates that unfavorable weather conditions (high air temperatures, deficiency of precipitation) negatively affect photosynthetic activity and carotenoid accumulation (Mesarović et al. 2019).

Through the complex interaction between the factors of year, cover crop and treatment, their statistical influence was manifested (Figure 3*b*, Table 2). The year had a significant impact, with generally higher average values

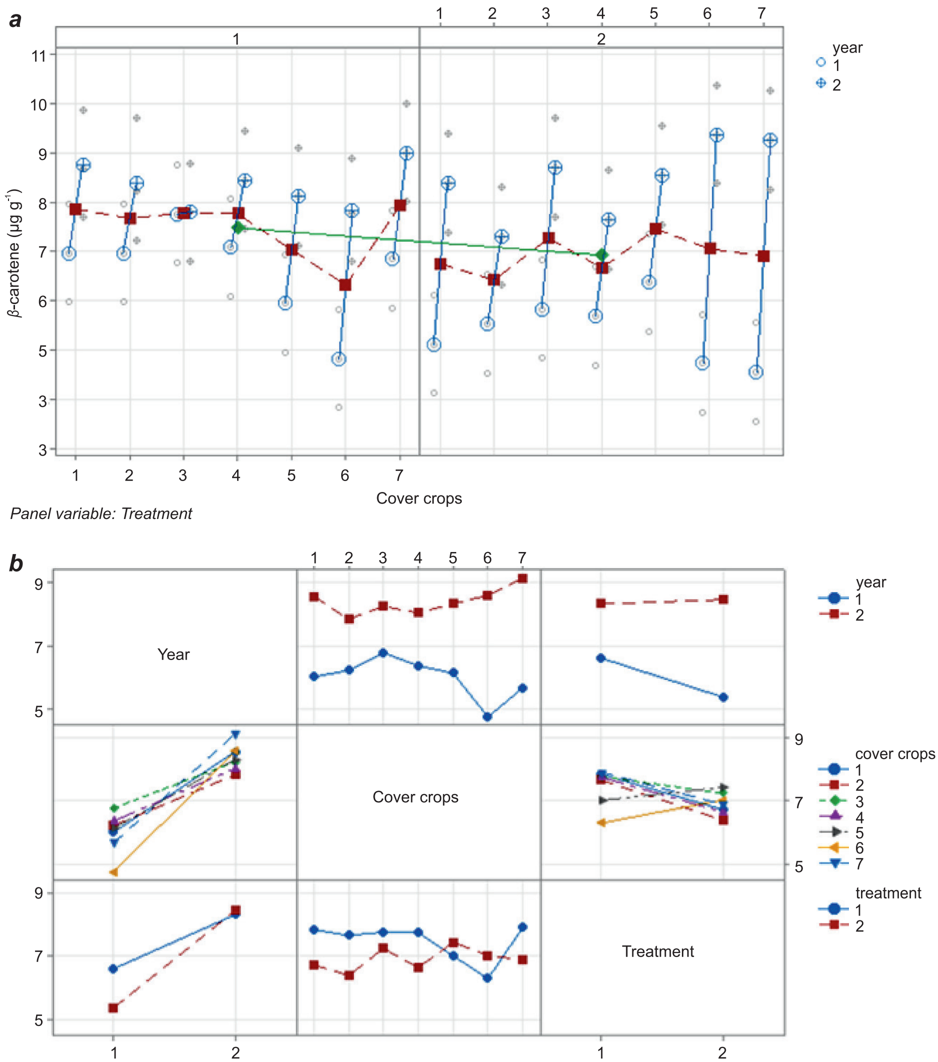

Fig. 3. Multi-Vari Chart for average value of ß-carotene (µg g-1) by year – treatment (*a*) and interaction plot for observed factors (*b*): year: 1 – (2014/2015), 2 – (2015/2016), cover crops: 1 – common vetch, 2 – winter oats, 3 – winter fodder kale, 4 – mixtures of winter fodder peas + winter oat, 5 – mixtures of common vetch + winter oats, 6 – winter fodder peas and 7 – control, treatment: 1 – with microbiological fertilizer, 2 – without with microbiological fertilizer

achieved in the second year of the research. Application of microbiological fertilizer had a positive effect on *β*-carotene level, while certain cover crops such as winter forage pea mixture showed superior results.

Table 2

Analysis of variance (ANOVA) for the effect of year (Y), cover crop (CC), treatment (T) and their interaction on β-carotene (μg g^{-1})

Source	SS	MS	F – Value	Sig.
Year (Y)	120.36	120.36	11.750	*
Cover Crops (CC)	5.4449	0.9074	2.8187	*
Treatment (T)	6.3470	6.3470	19.529	**
Y x CC	15.800	2.6334	8.1798	**
Y x T	9.7172	9.7172	29.899	**
CC x T	11.823	1.9706	6.0634	**
Y x CC x T	5.3651	0.8941	2.7513	*
Total	232.65	2.8031		

** Significant at 1% probability level, * significant at 5% probability level, df – degrees of freedom, SS – sum of squares, MS – mean Squares, *F* – *F* test (value calculated).

Total fiber

The interval graph shows the average values of total fiber in the sweet corn kernel and the 95% confidence interval for each individual treatment (Figure 4*a*). In both years of research, and especially in the second one, when the meteorological conditions were more favorable for the main crop, the highest average values were recorded in the treatment where microbiological fertilizer was applied. In the first year, they were the highest in the variant with winter oats (3.45%) and the mixture of winter fodder peas with winter oats (3.39%). In the second year, higher values than in the control were obtained from the variants with winter oats (3.74%) and winter fodder kale (3.68%). Significantly lower average values (2.79% and 3.04%) were measured in the variants without microbiological fertilizer, which highlights the effectiveness of the applied treatment. Dodevska et al. (2013) reported that the total fiber content varied from 2.5-20.8 g 100 g^{-1} in cereal products, while reaching 14.0-24.5 g 100 g^{-1} in cooked pulses. The influence of individual factors and their interactions can be seen in Figure 4*b*. All considered factors had a statistical impact on the values of total fiber, shown comprehensively through the analysis of variance (Figure 4c).

Soluble fiber

The average soluble fiber content of sweet corn hybrid kernels ranged from 0.27% to 0.56%, depending on the treatment combinations (Figure 5*a*, Table 3). In both years of the study, common vetch combined with the microbiological fertilizer achieved higher soluble fiber contents (0.43% and 0.49%, respectively) than the control variant. Winter cover crops such as winter forage kale and forage peas also increased the content of soluble fiber (0.48% and 0.50%, respectively) compared with the control. Analysis of the

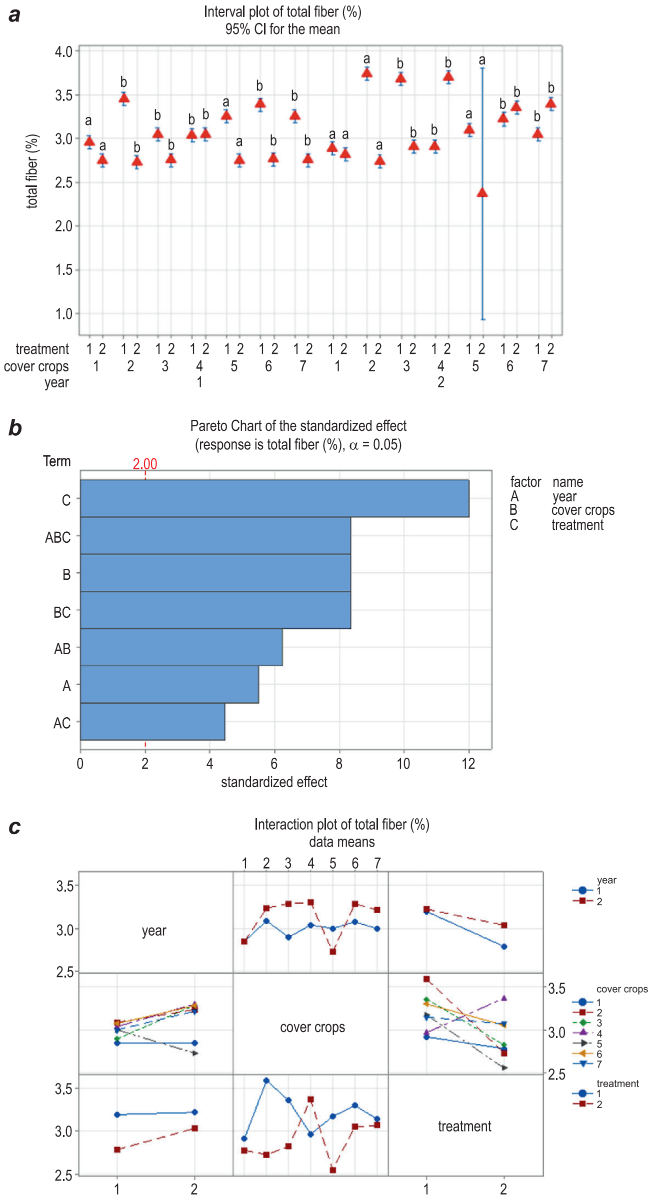

Fig. 4. Interval Plot for the average value of total fiber with a level of significance 0.05 – *a*, Pareto Chart of the Standardized Effect – *b*, and interaction plot for observed factors – *c* of total fiber (%): year (A): 1 – 2014/2015; 2 – 2015/2016; Cover crops (B): 1 – common vetch, 2 – winter oats, 3 – winter fodder kale, 4 – mixtures of winter fodder peas + winter oats, 5 – mixtures of common vetch + winter oats, 6 – winter fodder peas (6) and 7 – control, treatment (C): 1 – with microbiological fertilizer, 2 – without microbiological fertilizer, year x cover crops (AB), year x treatment (AC), cover crops x treatment (BC), year x cover crops x treatment (ABC). Different letters indicate significant differences according to the Tuckey's HSD test at p<0.05

Table 3

Descriptive Statistics of variable total fiber, soluble and insoluble fiber in kernels sweet corn

Variable	Mean	SE Mean	StDev	Sum of Squares	Min	Max
Total fiber (%)	3.0633	0.0380	0.3481	798.30	2.0033	3.7667
Soluble fiber (%)	0.3937	0.0109	0.0997	13.844	0.2000	0.6500
Insoluble fiber (%)	2.6935	0.0402	0.3683	620.65	1.9800	3.4800

SE Mean – standard error of the mean, StDev – standard deviation

main effects and their interactions showed that the year of cultivation had the strongest influence on the soluble fiber content, followed by the type of cover crop and the application of microbiological fertilizer. This is demonstrated by means of a critical value, which individual factors (A, B) exceed (Figure 5*b*), except for treatment (C). A significant interaction between year and cover crop type was also observed (Figure 5*c*), indicating that the effect of cover crops on soluble fiber content depended on the growing season.

Insoluble fiber

Different combinations of treatments, cover crops and years resulted in different levels of insoluble fiber, ranging from 2.22% to 3.30% (Figure 6*a*). In the first year, the highest values were obtained from the varieties grown with winter oats and winter fodder peas as cover crops (3.05% and 3.03%) and with the application of microbiological fertilizer, while in the second year those values were significantly higher at 3.30% (winter oats) and 3.19% (winter fodder kale). Analysis of the main effects and their interactions showed that the interaction between treatment and cover crops had the greatest influence on insoluble fiber content. As indicated by the length of the horizontal bars in Figure 6*b*, a statistically significant effect on the percentage of insoluble fiber was shown. The non-parallel lines in Figure 6*c* further demonstrate the presence of a significant interaction between these factors. Moreover, the application of microbiological fertilizer enhanced the accumulation of total and insoluble dietary fiber, thereby improving the nutritional quality of sweet corn kernels. This finding is of particular importance because dietary fiber contributes to digestive health and reduces the risk of chronic diseases (Barber et al. 2020).

Research (Dragičević et al. 2024) confirms that the combination of cover crops (fodder pea) and biostimulators (with growth parameters) directly improves the nutritional profile and mineral composition of kernels. The synergy of cover crops and microbiological fertilizers improves soil activity, as well as nutritional quality of food (Šević et al. 2025). However, further research is necessary to optimize these combinations for specific agroecological conditions.

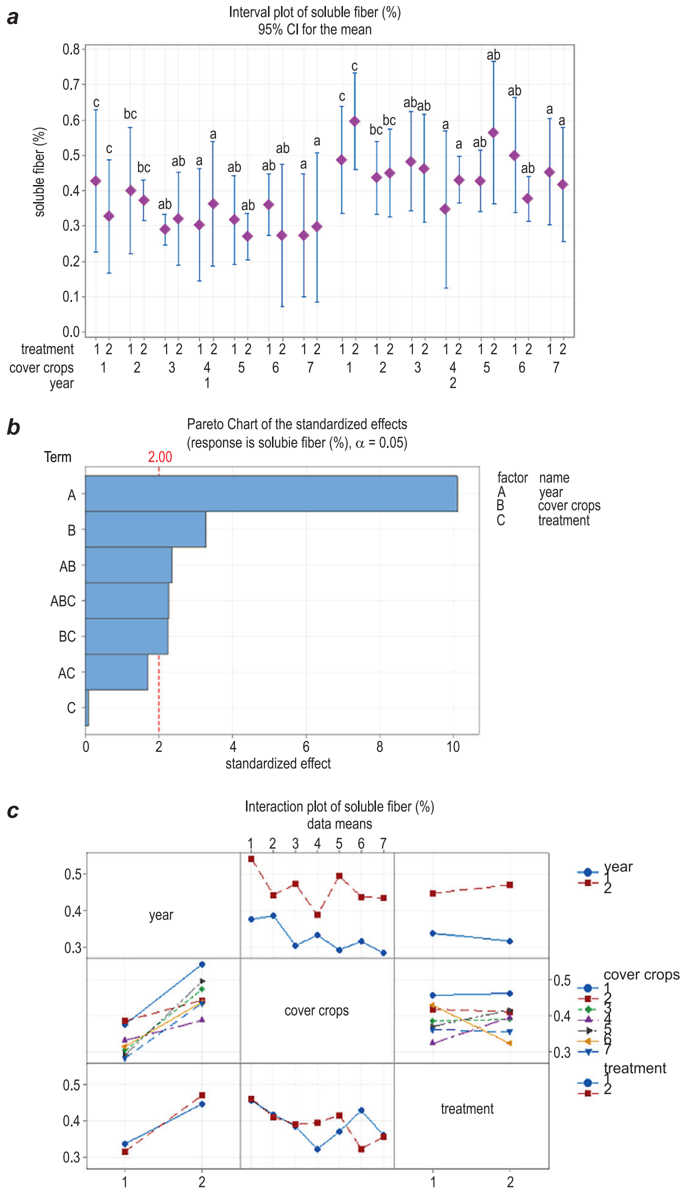

Fig. 5. Interval plot for the average value of soluble fiber with a level of significance 0.05 – *a*, Pareto Chart of the Standardized Effect – *b* and interaction plot for observed factors – *c* of soluble fiber (%): year (A): 1 – 2014/2015, 2 – 2015/2016, cover crops (B): 1 – common vetch, 2 – winter oats, 3 – winter fodder kale, 4 – mixtures of winter fodder peas + winter oats, 5 – mixtures of common vetch + winter oats, 6 – winter fodder peas (6) and 7 – control, treatment (C): 1 – with microbiological fertilizer, 2 – without microbiological fertilizer, year x cover crops (AB), year x treatment (AC), cover crops x treatment (BC), year x cover crops x treatment (ABC). Different letters indicate significant differences according to the Tuckey's HSD test at $p<0.05$

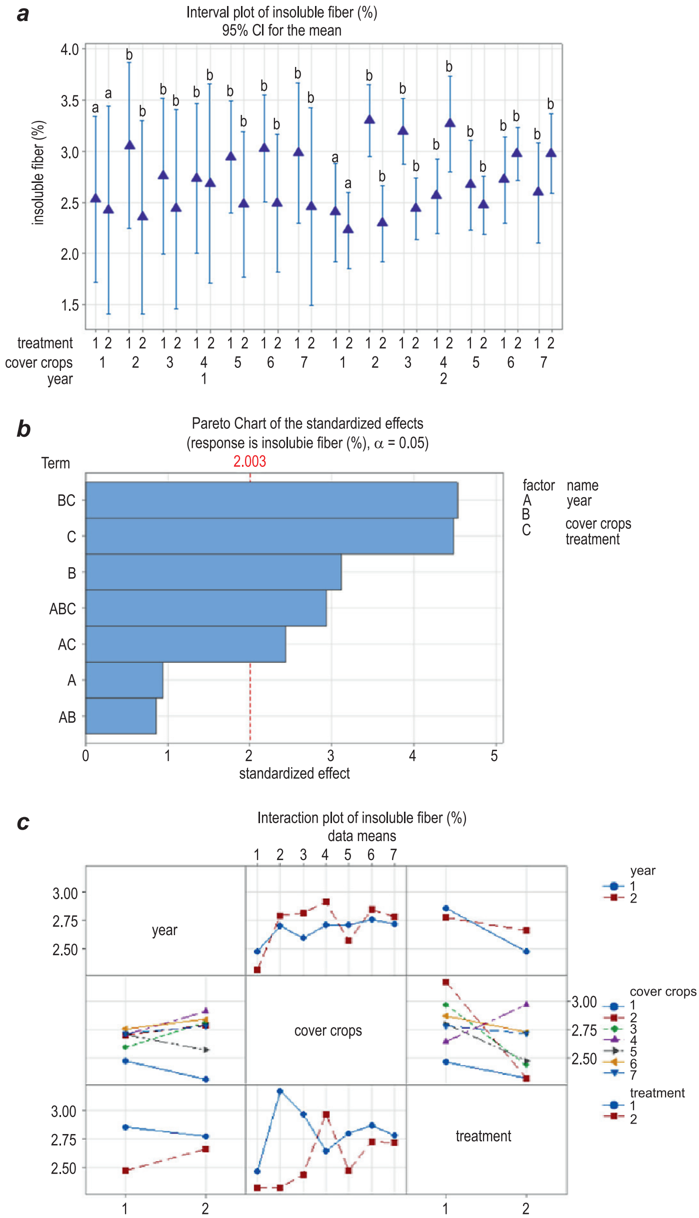

Fig. 6. Interval plot for average value of soluble fiber with a level of significance 0.05 (A), Pareto Chart of the Standardized Effect (B) and interaction plot for observed factors (C) of soluble fiber (%): year (A): 1 – 2014/2015, 2 – 2015/2016, cover crops (B): 1 – common vetch, 2 – winter oats, 3 – winter fodder kale, 4 – mixtures of winter fodder peas + winter oats, 5 – mixtures of common vetch + winter oats, 6 – winter fodder peas (6) and 7 – control, treatment (C): 1 – with microbiological, 2 – without with microbiological, year x cover crops (AB), year x treatment (AC), cover crops x treatment (BC), year x cver crops x treatment (ABC). Different letters indicate significant differences according to the Tuckey's HSD test at p<0.05.

CONCLUSIONS

This research confirms the link between the meteorological conditions that prevailed during the growing season and the nutritional profile of sweet corn. While the precipitation deficit and temperature extremes in the first year limited the level of β-carotene and fiber, cover crops, especially the mixture of winter fodder peas and winter oats with the application of microbiological fertilizer, contributed to the stability and high quality of corn kernels. By enriching the soil with aerial biomass of cover crops, conditions were created for better availability of nutrients, which resulted in better nutritional value of corn kernels, especially in the second year. Future directions of research should define optimal agrotechnical measures that will enable high kernel quality even in unpredictable meteorological conditions.

Author contributions

Methodology – B.Š, Ž.D., software – B.Š. and M.B., conceptualization – B.Š., Ž.D., J.S., validation – Ž.D., V.R., V.V., formal analysis – J.S, D.T, M.B., V.C., investigation – B.Š. and Ž.D., resources – J.S, V.C., data curation – B.Š, D.T., V.V., writing – original draft – B.Š, Ž.D, and J.S., writing – review & editing – B.Š, V.R. and J.S, visualization – D.T, M.B. V.V., supervision – D.T., V.V, M.B., project administration – B.Š., J.S., V.C., funding acquisition – B.Š, D.T, V.R and J.S.

All authors have read and agreed to the published version on the manuscript.

Conflicts of interest

The authors ensure that they have neither professional nor financial connections related to the manuscript sent to the Editorial Board.

ACKNOWLEDGMENTS

This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-33/2026-03/200216, 451-03-34/2026-03/200383 and 451-03-33/2026-03/200045) by the Bulgarian project, 2024-2027: “Intercropping in maize growing for sustainable agriculture”. Our study aligns with the United Nations 2030 Agenda for Sustainable Development, specifically with Goal 2: Zero Hunger.

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