

The impact of cultivation system on nutritional quality of Jerusalem artichoke tubers cultivated in semiarid marginal areas

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Abstract

Jerusalem artichoke grows underground tubers that store fructans, primarily inulin, which are considered as prebiotics and functional dietary fibre with positive physiological benefits on human health. The aim of this study was to assess the yield and nutritional quality of Jerusalem artichoke tubers according to different cropping systems on dry sandy soils from Southern Romania. The experiments were carried out during 2018-2020 at the Research and Development Station for Plant Culture on Sands Dăbuleni, using a randomized complete block design with three replications. The experimental combined factors applied were fertilization with plants density (5×2). After the tubers were harvested, their quality was evaluated using standard methods. The results suggest that Jerusalem artichoke crop has minimal requirements for fertilization and tolerates very well high plants density without affecting significantly the yield and the nutritional features analysed, respectively the contents in total dry matter, soluble dry matter, inulin, soluble carbo-hydrates and C vitamin. A significant positive correlation was determined between the soluble dry matter and soluble carbohydrates content. The assessed biochemical compounds displayed high values in both fertilized and unfertilized conditions and in both densities, showing that Jerusalem artichoke is a perennial crop with multifunctional high growing potential in marginal terrains usually improper for the conventional crops.

Keywords: density; fertilization; *Helianthus tuberosus*; nutritional value; tubers quality; yield

Introduction

Jerusalem artichoke (*Helianthus tuberosus*) (JA), also called “ground apple” “pork carrot” or “potato of the poor”, is a perennial plant of the *Asteraceae* family belonging to the genus *Helianthus*. It is originated from Central America (probably today's Mexico), recently being considered as quality food in Western Europe,

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Central-East and North-East Europe; as a fodder crop for animal feed (Seiler and Campbell, 2004); as a technical crop, respectively a potential source of ethanol due to its high carbohydrate content from tubers (Li *et al.*, 2013) and as medicinal vegetable (Neyrinck *et al.*, 2015; Sawicka *et al.*, 2020). Its value is based primarily on the chemical composition and nutraceutical benefits of the tubers, that are tasty, juicy, delicate, sweet, tasting like kohlrabi or asparagus. JA contains a fairly large amount of dry matter (up to 20%), of which up to 80% fructo-oligosaccharides as inulin (a polymer of fructose) that act as prebiotic fibre in the prevention of intestinal infections and diseases (Teferra, 2021; Tawfick *et al.*, 2022). According to Rao (1999), a daily intake of inulin can effectively increase the number of beneficial bacteria in the colon. Among the nutritional advantages of this fructan are the supply of dietary fibre, low caloric content, high biologically valuable proteins, improved bioavailability of calcium and magnesium absorption, decreased risk of cancer, and reinforcement of the immunological response (Rubel *et al.*, 2021; Tarifa *et al.*, 2021).

Jerusalem artichoke is the largest deposit of inulin in nature (Saengthongpinit and Sajjaanantakul, 2005; Rodriguez *et al.*, 2005; Ostermann-Porcel *et al.*, 2022), which gives a pleasant sweet taste; in the human body is hydrolysed to fructose and safe for diabetics, having a hypoglycaemic effect (Takahashi *et al.*, 2022). The longer JA is stored, sweeter the taste will be, due to the chemical processes that break down inulin into fructose; this fact is important in the process of using tubers, because the human body does not have the ability to process inulin.

JA tubers usually contain about 80% water. Also, they can play an important role in human nutrition as sources of protein (1-2%), carbohydrates (15%), vitamins, inulin (up to 20%) and minerals, especially iron (0.4 to 3.7 mg per 100 g), calcium (14 to 37 mg per 100 g) and potassium (420-657 mg per 100 g) (Kocsis *et al.*, 2008). JA tubers have a high metabolizable energy content of 15 MJ per kg of dry matter (Kleessen *et al.*, 2007). Biomass is considered a rich source for ethanol production (Denoroy, 1996). JA biogas production is much higher compared to other energy crops (Emmerling and Barton, 2007; Kim *et al.*, 2013).

The chemical composition of tubers, and in particular the content of inulin, protein, amino acids, and antioxidants in different genotypes of cultivated JA depend on climatic and soil conditions, cultivation location and cropping technology (Sawicka, 2016; Sawicka *et al.*, 2021). Lakić *et al.* (2018) estimated that the heritability of JA tubers ranged from 34.66% (plant height) to 50.99% (dry matter yield/plant) according to climate and geographic location. The chemical composition of tubers is also highly dependent on soil type, its productivity, genetic potential of the variety and growth phase (Sawicka and Kalembasa, 2013a), which are largely related to harvesting maturity (Saengthobpinit and Sajjaanantakul, 2005; Rodrigues *et al.* 2007). Previous findings showed that JA has the capacity to tolerate a great variety of environmental stresses, including drought, frost, as well as soil types (medium and weak soils, light, loamy sands and loose sands, with unregulated acidity between 4.5 to 8.2 pH) and some pests and diseases (Slimestad *et al.*, 2010; Chen *et al.* 2013; Ali *et al.*, 2021). Also, Bogucka *et al.* (2021) suggested that JA cultivation is possible in places with poorer soils as well as on neglected and abandoned ones thanks to well-developed JA root system.

In Romania JA has almost disappeared as crop, but in the last years is new interest for this plant, especially for medicinal use. The aim of the present work was to determine and to evaluate the chemical composition and nutritional quality of JA tubers cropped under different technological conditions (fertilization doses and planting densities) on sandy soils from marginal areas where other crops perform less. The analysis of the chemical composition of JA tubers was focused on the assessment of the amount of total dry matter, soluble dry matter, inulin, soluble carbohydrates and C vitamin.

Materials and Methods

The researches were carried out during 2018-2020 at the Research and Development Station for Plant Culture on Sands Dăbuleni, Romania (N 43° 48' 04" and E 24° 05'). The JA variety used in the experiment

was Rustic, which is 250 cm plant height with white tubers of about 43 g weight each. The Jerusalem artichokes were planted in sandy soil in 15 April 2018 and the tubers were harvested during the second half of November in each of experimental years, respectively on 16 November 2018, 18 November 2019 and 20 November 2020.

There was analysed the impact of JA cropping system (different fertilization doses and plants cultivation density) on the tubers nutritional quality. The experiment was performed using a randomized complete block design in three replications (Figure 1).



Figure 1. Jerusalem artichoke (*Helianthus tuberosus*): a) view from the experimental field; b) and c) harvesting JA tubers (photo original: Dima M.)

The factors taken into account were the following:

- Factor A- fertilizing doses:

A0- N0P0K0;

A1 - N40P40K40;

A2 - N80P80K80;

A3- N120P120K80;

A4 - N160P160K80;

- Factor B - Planting density:

B1 -35000 plants/ha (70 cm between rows and 40 cm between plants/row);

B2 -28000 plants/ha (70 cm between rows and 50 cm between plants/row).

The experiment was located on a sandy soil, that had been subject to wind erosion, with low nitrogen supply status (nitrogen content between 0.04-0.07%), characteristic of marginal land, known as “Oltenia’s Sahara”. The phosphorus content was between 45 ppm and 93 ppm; thus, the soil was well supplied with extractable phosphorus. Exchangeable potassium values (59-93 ppm) indicated low to medium values supplied. The non-uniformity of the soil could be observed from the values of organic carbon (0.61-0.97%). The pH of the soil showed values between 6.40-7.30, respectively a moderately acidic to neutral reaction.

From a climatic point of view, the three years of study were different. 2018 was a very warm year (20.4 °C average temperature during the vegetation of Jerusalem artichoke), but also rich in rainfall, especially during the period of intense plant growth and tuber initiation (Table 1). 2019 and 2020 were warm years, but with little rainfall compared to 2018. If in 2019 the amount of precipitation recorded was better represented in the first part of the vegetation, in 2020 throughout the vegetation period, were monthly recorded at least 40 mm of rainfall.

Table 1. The main climatic elements in the period 2018-2020 (Research and Development Station for Plant Culture on Sands Dăbuleni Meteorological Station)

Climatic element	Year		
	2018	2019	2020
Average temperature during the vegetation period (°C)	20.4	19.5	19.5
Rainfall (mm)	518.7	289.0	276.2
Absolute maximum temperature (°C)	35.7	38.4	37.3

To determine the quality of Jerusalem artichoke tubers, samples were taken at technological maturity (3 kg each). Three samples were taken from each plot. Chosen samples of tubers were washed and chopped, then chemical analysis of the fresh material was carried out immediately after harvest, according with standard methods, and the following determinations were performed in the laboratory:

1. total dry matter (TDM) (%) - gravimetric method (oven-dry method, NFTA (2001));
2. soluble dry matter (SDM) (%) - refractometric method (ISO 2173 (2003));
3. vitamin C (mg/100 g f.s.) - titrating with 2,6-dichlorophenolindophenol sodium salt method (ISO 6557-2 (1984));
4. inulin (%) - spectrophotometric method (Saengkanuk *et al.*, 2011);
5. soluble carbohydrates (%) - Fehling-Soxhlet method (AOAC, 1980);
6. production per variant (kg/ha) - by weighing with DESSIS type scales, with three decimals (error \pm 5/10 g).

Using an accelerated solvent extraction method, the inulin was removed from the raw material before being hydrolysed in acid condition. Spectrophotometry was used to determine the fructose content of the hydrolysates. The spectrophotometric method relied on the oxidation of fructose by periodate and the measurement of the absorbance at 350 nm of the triiodide complex generated after the addition of potassium iodide to determine how much periodate was still remaining. The optimum conditions for the detection of fructose were 1 mmol L⁻¹ periodate and 1.5 mmol L⁻¹ potassium iodide at pH 6 (Saengkanuk *et al.*, 2011);

The content of vitamin C (mg per 100 g⁻¹) was determined by titrating with 2,6-dichlorophenolindophenol sodium salt.

The results were statistically analysed by using Microsoft Office Excel (2019) software and JASP 0.17.1.0 (JASP Team, 2020). The descriptive results were displayed together with standard error. The software used for the design of the diagrams were JASP 0.17.1.0 for Figure 2 and Figure 3, respectively Excel 2019 for Figure 4. The statistical relationship between the studied variables was defined by correlation analysis (Pearson's correlation coefficients) and the confidence intervals ($p < 0.05$), they being calculated with JASP 0.17.1.0. On the scatterplots matrix designed with JASP 0.17.1.0, were represented the grouped pairs of the considered variables. There were displayed the following statistical outputs: the trendline, the confidence intervals (95%) and the prediction intervals (95%).

Results and Discussion

The chemical composition of JA tubers is mostly connected to their quality. Dry matter content is one of the most important parameters of the chemical composition of Jerusalem artichoke tubers and it is dependent on the genetic characteristics of the cultivars, weather conditions in the years of research, technological conditions, as well as on the interaction of these factors (Sawicka and Kalembasa, 2011; Sawicka *et al.*, 2020).

In Figure 2 a-f is presented the influence of the fertilization variants from the experiment on the fresh tubers yield and the considered quality features of the tubers, respectively yield, total dry matter (TDM) soluble dry matter (SDM), inulin, soluble carbohydrates and C vitamin.

From the diagrams is very obvious that fertilization influences in various ways the tubers yield and their quality. Thus, the greatest tubers yields were obtained in the variant A3 fertilized with N120P120K80 and the lowest in the non-fertilized variant A0 (Figure 2a). In the case of TDM are visible differences (Figure 2b), but they aren't so distinct and in the case of tubers yield.

Referring to the SDM content in tubers (Figure 2c), the situation is opposite compared with the tubers yield, respectively the variant non-fertilized (A0) has the greatest SDM and the variant A3 (N120P120K80) has the lowest SDM content. Inulin content in tubers determined by fertilization (Figure 2d) was highest in the variant A1 fertilized with the lowest dose, respectively N40P40K40. The content in soluble carbohydrates manifested a similar impact of fertilization applied as in the case of SDM, respectively variant A1 non-fertilized had the greatest soluble carbohydrates content while the lowest was determined in variant A3 (N120P120K80) (Figure 2e). The greatest C vitamin content was determined in the variant A2 fertilized with N80P80K80, the higher values determining the decrease of C vitamin content as it cannot be noticed in Figure 2f.

In Figure 3 a-f is presented the influence of the considered plants density variants on the tubers yield and their chemical composition. Thus, high densities of 35000 plants/ha⁻¹ (B1) determinates higher yields, lower TDM, SDM and carbohydrate contents, but in the case of inulin and C vitamin content the impact of the analysed densities isn't such obvious.

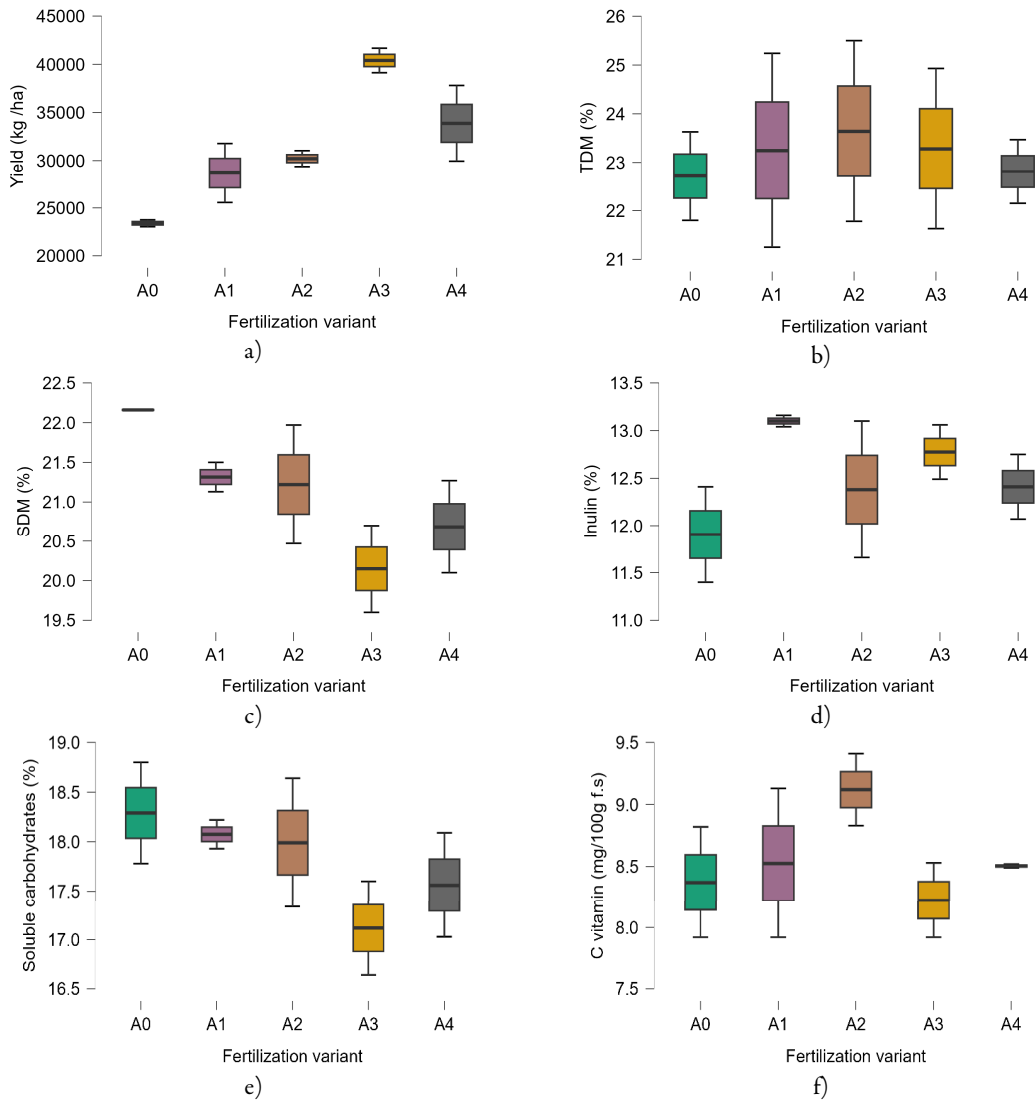


Figure 2. (a-f). Yield and biochemical composition of Jerusalem artichoke tubers depending by fertilization during 2018-2020 (standard error displayed): a) yield; b) total dry matter – TDM; c) soluble dry matter - SDM; d) inulin; e) soluble carbohydrates; f) C vitamin

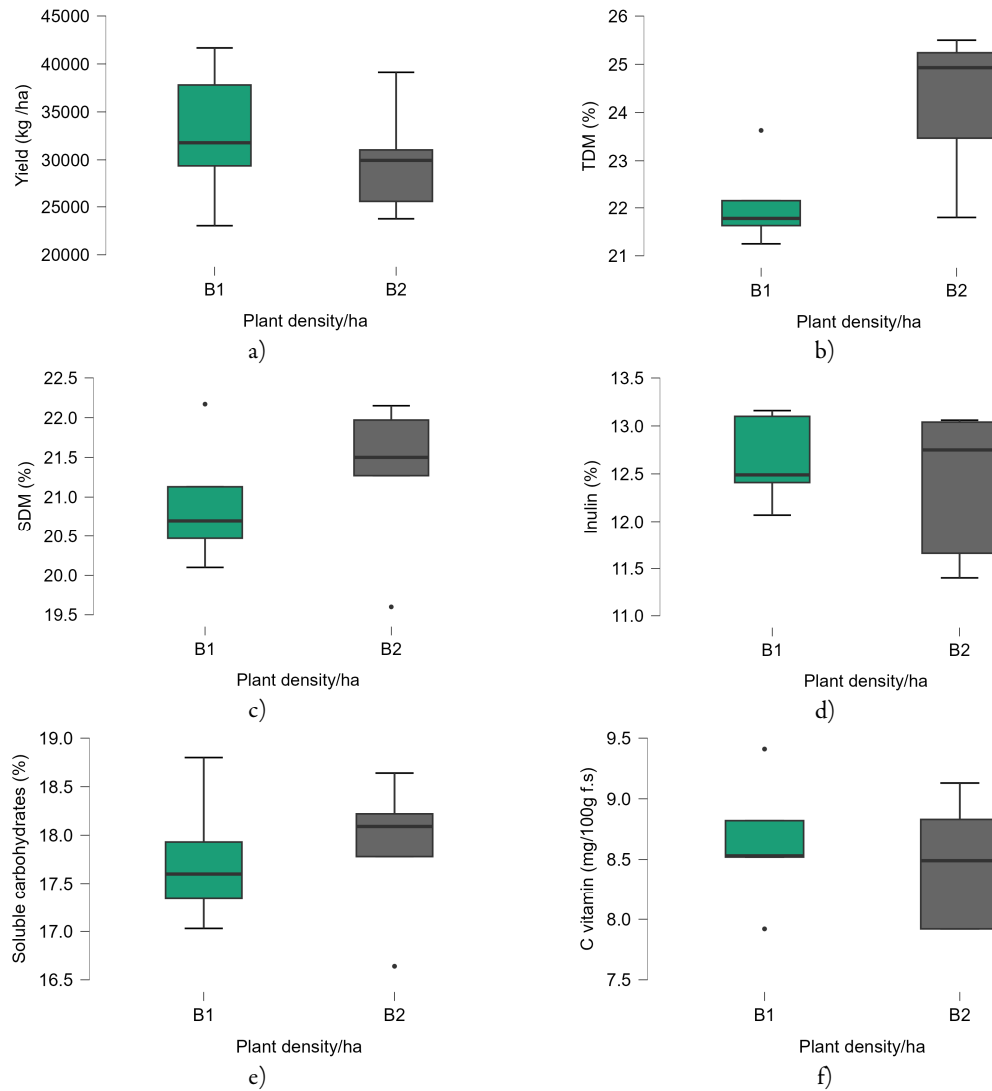


Figure 3. (a-f). Yield and biochemical composition of Jerusalem artichoke tubers depending by plants density per hectare during 2018-2020 (standard error displayed): a) yield; b) total dry matter – TDM; c) soluble dry matter - SDM; d) inulin; e) soluble carbohydrates; f) C vitamin

The combined effect of fertilization doses and plants density is presented in Figure 4 a-f. The highest yield of tubers (41671 kg ha^{-1}) was determined in the variant fertilized with N120P120K80 at a density of 35000 plants/ha (A3B1) (Figure 4a), and the lowest in the variant nonfertilized and with the same density of 35000 plants/ha, respectively variant A0B1. Thus, according to fertilization system and planting density (during the years 2018-2020) in the Jerusalem artichoke tubers the total dry matter content (TDM) ranged between 21.25% in the variant fertilized with N40P40K40 at a density of 35000 plants/ha (A1B1) and 25.50% in the variant fertilized with N80P80K40 at a density of 28000 plants/ha (A2B2) (Figure 4b).

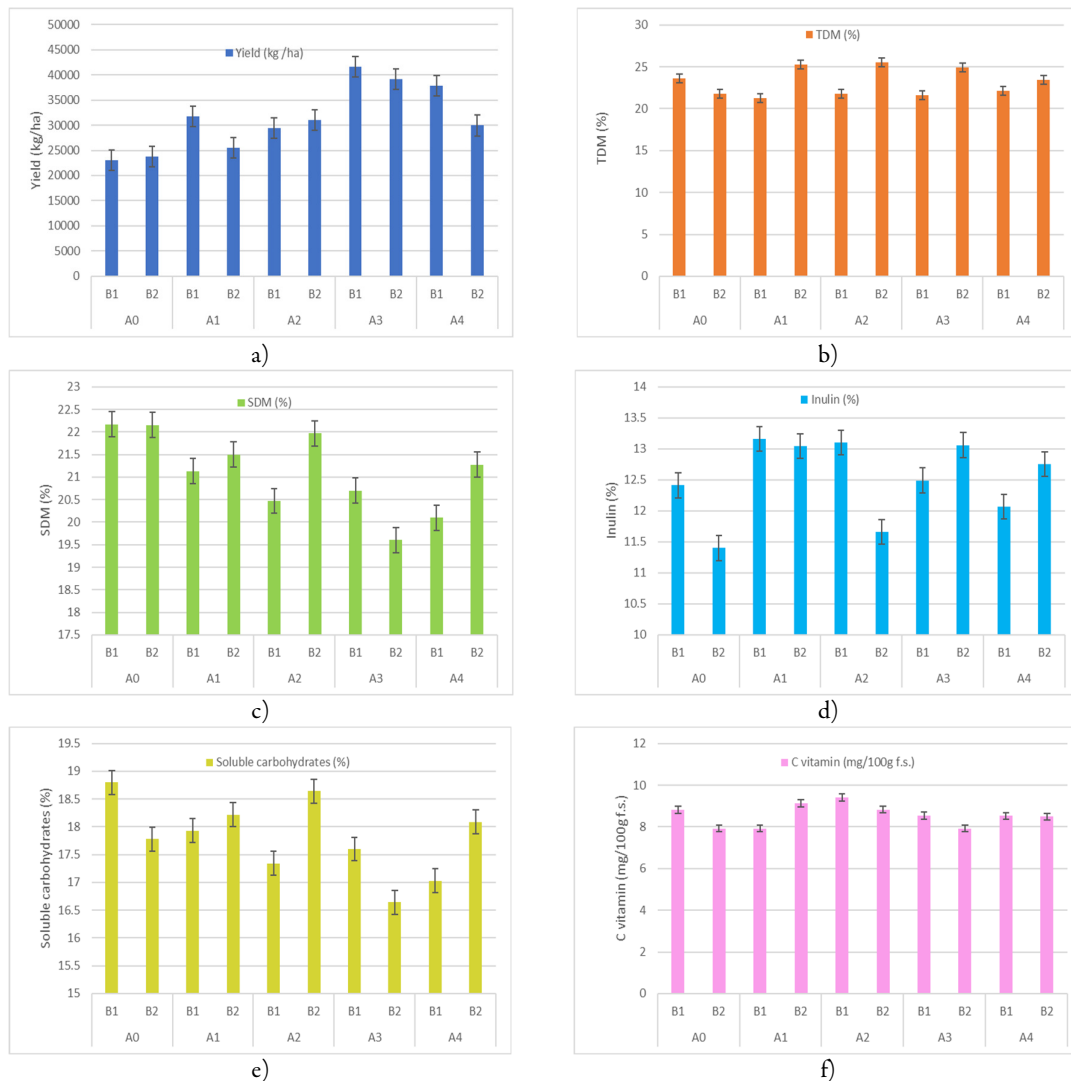


Figure 4. Yield and biochemical composition of Jerusalem artichoke tubers depending by fertilization rate and planting density during 2018-2020 (standard error displayed); a) yield; b) total dry matter – TDM; c) soluble dry matter - SDM; d) inulin; e) soluble carbohydrates; f) C vitamin

Similar results were obtained by Žaldarienė *et al.* (2012), in a study conducted on a farm in Lithuania where dry matter content was 23.21%, and the average weight of the tubers was 26.1 g. The water content from the JA tubers represents the difference from the total fresh yield and total dry matter content (TDM). Vânătoru (2017) emphasized the value of water from Jerusalem artichoke tubers for the human body. De Santes and Frangipane (2017) determined in the Jerusalem artichoke tubers a water content of 79.76 - 81.25 %, while Cieślík *et al.* (2011) and Qiu *et al.* (2018) found that the fresh mass of *H. tuberosus* tubers contained approximately 75 to 79% water. Certain cells can be rejuvenated by the cellular water that the Jerusalem artichoke produces and metabolizes because of its unique physical characteristics. Recent studies showed that Jerusalem artichoke could help to keep the heart muscle healthy (Sawicka *et al.*, 2020; Saiki *et al.*, 2022).

The soluble dry matter values (SDM) (Figure 4c) that ranged between 19.6% in the fertilized variant with a dose of N120P120K80 at a density of 28000 plants/ha (A3B2) and 22.17% in the unfertilized variant at a density of 35000 plants/ha (A0B1).

The particularity of this crop is that JA tubers accumulate high levels of inulin and fructo-oligosaccharides instead of starch (Yovchev and Le-Bail, 2021). Compared to other plants, it has been found that the inulin in Jerusalem artichoke has the lowest percentage of glucose and sucrose, thereby helping patients with diabetes to normalize blood sugar (Takahashi *et al.*, 2022)

The highest inulin content was 13.16%, being obtained in tubers grown on sandy soils was determined in the variant fertilized with N40P40K40 and at a density of 35000 plants/ha (A1B1) and the lowest inulin content was determined in the variant nonfertilized at a density of 28000 plants/ha (A0B2) (Figure 4d). Sawicka (2002), found that the inulin content was highest when fertilizing with nitrogen 50 kg ha⁻¹. In contrary, Nashwa *et al.* (2019) showed that the application of 100 kg ha⁻¹ N led to an increase in the percentage of inulin in the tubers, but our results showed highest content of inulin at relatively low nitrogen application rate at both plants densities analysed in the experiment. As the nitrogen applied increased twice or triple the results regarding the inulin content were relatively similar, respectively 13.1% (A2B1) and 13.06% (A3B2).

Kays and Nottingham (2007), in a Canadian study determined in different groups of JA varieties a carbohydrate content comprised between 8.2% and 20.7%. At Research and Development Station for Plants Culture on Sands Dăbuleni, the carbohydrate content in the variety Rustic was comprised between 16.64% (A3B2) and 18.8% (A0B1) (Figure 4e). JA tubers are a source of C vitamin (4.1 mg/100 g f.s.) (Scollo *et al.* 2011). Mahrous *et al.* 2016 and Ermosh *et al.* 2020, determined in Jerusalem artichoke tubers an amount of C vitamin comprised between 17-18.64 mg/100 g f.s. Thus, Yue Wang *et al.* (2020) found in Jerusalem artichoke tubers a C vitamin content between 7-26 mg/100 g f.s. In our research, the highest amount of C vitamin (9.41 mg/100 g f.s.) was recorded in the variant fertilized with N80P80K80 at a density of 35000 plants/ha (A2B1) (Figure 4f). The lowest C vitamin content (7.92 mg/100 g f.s.) was determined in three very different variants as fertilization dose and plant densities, respectively A0B2, A1B1 and A3B2.

In Table 2 are presented the correlation coefficients between the fertilization dose and the yield and analysed quality features. As it can be noticed, there were significant positive correlations between the fertilization with N, P and K on the tubers yield ($r = 0.754^*$) and negative significant correlations with SDM ($r = -0.695^*$).

Table 2. Correlation of the fertilization dose on Jerusalem artichoke yield and chemical composition (total dry matter (TDM) soluble dry matter (SDM), inulin, soluble carbohydrates and C vitamin)

Variable		Yield (kg ha ⁻¹)	TDM (%)	SDM (%)	Inulin (%)	Soluble carbohydrates (%)	C vitamin (mg/100 g f.s.)
N	Pearson's r	0.754*	0.020	-0.695*	0.159	-0.529	-0.010
	p-value	0.012	0.957	0.026	0.660	0.116	0.978
P	Pearson's r	0.754*	0.020	-0.695*	0.159	-0.529	-0.010
	p-value	0.012	0.957	0.026	0.660	0.116	0.978
K	Pearson's r	0.754*	0.119	-0.692*	0.261	-0.478	0.194
	p-value	0.012	0.744	0.027	0.467	0.162	0.592

Thus, the application of NPK determinates the increase of the tubers yields of JA, but in the same time determinates the decrease of the soluble dry matter content. Sawicka and Kalembasa (2013b) suggested that environmental factors influenced 34.2%, geographical location 12.1%, and cultivars 11.9%, the yield variability. The rest of the phenotypic variability was attributable to the interaction of cultivars and locations with the years of research.

Drought and fertilizers with nitrogen, phosphorus and potassium can strongly affect the weight of dry matter (Monti *et al.* 2005, Long *et al.* 2008). Multiple studies have described the effect on fertilizer application for Jerusalem artichoke. For example, lack of phosphorus or potassium alters the morphogenesis, growth and yield of tubers, more pronounced compared to the aerial part (Soja *et al.* 1990).

However, the influence of nitrogen on yield is stronger than that of potassium, due to differences in their original soil content; nitrogen determines the photosynthesis potential and somewhat increases the efficiency of water use (Soja and Haunold, 1991). At harvest, tuber production can reach up to 62 t ha⁻¹ (Zhong *et al.*, 2019). The dry weight of JA tubers and the rate of inulin increased with the increase of the nitrogen rate up to 90 kg ha⁻¹ N (Ezzat *et al.*, 2013). Sawicka (2002), found that the inulin content was highest when fertilizing with 50 kg ha⁻¹ N, while the dry matter content of the tubers increased to 100 kg ha⁻¹ N. Also, Nashwa *et al.* (2019) showed that the application of 100 kg ha⁻¹ N led to an increase in the percentage of dry matter and inulin in the tubers. Tony (2013) showed that the use of mixed bio-fertilizers with chemical fertilization led to an increase in dry weight by 18.1% compared to the unfertilized control.

Thus, there was considered the potential statistical interrelation among the production and some quality features of the JA tubers. In this way the obtained results were correlated (Table 3), there being found some correlations. The analysis of Pearson's simple correlation coefficients carried out in this study showed that the most significant correlation coefficient was determined between the SDM and soluble carbohydrates content, respectively $r = 0.903^{***}$. The other correlation identified are two negative ones, respectively between the yield and SDM ($r = -0.794^{**}$) and between yield and soluble carbohydrates ($r = -0.666^*$). Ahmed *et al.* (2005) highlighted a significant influence of the interaction between the genotype and the environment (G × E) and a significant interaction between the studied strain and the place of growth.

Table 3. Correlation among the Jerusalem artichoke yield and chemical composition (total dry matter (TDM) soluble dry matter (SDM), inulin, soluble carbohydrates and C vitamin)

Variable		Yield (kg ha ⁻¹)	TDM (%)	SDM (%)	Inulin (%)	Soluble carbohydrates (%)
TDM (%)	Pearson's r	-0.142	—			
	p-value	0.697	—			
SDM (%)	Pearson's r	-0.794**	0.137	—		
	p-value	0.006	0.706	—		
Inulin (%)	Pearson's r	0.177	0.005	-0.498	—	
	p-value	0.625	0.990	0.143	—	
Soluble carbohydrates (%)	Pearson's r	-0.666*	0.284	0.903***	-0.254	—
	p-value	0.035	0.426	< 0.001	0.478	—
C vitamin (mg/100g f.s)	Pearson's r	-0.268	0.235	0.125	0.167	0.322
	p-value	0.454	0.514	0.731	0.644	0.364

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

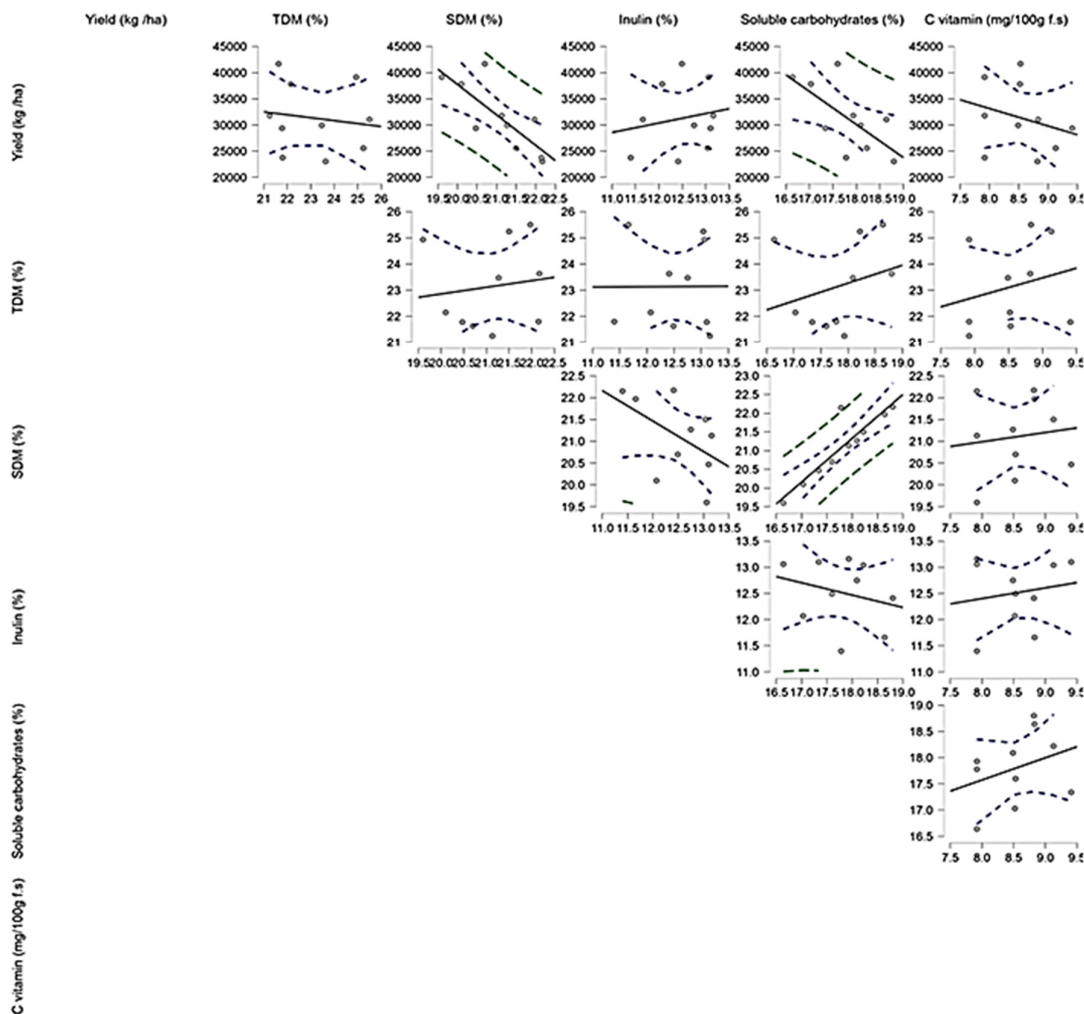


Figure 5. Correlation plot among the Jerusalem artichoke yield and the analysed quality parameters (total dry matter (TDM) soluble dry matter (SDM), inulin, soluble carbohydrates and C vitamin); there are displayed: trendlines, confidence intervals (95%) (in case of the existence of statistical significance) and prediction intervals (95%)

In Figure 5 is presented the correlation plot among the yield and the quality features of JA tubers analysed here. On the scatterplots are displayed: trendline, confidence intervals (95%) and prediction intervals (95%).

There is few research focused in the correlation of some production and quality of JA, they mostly are regarding to correlate some productive features with biometrical and vegetative features of this crop in marginal areas on sandy soils (Lakic *et al.*, 2018).

Previous results showed that Jerusalem artichoke (JA) is a productive crop with a relatively low input, suitable for poor soils from marginal areas, with a highly climatic adaptability and therefore, in the future, it can be considered an important source for food, fibre and energy.

Conclusions

The results obtained regarding the nutritional quality of Jerusalem artichoke tubers highlight the low requirements of the species for the consumption of fertilizers. The studied biochemical compounds showed in general a high content at low doses of fertilizers as well as in the unfertilized variant. The planting density of the tubers doesn't influence significantly the quality of the Jerusalem artichoke tubers. Fertilization applied was correlated positively with the yield and negatively with soluble dry matter content of JA. Jerusalem artichoke has a good potential for cultivation on dry and poor sandy soils due to the adaptability to harsh environments, where can provide satisfactory yields both quantitative and qualitative. Its specific high content in inulin could increase the interest for cultivation, but also the other potential uses. Thus, this species hasn't special technological requirements, being from this perspective a crop that can contribute successfully to the concept of food safety species, because it grows success-fully especially in semiarid marginal areas that cannot be cultivated with other species, where it can be maintained many years due to its perennity.

Authors' Contributions

Conceptualization MD, MP, OC, VS; Data curation MD, AD; Formal analysis EB, MP; Funding acquisition MD, MP; Investigation MD, MP, OC, VS, CS, ALO; Methodology MD, MP, OC; Project administration MD; Resources ALO, MD; Software VS, EB; Supervision MD, CS, SV, MP; Validation MD, MP, VS, OC; Visualization AD, EB, CS, ALO; Writing - original draft MD, MP, OC, VS; Writing - review and editing AD, EB, CS, ALO. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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