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Yields and Bioactive Substances of Selected European Asparagus Cultivars Grown for Green Spear Production as Influenced by of Post-Harvest Drip Irrigation on Sandy Soil in Central Poland

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ABSTRACT

The field experiment was conducted during the years 2006–2008 on a very light soil in central Poland in an area particularly deficient in water. The key aim of the study was the reaction of 10 European asparagus (*Asparagus officinalis* L.) cultivars: Ravel, Rambo, Rally, Ramada, Rapsody, Cipres, Plaverd, Backlim, Grolim, Orane, grown for green spear production to surface drip irrigation. Drip irrigation of the asparagus plants had a positive effect both on summer stalks and green spears. A significant increase in the height, number and diameter of summer stalks, as well as an increase in the marketable yield, weight and number of green spears was observed for most of the cultivars. Both factors, the irrigation used and the asparagus cultivars, significantly modified the antioxidant content in asparagus spears. The Rapsody cultivar accumulated significantly more, and the Grolim cultivar significantly less, total polyphenols in asparagus spears at unirrigated plots. An inverse relationship was obtained in the Grolim cultivar with respect to the content of vitamin C, which accumulated the most of it under the irrigation conditions. The Ramada cultivar from irrigated plots contained significantly the highest amount of total carotenoids. In turn, the Cipres and Grolim cultivars from irrigated plots were characterized by the highest antioxidant activity.

Keywords: asparagus, European cultivars, water needs, drip irrigation, yield, very light soil.

INTRODUCTION

Asparagus (*Asparagus officinalis* L.) is a perennial vegetable, which is classified under the *Asparagaceae* family [Kobus-Cisowska et al., 2019]. This species comes from the eastern Mediterranean and Asia Minor and has been cultivated for over 2,000 years. Asparagus is grown all over the world, including: in the United States, Italy, the Netherlands, Canada, Germany.

Asparagus is cultivated on a large scale in temperate climates both in Europe (Germany, Spain), Asia (China) and South America (Peru). The current total area of this vegetable in the world is approximately 200,000 hectares, the world harvest is approximately 1.5 million tons [Fuentes-Alventosa, 2009; Dziedziński et al., 2019; Szczepaniak et al., 2019]. However, Poland is not a country with a large production of asparagus, and the crops of shoots from local crops are mainly exported to European Union countries (mainly Germany) [Rolbiecki, 2013; Szczepaniak et al., 2019]. The demand for this valuable vegetable is high mainly among domestic consumers, who care about eating healthily. *A. officinalis* is a low-calorie vegetable that has deacidifying properties. Due to the presence of many minerals, vitamins and bioactive compounds in the tissues, such as polyphenols, anthocyanins and saponins, this vegetable has health-promoting properties. Based on *in vitro* and *in vivo* studies, it has been shown that this species has anticancer, antioxidant, immunomodulatory, antihypertensive and antiepileptic, hypoglycemic, laxative and diuretic properties [Elsaid et al., 2015; Mastropasqua et al., 2016; Sullivan et al., 2017; Dziedziński et al., 2019; Guo, 2020]. In folk medicine, various parts of asparagus have been used for centuries to treat neuralgia, rheumatism and support eyesight Cieślik and Siembida [2011]. Due to the presence of the antioxidant glutathione in the shoots, eating this vegetable is helpful in the treatment of cataracts and supports the functioning of the heart, regulation of blood pressure and the nervous system. Thanks to the presence of phytosterols, vegetables help reduce cholesterol levels and cleanse blood vessels of deposits [Low Dog, 2009; Conversa et al., 2019]. According to the tradition of the Far East, asparagus alleviates the course of diseases such as diabetes, bronchitis, whooping cough, tuberculosis, and also helps in disrupting the menstrual cycle [Park et al., 2016].

Growing asparagus is very demanding. Obtaining high-quality asparagus spears depends not only on the cultivar but also on the agrotechnical procedures carried out during the growing season, including the method of irrigation, which determines the properties and quality of the obtained shoots. New cultivars of asparagus usually have high soil and water requirements [Rolbiecki and Rolbiecki, 2008; Rolbiecki, 2013; Szczepaniak et al., 2019; Rolbiecki et al., 2021a]. Therefore, it is important to create optimal conditions for growth and development during the growing season for obtaining a satisfactory commercial yield of a given asparagus cultivar [Rolbiecki, 2013; Szczepaniak et al., 2019; Rolbiecki et al., 2021a; Cruz-Bautista et al., 2023].

Water is the main component of living organisms and is necessary for the growth and development of plants. Globally, agriculture uses approximately 70% of available freshwater to irrigate crops. On light soils with low retention capacity in arid and semi-arid regions, the need for fresh water is nearly 90% for irrigation [Li et al., 2020]. In Poland, almost half of the land intended for cultivation consists of light and very light soils [Pierzgalski and Jeznach, 2006]. Their main disadvantages include unfavorable water properties, such as: too high permeability, poor drainage, low water retention, short-term reserves of water easily available to plants, rapid drying of the soil, longer and more dangerous dry periods for plants compared to medium and heavy soils [Rolbiecki, 2023]. For sustainable water management in agriculture area, using simulation model such as Aquacrop and irrigation systems are useful tolls to estimate effect of applied water depth and quality of irrigation water on crop yield [Kale Celik, 2022]. In Poland's climatic conditions, the greatest rainfall deficits, extremely unfavorable water balances and increased frequency of long periods without rainfall occur in the central part of the country, the so-called The Land of Great Valleys, which also includes the Bydgoszcz region [Żarski, 2011; Rolbiecki, 2013]. In order to increase the productivity of these soils, frequent water shortages should be supplemented using irrigation. Scientific research conducted in the Bydgoszcz region has shown the high advisability of using this basic yield factor on soils with low retention capacity [Rolbiecki and Robliecki, 2008; Rolbiecki et al.; 2011; Rolbiecki, 2013; Rolbiecki et al., 2021a; Rolbiecki et al., 2021b]. A modern irrigation technique for field crops is drip irrigation [Kaniszewski 2005, Jeznach, 2009; Rolbiecki et al., 2021a; Rolbiecki et al., 2021b]. One of the many advantages of this system is the easy and precise administration of small doses of water directly to the root zone of plants. This modern system has many advantages, one of which is the easy and accurate application of small doses of water directly to the root zone of plants [Rolbiecki, 2013; Rolbiecki at al., 2021ab].

The goal of the research was to verify the response of 10 European asparagus cultivars (Ravel, Rambo, Rally, Ramada, Rapsody, Cipres, Plaverd, Backlim, Grolim, Orane) grown under drip irrigation conditions. The experiment was carried out on the very light, sandy soil and in an area particularly poor in water (region of central Poland), where the use of supplemental irrigation is justified.

MATERIALS AND METHODS

Experimental site and design

A four-year (2006–2008) field study was carried out on post-agricultural land located in Kruszyn Krajeński (53°04′53″N, 17°51′52″E) near Bydgoszcz in central Poland. The area where the experiment was carried out belongs to the so-called Land of the Great Valleys, where there are deficits in precipitation, extremely unfavorable water balances and increased frequency of long-term periods without precipitation [Żarski, 2011; Rolbiecki, 2013].

The field experiment was established and carried out-in four repetitions-as a single-factor experiment in a randomized block design ”split-plot”. The first factor of the experiment was irrigation. This factor was used in two variants: unirrigated plots (O-control), and drip irrigated plots (D-drip irrigation). The second factor was 10 European varieties of *A. officinalis*, including: Ravel, Rambo, Rally, Ramada, Rapsody, Cipres, Plaverd, Backlim, Grolim, Orane. Based on the readings of tensiometer devices (according to the Institute of Horticulture in Geisenheim, Germany), terms of individual irrigation treatments of asparagus were determined [Paschold and Weithaler, 2000]. During the drip irrigation period, the soil water potential was not less than -50 kPa. This value was pF 2.7, which corresponded to the depletion of 50–60% of EWC. The tensiometer filters were placed at a depth of 25 and 50 cm. Soil suction pressure measurements were made every 2–3 days. Additionally, additional, ongoing observations of the appearance of plants and an organoleptic assessment of soil moisture were also made. The surface drip irrigation of asparagus plants was done with the use of drip line T Tape, where the distances between drippers were 20 cm. The soil of the experimental field was black gley soil made of alluvial sand. The soil was classified as class VI, a very weak rye complex. It was characterized by a low specific density of 2.29–2.74 $Mg\cdot m^{-3}$ in the 0–60 cm layer. Porosity ranged from 39.7% for the parent rock to 42.2% for the arable-humus horizon. The soil pH was slightly acidic to neutral (pH in H_2O was 5.5). The soil was characterized by a well-developed arable-humus horizon with an average content of humus and nutrients, probably the result of long-term fertilization with manure. The average humus content in the 0–60 cm layer was 1.35%, while the contents of selected nutrients were as follows: P – 52.5 $mg\cdot dm^{-3}$ of soil, K – 71.25 $mg\cdot dm^{-3}$ of soil, Mg – 59.0 $mg\cdot dm^{-3}$ of soil. In the year preceding its establishment, manure was applied at a dose of 60 $t\cdot ha^{-1}$. Before setting up the experiment, magnesium lime was applied at a dose of 1.5 $t\cdot ha^{-1}$ to increase the soil pH. The agrotechnical treatments and fertilizers applied before and during the experiment were consistent with the generally accepted principles proposed by Knaflewski [2005]. Phosphorus-potassium fertilization was determined depending on the content of nutrients in the soil in the amount of 100–120 $kg\cdot P_2O_5$ and 200–250 $kg\cdot K_2O$. Nitrogen fertilization (120 $kg\cdot N\cdot ha^{-1}$) was applied in three equal doses of 40 $kg\cdot N\cdot ha^{-1}$. The following fertilizers were used for mineral fertilization: ammonium nitrate (34%), potassium salt (55%), granulated triple superphosphate (46%). One-year-old asparagus spears were planted in the ground in May 2006. Male cultivars with high yield potential, suitable for intensive cultivation, were selected for the experiment. The crop was grown for green spear.

The beginning of the harvest took place, depending on the year of cultivation, in the third decade of April or the first of May, while the end of the harvest usually fell at the end of the second or the beginning of the third decade of June. During each harvest (in 2007 and 2008), measurements were taken of the marketable yield ($t\cdot ha^{-1}$) of the asparagus green spears per plot as well as the weight (g) and the number (pcs) of the green spears. After harvesting of green spears bioactive components were determination: total polyphenols ($mg\cdot GAE\cdot kg^{-1}$ FW), ascorbic acid ($mg\cdot kg^{-1}$ FM), total chlorophyll ($mg\cdot kg^{-1}\cdot FW$), total carotenoids ($mg\cdot kg^{-1}$ FW), antioxidant activity ($mmol\cdot Fe^{2+}\cdot kg^{-1}$). After the end of the growing season in 2006 and 2007, measurements were made of the basic parameters of the asparagus summer stalks (cm), i.e. height (cm), number of the asparagus summer stalks (pcs), number of assimilative shoots from one plant and shoot diameter [mm] at a height of 3–5 cm from the ground surface.

Meteorological conditions

The meteorological conditions prevailing in the years 2006–2008 and in the years 1971–2000 are summarized in Tables 1 and 2 based on data from the meteorological station of the Department of Melioration and Agrometeorology of the University of Technology and Life Sciences located at the Research Station of the Faculty of Agriculture and Biotechnology in Mochełek near Bydgoszcz, where the strict vegetation research. This area belongs to the so-called climatic region of Poland. The Land of the Great Valleys, characterized by an increase in the amplitude of average annual temperatures and relatively little rainfall. The average length of the thermal growing season in this area ranges from 210 to 217 days [Żarski, 2011]. In all years of the research period 2006–2008, the average temperature during the growing season was higher than the temperature in the

Table 1. Air temperature (°C) in the vegetation of asparagus season in 2006–2008 against the background of the long-term mean in the Bydgoszcz region in 1971–2000

Years of research	Decade	Month of vegetation season						Mean
		April	May	June	July	August	September	
2006	I	5.3	12.9	11.8	22.7	17.6	15.2	
	II	7.3	13.1	18.9	21.8	17.4	15.7	
	III	8.7	11.4	19.7	22.7	15.0	14.6	
	Mean	7.1	12.5	16.8	22.4	16.6	15.2	15.1
2007	I	5.9	9.3	18.8	15.7	18.6	12.6	
	II	9.3	12.7	19.5	21.1	18.6	11.3	
	III	10.2	19.0	16.2	17.3	16.4	13.2	
	Mean	8.5	13.8	18.2	18.0	17.8	12.4	14.8
2008	I	5,7	12,6	19,1	19,1	19,1	16,8	
	II	6,7	13,0	15,6	18,2	18,3	9,7	
	III	10,4	14,0	18,0	20,3	16,2	10,7	
	Mean	7,6	13,2	17,6	19,2	17,8	12,4	14,6
2006–2008		7.7	13.2	17.5	19.9	17.4	13.3	14.8
1971–2000		7.6	13.1	16.3	18.0	17.7	13.1	14.3
Difference (+/-)		+0.1	+0.1	+1.2	+1.9	-0.3	+0.2	+0.5

Table 2. Rainfalls (mm) in the vegetation season of asparagus in 2006–2008 against the background of the long-term mean in the Bydgoszcz region in 1971–2000

Years of research	Decade	Month of vegetation season						Mean
		April	May	June	July	August	September	
2006	I	0	10	7	0	75	37	
	II	0	20	15	26	23	0	
	III	45	34	0	5	17	4	
	Sum	45	64	22	31	115	42	317
2007	I	5	21	43	79	3	18	
	II	0	23	24	4	11	5	
	III	3	5	36	29	46	13	
	Sum	8	49	103	112	60	36	367
2008	I	12	0	0	9	12	5	
	II	13	3	5	38	36	2	
	III	0	0	27	0	34	19	
	Sum	25	3	32	47	82	26	215
Mean for 2006–2008		26	39	52	52	86	35	300
Mean for 1971–2000		25	43	60	67	51	42	288

1971–2000 period (by +0.5°C on average). The highest average temperature in the growing season was in 2008 15.1°C (+0.8°C in relation to the average from 1971–2000). The lowest temperature occurred in 2008 (14.6°C). In this year, the average temperature during the growing season was higher than the temperature in the years 1971–2000 (+0.5°C) (Table 1). In the analyzed research period, on average, higher rainfall was recorded in relation to the average values for the years 1971–2000 (Table 2). The average total rainfall in the growing season for the research period was 300 mm and was 12 mm higher than the average for the years 1971–2000. The highest rainfall sum was recorded in the second year of the experiment (2007), which amounted to 367 mm and was higher than the long-term average by 79 mm. In turn, the year with the least amount of rain was 2008, when the sum amounted to 215 mm and was 73 mm lower than the average for the years 1971–2000.

Biochemical analyses of asparagus green spears

Ascorbic acid determination

The determination of vitamin C (ascorbic acid – AA) concentration in the asparagus was determined by the Tillman's titration method with the use of standard, blue, 2,6-dichlorophenolindophenol dye method using PN-A-04019 [1998]. AA contents were expressed as milligrams of ascorbic or dehydroascorbic acid per kilogram of fresh weight ($mg \cdot kg^{-1}$).

Chlorophyll and total carotenoids determination

Chlorophyll and carotenoids were extracted from 0.5 g of fresh samples by homogenization in 10 ml methanol according to the method of Wellburn [1994]. The vessel was placed on a shaker and shaken for 10 min, then centrifuged at 3,500 rpm (g) for 15 min. The supernatant from the sample (clear fraction) was transferred to a 25 ml glass flask. This steps was repeated three times and all supernatants from the samples were collected into 1 flask (total of 4 extractions of 1 sample). The flask was filled with methanol up to the marked line. A cuvette was filled with this extract and the absorbance was measured at 470, 653 and 666 nm. Results were expressed in mg per kg of fresh sample.

Total polyphenols determination

Total polyphenols content was determined using the Folin–Ciocalteu reagent (Sigma-Aldrich, Darmstadt, Germany) according to the method of Singleton and Orthofer [1999]. A volume of 0.5 mL of Folin–Ciocalteu reagent previously diluted with distilled water (1:10) was mixed with 0.1 mL of each sample. The solution was allowed to stand for 5 min at 25 °C before adding 1.7 mL of sodium carbonate solution (20%). Then, 10 mL of distilled water was added to the mixture and the absorbance was measured at λ = 735 nm after 20 min of incubation with agitation at room temperature. Results were expressed in mg of gallic acid equivalents (GAE) per kg of fresh sample.

Antioxidant capacity (FRAP) determination

The antioxidant capacity of the supernatants was determined using the FRAP assay [Benzie and Strain, 1999). The samples (200 μL) were mixed with 3 mL FRAP reagent. The FRAP reagent was prepared fresh daily by combining 100 mM sodium acetate buffer (pH 3.6), 10 mM 2,4,5,-tripyridyl-Striazine in 40 mM HCl, and 20 mM$FeCl_3$ in a ratio of 10:1:1 (v:v:v). The mixture was incubated at 21°C for 30 min, the absorbance at 593 nm was then measured in a spectrophotometer. FRAP values were calculated from Trolox standard curves, and expressed as milligram Trolox equivalent per kilogram fresh weight sample.

Water needs and rainfall deficits

The water needs of asparagus were calculated using the plant coefficient method, assuming that these needs are identified with the potential evapotranspiration of this species (*ETp*). The *ETp* of *A. officinalis* was calculated using the formula:

$$ETp = kc \cdot ETo \tag{1}$$

where: *kc* – plant coefficient, defined as the quotient of evapotranspiration measured in conditions of sufficient humidity and the indicator evapotranspiration [Łabędzki, 2006], *ETo* – indicator evapotranspiration (mm).

The values of the kc coefficient were determined from the quotient of the total water consumption (*S*; mm) by asparagus plants during the irrigation period (i.e. evapotranspiration measured in conditions of sufficient humidity) in the years 2002–2007, included in the work by Rolbiecki [2013] and the indicator evapotranspiration

(ETo; mm) according to Blaney-Criddle in the same time frames:

$$kc = S/ETo \quad (2)$$

The *kc* coefficient values determined in this way are presented in Table 3.

Index evapotranspiration was determined based on the Blaney-Criddle formula modified by Żakowicz [Żakowicz, 2010]:

$$ETo = n \cdot [p \cdot (0.437\, t + 7.6) - 1.5] \quad (3)$$

where: n – number of days in a month; p – evaporation coefficients according to Doorenbos and Pruitt [1977] for months and latitude determined from tables; t – average monthly air temperature (°C).

The amount of rainfall deficits (N) for asparagus was determined from the formula:

$$N = ETp - P \quad (4)$$

where: N – precipitation deficit (mm·period^{-1}), ETp – long-term average amount of evapotranspiration in the analyzed period (mm·period^{-1}), P – multiannual average amount of precipitation in the analyzed period (mm·period^{-1}).

The water needs of asparagus from June 21 to August 31 were higher in the first year of research (2006) and amounted to 253 mm, while in the second year (2007) they amounted to 238 mm (Table 4). Asparagus plants in July and August - among the months of the irrigation period - were characterized by the same total water needs, amounting to 113 mm. In turn, the time distribution and amount of natural precipitation during the asparagus irrigation period – in relation to its water needs – were the opposite: in 2006, from June 21 to August 31, only 146 mm was recorded, and in 2007 it was 208 mm.

Combining the water needs of asparagus with natural rainfall results in rainfall deficits, which should be covered by water supplied to asparagus plants through the irrigation system. The difference between water needs and precipitation shows that larger deficits in natural precipitation – amounting to 111 mm – occurred in 2006, and smaller ones (55 mm) in 2007.

Seasonal irrigation doses used in asparagus cultivation depended on natural rainfall deficits (Fig. 1). More water was given to asparagus plants in 2006 year of the study, and less – in 2007 year. Therefore, for the years respectively, the seasonal water doses were 92 mm and 54 mm. The amounts of water applied using the drip irrigation system are – compared to the calculated rainfall deficit – slightly smaller. This is due to the fact that irrigation was carried out based on the measurement of water potential in the soil measured using tensiometers. These differences result from the uneven (temporal) distribution of precipitation on individual days of the asparagus growing season (irrigation was complementary to natural rainfall during the irrigation period). Therefore, depending on the

Table 3. Values of the crop coefficient for the Blaney-Criddle'a formula (modified by Żakowicz) [Żakowicz, 2010] for asparagus cultivated in the Central Poland under drip irrigation (own elaboration)

Month	21–30 June	1–31 July	1–31 August
Crop coefficient	0.4	0.8	1.0

Table 4. Summary of the total water needs of asparagus, precipitation and rainfall deficit during the asparagus irrigation period (mm)

Year	Asparagus irrigation period			21 June–31 August
	21–30 June	1–31 July	1–31 August	
Water needs of asparagus (ETp; mm)				
2006	17	125	111	253
2007	18	105	115	238
Precipitation (P; mm)				
2006	0	31	115	146
2007	36	112	60	208
Precipitation deficit (N; mm)				
2006	17	94	-4	111
2007	-18	-7	55	55

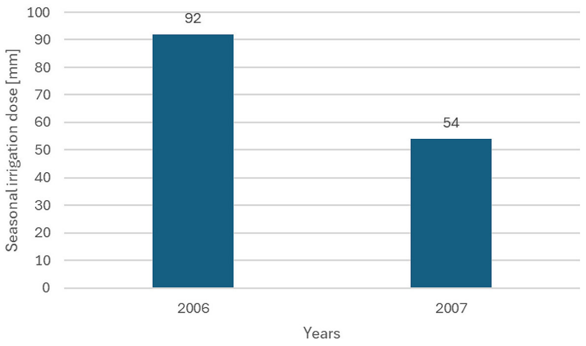

Figure 1. Amount of seasonal irrigation rates of asparagus in the investigated years

distribution of natural precipitation, the irrigation period in the year with greater deficits in natural precipitation (2006) lasted 59 days and 10 single doses were used. In turn, in 2007, the irrigation period lasted 37 days and 6 single doses were used

Statistical analysis

The measurements of the basic parameters of the asparagus summer stalks (cm), i.e. height (cm), number of the asparagus summer stalks (pcs), number of assimilative shoots from one plant and shoot diameter (mm) at a height of 3–5 cm from the ground surface and parameters of the asparagus green spears: marketable yield ($t \cdot ha^{-1}$), weight (g), number (pcs), bioactive components of the asparagus green spears: total polyphenols ($mg \cdot GAE \cdot kg^{-1} \cdot FW$), ascorbic acid ($mg \cdot kg^{-1} \cdot FM$), total chlorophyll ($mg \cdot kg^{-1} \cdot FW$), total carotenoids ($mg \cdot kg^{-1} \cdot FW$), antioxidant activity ($mmol \cdot Fe^{2+} \cdot kg^{-1}$). were tested for differences by two-way ANOVA using of Statistica® 13.1 package. The significance of differences (LSD – lowest significant difference) was evaluated using the Tukey multiple confidence intervals for the significance level of $p = 0.05$.

RESULTS AND DISCUSSION

Growth parameters of asparagus summer stalks

Drip irrigation - used in the post-harvest period, i.e. from the third decade of June to the end of August - significantly increased the height of asparagus assimilation shoots. The height of plants - on average for the examined varieties and years - increased under drip irrigation conditions from 153.66 cm to 166.39 cm (Table 5). The increase in shoot height obtained thanks to irrigation – on average for the tested varieties and two years of research – was 12.73 cm (8.3%). This indicator was higher in the second year of research (2007), amounting to 15 cm (9.7%), than in the first year (2006) - 10.46 cm (6.9%), respectively. The highest height of assimilation shoots in conditions of drip irrigation – on average for the 2 investigated years – was characteristic of the Backlim cultivar (183.63 cm), and plants of the Rambo, Rally, Grolim and Orane cultivars were also tall (over 170

Table 5. Height of the asparagus summer stalks (cm) as dependent on cultivar and irrigation

Cultivar	Control (without irrigation)			Drip irrigation			Increase of the height of summer stalks		
	2006	2007	mean	2006	2007	mean	2006	2007	mean
Ravel	144.50	145.00	144.75	152.05	158.00	155.02	7.55	13.00	10.27
Rambo	160.10	158.00	159.05	173.33	175.00	174.16	13.23	17.00	15.11
Rally	166.67	163.00	164.83	169.77	172.00	170.88	3.10	9.00	6.05
Ramada	142.75	150.00	146.37	166.93	168.00	167.46	24.18	18.00	21.09
Rapsody	137.60	145.00	141.30	167.85	169.00	168.42	30.25	24.00	27.12
Cipres	136.43	148.00	142.21	138.10	155.00	146.55	1.67	7.00	4.34
Plaverd	127.35	136.00	131.67	129.17	159.00	144.08	1.82	23.00	12.41
Backlim	170.90	169.00	169.95	184.27	183.00	183.63	13.37	14.00	13.68
Grolim	167.75	165.00	166.37	177.65	179.00	178.32	9.90	14.00	11.95
Orane	170.07	170.00	170.03	169.60	181.00	175.30	-0.47	11.00	5.27
Mean	152.41	155.00	153.66	162.87	170.00	166.39	10.46	15.00	12.73

Note: LSD = the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$; 2006: $LSD_{0.05}$ for: Irrigation = 10.001; Cultivars = 16.585; Interaction: Cultivars/Irrigation = 25.420; Irrigation/Cultivars = 15.804. 2007: $LSD_{0.05}$ for: Irrigation = 9.221; Cultivars = 13.115; Interaction: Cultivars/Irrigation = 18.225; Irrigation/Cultivars = 12.113. 2006–2007: $LSD_{0.05}$ for: Irrigation = 3.792; Cultivars = 14.430; Interaction: Cultivars/Irrigation - n.s.; Irrigation/Cultivars - n.s cm). The Plaverd and Cipres cultivars had the lowest height (144.08 cm and 146.55 cm, respectively).

Best reaction for drip irrigation – in terms of this growth strength feature – was found in the Ramada and Rapsody cultivars. Drip irrigation increased the height of assimilation shoots in these cultivars by 21.09 cm, respectively. (i.e. by 14.4%) and by 27.12 cm (19.2%).

A statistically proven influence of irrigation on the height of asparagus summer stalks,in the year preceding harvest was also demonstrated by other authors, including: Hartmann [1981a, b], Drost and Wilcox-Lee [1997], Pardo et al. [1997], Pashold et al. [2004]. Sterrett et al [1990] obtained an average increase in the height of asparagus summer stalks, of 14 cm in the 3rd and 4th year of cultivation compared to the unirrigated control. The significant increment of the height of asparagus summer stalks (in the range 152–172 cm) as influenced by drip irrigation was found also by Rolbiecki et al. [2021a].

Drip irrigation used in the post-harvest period – on average for the 10 investigated cultivars and 2 years – had a positive significant influence on the number of assimilation shoots per plant from 8.23 to 10.88 (Table 6). The number of shoots on one plant increased thanks to irrigation (on average for cultivars and years), by 2.65 pcs. (32%). The following cultivars were characterized by the highest number of shoots per plant (over 11) in conditions of drip irrigation, meanly for two years of field experiment: Ravel, Rambo, Rally, Ramada, Rapsody and Cipres. The Plaverd and Orane cultivars had the smallest number of shoots per plant (less than 10).

Cipres cultivar was characterized by best response to drip irrigation – in terms of the growth strength feature. The usage of drip irrigation caused an increase in the number of shoots on one plant by 4.18 pcs., i.e. by 56.7%, respectively.

Hartmann [1981b], Hartmann et al. [1990] and Pashold et al. [2004] – under soil-climatic conditions of east part of Germany – also noted the positive influence of drip irrigation in the increase of the assimilation shoots number. Drost [1999] reports that under dry climate conditions, lowering the moisture content of sandy soil below -50 kPa caused a reduction in the number and height of shoots in comparison to cultivars grown under irrigation. Sterrett et al. [1990] and Battilani [1997] achieved an increase in the number of shoots thanks to irrigation by an average of 4 pcs. per plant and 1 pc. per plant, respectively. The varied cultivars'reaction for drip irrigation is confirmed, among others, by effects of experiments conducted in the Netherlands [Mulder and Lavrijsen, 2008] and in Poland [Rolbiecki, 2013; Rolbiecki et al., 2021a].

Drip irrigation, on average for the examined cultivars and years, did not significantly affect the diameter of asparagus assimilation shoots (Table 7).

There was a varied response of individual asparagus cultivars to drip irrigation in relation to this feature. The largest diameter of assimilation

Table 6. Number of the asparagus summer stalks (pcs) as dependent on cultivar and irrigation

Cultivar	Control (without irrigation)			Drip irrigation			Increase of the height of summer stalks		
	2006	2007	mean	2006	2007	mean	2006	2007	mean
Ravel	9.10	8.80	8.95	11.60	12.10	11.85	2.50	3.30	2.90
Rambo	9.85	9.60	9.72	11.10	11.00	11.05	1.25	1.40	1.33
Rally	9.00	9.20	9.10	11.60	12.00	11.80	2.60	2.80	2.70
Ramada	8.00	7.90	7.95	11.00	11.30	11.15	3.00	3.40	3.20
Rapsody	9.50	9.40	9.45	11.00	11.50	11.25	1.50	2.10	1.80
Cipres	7.35	7.40	7.37	11.50	11.60	11.55	4.15	4.20	4.18
Plaverd	6.25	6.70	6.47	10.10	9.80	9.95	3.85	3.10	3.48
Backlim	7.85	7.70	7.77	10.75	10.90	10.82	2.90	3.20	3.05
Grolim	6.75	6.90	6.82	10.50	10.40	10.45	3.75	3.50	3.63
Orane	8.70	8.60	8.65	8.70	9.20	8.95	0.00	0.60	0.30
Mean	8.23	8.20	8.23	10.78	11.00	10.88	2.55	2.80	2.65

Note: LSD = the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$; 2006: $LSD_{0.05}$ for: Irrigation = 0.934; Cultivars = 2.981; Interaction: Cultivars/Irrigation = 3.828; Irrigation/Cultivars = 2.152. 2007: $LSD_{0.05}$ for: Irrigation = 0.665; Cultivars = 1.897; Interaction: Cultivars/Irrigation = 3.361; Irrigation/Cultivars = 1.831. 2006–2007: $LSD_{0.05}$ for: Irrigation = 0.129; Cultivars = 0.493; Interaction: Cultivars/Irrigation = 0.697; Irrigation/Cultivars = 0.409.

Table 7. Diameter of the asparagus summer stalks (mm) as dependent on cultivar and irrigation

Cultivar	Control (without irrigation)			Drip irrigation			Increase of the height of summer stalks		
	2006	2007	mean	2006	2007	mean	2006	2007	mean
Ravel	11.45	11.20	11.32	10.07	12.10	11.08	-1.38	0.90	-0.24
Rambo	12.85	12.70	12.77	13.43	13.80	13.61	0.58	1.10	0.84
Rally	14.27	14.10	14.18	10.17	15.20	12.68	-4.10	1.10	-1.50
Ramada	15.03	13.60	14.31	9.10	14.50	11.80	-5.93	0.90	-2.51
Rapsody	11.45	12.10	11.77	11.75	13.50	12.62	0.30	1.40	0.85
Cipres	10.35	10.50	10.42	12.57	13.40	12.98	2.22	2.90	2.56
Plaverd	10.65	10.70	10.67	11.33	12.30	11.81	0.68	1.60	1.14
Backlim	12.85	12.60	12.72	10.35	13.40	11.87	-2.50	0.80	-0.85
Grolim	14.23	13.70	13.96	15.65	15.80	15.72	1.42	2.10	1.76
Orane	15.65	14.50	15.07	10.33	16.20	13.26	-5.32	1.70	-1.81
Mean	12.88	12.60	12.72	11.47	14.00	12.75	-1.41	1.40	0.03

Note: LSD = the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$; .2006: $LSD_{0.05}$ for: Irrigation = ns; Cultivars = 2.824; Interaction: Cultivars/Irrigation = 3.994; Irrigation/Cultivars = 2.515. 2007: $LSD_{0.05}$ for: Irrigation = 0.983; Cultivars = 2.749; Interaction: Cultivars/Irrigation = 3.225; Irrigation/Cultivars = 1.873. 2006–2007: $LSD_{0.05}$ for: Irrigation - n.s.; Cultivars = 3.799; Interaction: Cultivars/Irrigation - n.s.; Irrigation/Cultivars - n.s.

shoots in conditions of drip irrigation (on average for two investigated years) – was characteristic of the Grolim cultivar (15.72 mm). The best reaction for drip irrigation – in relation to this growth strength feature – was found in the Cipres cultivar. The use of drip irrigation caused the increase of the diameter of assimilation shoots by 2.56 mm (i.e. by 25.6%).

A significant effect of drip irrigation on the shoot diameter was also observed by other authors, including: Sterrett et al. [1990], Battilani [1997] and Rolbiecki et al. [2021a]. According to many authors, irrigation had the significant influence on the growth of assimilation shoots and, as a result, the yield of asparagus spears in the following year [Hartmann, 1985; Kaufmann, 1990; Ferreyra et al., 1995; Paschold et al., 1999]. Rolbiecki and Rolbiecki [2008], on the base of the results of the cultivar experiment carried out as part of the 3rd IACT (comparison of 31 asparagus cultivars) noted a significant influence of drip irrigation on the growth of assimilation shoots as well as on the yield of spears obtained in the first year of harvest. According to numerous authors, the use of irrigation – securing optimal moisture conditions – cause an increased accumulation of carbohydrates in asparagus roots which the plant uses in the next year during the spring season of the harvest year [Pressman et al., 1989; Martin and Hartmann, 1990; Sterrett et al., 1990; Pressman et al., 1994; Drost, 1996; Drost and Wilcox-Lee, 1997; Drost, 1999].

Growth parameters of asparagus green spears

Drip irrigation, on average for the examined cultivars and years, significantly increased the yield of the asparagus green spears from 3.93 $t \cdot ha^{-1}$ to 5.86 $t \cdot ha^{-1}$ (Table 8). The increase in marketable yield of the asparagus green spears was achieved thanks to irrigation, on average for the tested cultivars and two years of research, amounted to 1.93 $t \cdot ha^{-1}$ (49%).

The Ravel cultivar – grown in conditions of drip irrigation – was characterized by the highest marketable yield of the asparagus green spears amounting 8.04 $t \cdot ha^{-1}$. High yields under irrigation conditions (7.36 $t \cdot ha^{-1}$) on average for two years of experiment – were obtained for the Grolim cultivar. The lowest yields in conditions of (3.13 $t \cdot ha^{-1}$) were noted in case of the Orane cultivar. The best response to drip irrigation was found in the Cipres and Grolim cultivars. Drip irrigation increased the marketable yields of these cultivars by 3.62 $t \cdot ha^{-1}$ (137%) and 3.45 $t \cdot ha^{-1}$ (88%), respectively. The smallest increase marketable yield (0.46 $t \cdot ha^{-1}$) was achieved by drip irrigation in the Orane cultivar.

The obtained results are confirmed by the results of research by foreign authors. Hartmann [1981a, b] in conditions of Germany noted a yield increase of 50% and 25% in an experiment with drip irrigation on sandy and clay soils, respectively. Pashold et al. [1996, 1999, 2008], while conducting a cultivars experiment using drip irrigation, the

Table 8. Marketable yield of the asparagus green spears (t·ha-1) as dependent on cultivar and irrigation

Cultivar	Control (without irrigation)			Drip irrigation			Increase of the marketable yield of green spears		
	2007	2008	mean	2007	2008	mean	2007	2008	mean
Ravel	6.20	5.21	5.70	7.87	8.22	8.04	1.67	3.01	2.34
Rambo	4.84	4.01	4.42	5.39	6.42	5.90	0.55	2.41	1.48
Rally	5.84	4.21	5.02	5.43	7.44	6.43	-0.41	3.23	1.41
Ramada	5.29	4.89	5.09	5.35	7.25	6.30	0.06	2.36	1.21
Rapsody	3.84	3.11	3.47	5.04	5.75	5.39	1.20	2.64	1.92
Cipres	2.88	2.42	2.65	5.74	6.81	6.27	2.86	4.39	3.62
Plaverd	2.78	2.33	2.55	4.37	5.41	4.89	1.59	3.08	2.34
Backlim	3.64	3.87	3.75	3.84	5.91	4.87	0.20	2.04	1.12
Grolim	3.61	4.21	3.91	6.40	8.33	7.36	2.79	4.12	3.45
Orane	2.53	2.81	2.67	2.82	3.45	3.13	0.29	0.64	0.46
Mean	4.15	3.71	3.93	5.23	6.49	5.86	1.08	2.78	1.93

Note: LSD = the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$; 2007: $LSD_{0.05}$ for: Irrigation = 0.565; Cultivars = 1.126; Interaction: Cultivars/Irrigation = 1.593; Irrigation/Cultivars = 0.986. 2008: $LSD_{0.05}$ for: Irrigation = 0.721; Cultivars = 1.005; Interaction: Cultivars/Irrigation = 1.221; Irrigation /Cultivars = 1.003. 2007–2008: $LSD_{0.05}$ for: Irrigation = 0.508; Cultivars = 1.934; Interaction: Cultivars/Irrigation - n.s.; Irrigation/Cultivars - n.s.

highest marketable yield of the asparagus spears were recorded in the Gijnlim cultivar.

In Polish conditions, the Gijnlim cultivar was also characterized by the highest yields both in control objects (without irrigation) as well as in drip-irrigated objects, amounting 6.5 t·ha–1 and 10.9 t·ha-1, accordingly. Pinkau and Grutz [1985] obtained much lower increases in the marketable yield spears - on average 12.4%. However, they found the highest yield increases in dry years. In an experiment conducted in the Netherlands under sprinkler irrigation, Mulder and Lavrijsen [2008] noted the highest yields in case of Gijnlim cultivar, amounting to 4.5 t·ha–1 and 12.8 t·ha–1 and in the first and the year of harvest, respectively. Many other authors also present a significant influence of irrigation on the increase in the yield of spears of asparagus grown in various climatic zones as compared to that of Poland [Sterrett et al., 1990; Drost and Wilcox-Lee, 1997; Drost, 1999; Brainard et al., 2019; Campi et al., al. 2019].

Drip irrigation applied in the post-harvest period (from the third decade of June to the end of August) in the growing season of the year preceding the harvest, on average for the examined cultivars and years, significantly increased the average weight of asparagus green spears from 34.83 g to 41.86 g (Table 9). The increase in the average weight of spears achieved by irrigation, on average for the tested cultivars and two years of research, was therefore 7.04 g (20%).

The Grolim cultivar grown on irrigated plots had the highest average weight of asparagus spears which amounted 54.78 g, on average for the both investigated years. The cultivars Cipres (47.68 g), Backlim (44.78 g), Ramada (41.26 g) and Rapsody (40.48 g) were also characterized by high weight of spears (over 40 g).

The best reaction for drip irrigation – in relation to this yield feature – was found in the Cipres and Grolim cultivars. The use of drip irrigation caused the increase in the average weight of asparagus spears by 15.89 g (50%) and 10.74 g (24%), respectively. For comparison, the weight of the spears of the Gijnlim cultivar grown on irrigated plots in the investigation carried out by Mulder and Lavrijsen [2008] was approximately 40 g. Paschold et al. [2008] noted level of 35 g, while Sterrett et al. [1990], found a plant weighing 25 g.

The use of drip irrigation – on average for the 10 cultivars and 2 years – caused the significant increase in the number of asparagus green spears from one plant from 6.09 to 8.13 (Table 10). Irrigation increased the number of spears on one plant by over 2 pieces (33%), on average for the investigated cultivars and years.

The Ravel cultivar had the highest number of asparagus spears per plant (11.82) in conditions of irrigation, on average for the two investigated years and the Orane cultivar had the smallest number (6.05). The Rambo, Rally, Ramada and Rapsody cultivars were characterized by the number of spears exceeding 8 per plant, and the Cipres, Plaverd, Backlim and Grolim cultivars – more than 7. The Ravel cultivar was characterized by the best reaction for

Table 9. Weight of the asparagus green spears (g) as dependent on cultivar and irrigation

Cultivar	Control (without irrigation)			Drip irrigation			Increase of the marketable yield of green spears		
	2007	2008	mean	2007	2008	mean	2007	2008	mean
Ravel	34.57	32.21	33.39	37.89	40.21	39.05	3.32	8.00	5.66
Rambo	37.80	34.80	36.30	38.65	41.01	39.83	0.85	6.21	3.53
Rally	32.48	33.22	32.85	37.59	39.65	38.62	5.11	6.43	5.77
Ramada	33.45	31.14	32.29	40.31	42.22	41.26	6.86	11.08	8.97
Rapsody	31.43	33.08	32.25	40.96	40.01	40.48	9.53	6.93	8.23
Cipres	32.34	31.24	31.79	49.64	45.72	47.68	17.30	14.48	15.89
Plaverd	31.38	32.41	31.89	32.23	35.88	34.05	0.85	3.47	2.16
Backlim	37.14	36.28	36.71	45.25	44.31	44.78	8.11	8.03	8.07
Grolim	43.86	44.22	44.04	55.39	54.18	54.78	11.53	9.96	10.74
Orane	38.51	35.14	36.82	37.43	38.58	38.00	-1.08	3.44	1.18
Mean	35.30	34.37	34.83	41.53	42.18	41.86	6.23	7.81	7.03

Note: LSD = the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$; 2007: $LSD_{0.05}$ for: Irrigation = 0.901; Cultivars = 6.018; Interaction: Cultivars/Irrigation = 8.510; Irrigation/Cultivars = 4.946. 2008: $LSD_{0.05}$ for: Irrigation = 6.228; Cultivars = 5.211; Interaction: Cultivars/Irrigation = 7.414; Irrigation /Cultivars = 3.844. 2007–2008: $LSD_{0.05}$ for: Irrigation = 1.015; Cultivars = 3.863; Interaction: Cultivars/Irrigation = 5.464; Irrigation/Cultivars = 3.210.

Table 10. Number of the asparagus green spears (pcs) as dependent on cultivar and irrigation

Cultivar	Control (without irrigation)			Drip irrigation			Increase of the marketable yield of green spears		
	2007	2008	mean	2007	2008	mean	2007	2008	mean
Ravel	8.37	7.22	7.79	12.27	11.37	11.82	3.90	4.15	4.03
Rambo	5.97	6.41	6.19	8.20	9.22	8.71	2.23	2.81	2.52
Rally	6.56	6.11	6.33	7.84	8.44	8.14	1.28	2.33	1.81
Ramada	6.94	6.50	6.72	7.77	8.30	8.03	0.83	1.80	1.31
Rapsody	6.71	7.21	6.96	8.21	8.11	8.16	1.50	0.90	1.20
Cipres	4.76	5.01	4.88	6.94	7.23	7.08	2.18	2.22	2.20
Plaverd	6.35	5.86	6.10	7.66	8.33	7.99	1.31	2.47	1.89
Backlim	5.56	5.89	5.72	9.09	6.74	7.91	3.53	0.85	2.19
Grolim	5.11	5.22	5.16	6.97	7.86	7.41	1.86	2.64	2.25
Orane	4.64	5.41	5.02	5.50	6.61	6.05	0.86	1.20	1.03
Mean	6.10	6.08	6.09	7.75	8.22	8.13	1.65	2.14	2.04

Note: LSD = the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$; 2007: $LSD_{0.05}$ for: Irrigation = 0.960; Cultivars = 1.476; Interaction: Cultivars/Irrigation = 2.087; Irrigation /Cultivars = 1.362. 2008: $LSD_{0.05}$ for: Irrigation = 0.845; Cultivars = 1.117; Interaction: Cultivars/Irrigation = 1.885; Irrigation /Cultivars = 0.967. 2007–2008: $LSD_{0.05}$ for: Irrigation = 0.396; Cultivars = 1.508; Interaction: Cultivars/ Irrigation - n.s.; Irrigation/Cultivars - n.s.

drip irrigation - in relation to this yield feature. The use of drip irrigation caused the increase in the number of asparagus spears on one plant by over 4 (i.e. 52%). An increase in the number of asparagus spears as influenced by drip irrigation was also recorded in other experiments conducted in the climatic and soil conditions of Germany [Hartmann, 1981b; Paschold et al., 1996] and Poland [Rolbiecki and Rolbiecki, 2008; Rolbiecki, 2013; Rolbiecki et al., 2021a].

Content of bioactive substances in asparagus green spears

Antioxidants are biologically active compounds important not only from the point of view of human nutrition, but also necessary for the growth and development of plants. They constitute an important link in the antioxidant system, as a mechanism that protects, among others, against reactive oxygen species [Smirnoff, 2000;

Benzie, 2003]. Both the applied irrigation and the cultivar factor as well as the interaction of both factors significantly influenced the content of bioactive compounds, i.e. total polyphenols, vitamin C, chlorophyll and total carotenoids, as well as the antioxidant activity of FRAP in asparagus spears (Table 11). Antioxidant compounds in plants are phenols or phenolic compounds,

Table 11. Influence of drip fertigation on the selected bioactive components of asparagus green spears cultivars (mean for the years 2007–2008)

Irrigation Treatment	Cultivar	Total Polyphenols (mg GAE kg^{-1} FW)	Vitamin C ($mg \cdot kg^{-1}$ FW)	Total chlorophyll ($mg \cdot kg^{-1}$ FW)	Total carotenoids ($mg \cdot kg^{-1}$ FW)	Antioxidant activity (mmol Fe^{2+} kg^{-1})
Control (without irrigation)	Ravel	375.05	310.10	121.20	60.88	4.79
	Rambo	369.90	278.20	134.25	64.88	4.24
	Rally	354.15	281.15	132.80	65.05	4.66
	Ramada	387.80	319.25	142.75	68.93	5.13
	Rapsody	389.20	312.35	142.90	64.53	6.07
	Cipres	332.20	512.15	151.15	63.08	6.23
	Plaverd	328.95	489.30	134.25	59.95	6.04
	Backlim	368.20	451.10	128.80	61.08	5.99
	Grolim	310.10	526.40	111.10	68.15	6.60
	Orane	344.10	276.45	128.80	65.05	4.28
	Mean	355.97	375.75	132.80	64.11	5.40
Drip irrigation	Ravel	368.25	316.45	128.95	62.10	4.96
	Rambo	345.80	295.65	137.80	65.20	4.61
	Rally	338.80	305.30	135.95	67.05	4.85
	Ramada	375.20	328.30	151.80	70.60	5.25
	Rapsody	369.25	321.15	156.10	65.60	6.22
	Cipres	328.80	529.30	162.05	67.15	6.55
	Plaverd	367.15	501.15	142.15	60.10	6.33
	Backlim	351.10	489.30	134.10	62.05	6.12
	Grolim	299.30	528.15	119.30	69.20	6.41
	Orane	329.30	287.20	132.05	66.55	4.59
	Mean	327.30	390.20	140.03	65.56	5.59
Mean	Ravel	371,65	313.28	125.08	61.49	4.87
	Rambo	357,85	286.93	136.03	65.04	4.42
	Rally	346,48	293.23	134.38	66.05	4.75
	Ramada	381,50	323.78	147.28	69.76	5.19
	Rapsody	329,23	316.75	149.50	65.06	6.15
	Cipres	330,50	520.73	156.60	65.11	6.39
	Plaverd	348,05	495.23	138.20	60.03	6.19
	Backlim	359,65	470.20	131.45	61.56	6.05
	Grolim	304,70	527.28	115.20	68.68	6.50
	Orane	336,70	281.83	130.43	65.80	4.43
Mean		341.63	382.92	136.41	64.86	5.49
$LSD_{0.05}$ for irrigation		0.381	0.635	0.318	1.334	0.159
Cultivars		0.645	0.510	0.658	0.885	0.142
Interaction: cultivars/irrigation		0.912	0.549	0.547	1.252	0.201
Interaction: irrigation/cultivars		0.550	0.722	0.931	1.067	0.145

Note: LSD = the lowest significant difference (Tukey's confidence half-interval) at $p < 0.05$.

which are secondary metabolites. Moreover, they influence the taste, consistency and color of food [Papoulias et al., 2009]. Phenols are not essential for humans, but their benefits are mainly attributed to their antioxidant effects [Rickman et al., 2007]. The content of polyphenols in asparagus spears was on average 341.63 mg expressed as gallic acid per kg of fresh weight (mg·GAE·kg^{-1}·FW) (Table 11). They obtained similar values in their research Takács-Hájos and László Zsombik [2015] and the level of these compounds depended on the years of research and the cultivar. The Ramada cultivar contained significantly the most total polyphenols (381.50 mg·GAE·kg^{-1}·FW). In turn, the Grolim cultivar contained the least of these compounds (304.70 mg·GAE·kg^{-1}·FW). Lack of irrigation during plant vegetation increased the content of total polyphenols in asparagus spears (355.97 mg·GAE·kg^{-1}·FW). The interaction of both research factors resulted in an increase in the amount of tested compounds in the Rapsody cultivar (389.20 mg· GAE·kg^{-1}·FW), the material for analysis came from control plots. In turn, the Grolim cultivar accumulated the least of these compounds under the influence of irrigation (299.30 mg·GAE·kg^{-1}·FW). The level of polyphenol compounds in a plant is not only a species or cultivar feature, but primarily a result of the climatic and soil conditions prevailing during the growing season. Antioxidants, including polyphenols, are a group of compounds that are extremely active under stress conditions in plants [Lee and Kadar, 2000]. The increase in their concentration is related to the plants' resistance or the ability to quickly acclimatize to unfavorable or changing environmental conditions, e.g. during water shortage during vegetation.

The asparagus is rich in vitamin C which very beneficial for human organism. It is one of the most important antioxidants. Human organism do not synthesize vitamin C and do not accumulate its resources, therefore it is very important to get it with food the research by Žebrauskienė et al. [2013] indicated that spears of different asparagus cultivars accumulated different amounts of the vitamin C. Similarly to our own research the Grolim cultivar contained significantly the most vitamin C (527.28 mg·kg^{-1}·FW), while the Orane cultivar contained significantly the least (281.83 mg·kg^{-1}·FW). Irrigated asparagus accumulated significantly more vitamin C than those grown on non-irrigated plots. Both irrigation and the cultivar influenced the growth of the tested compound - the Grolim cultivar from irrigated plots contained significantly the most vitamin C (528.15 mg·kg^{-1}·FW) (Table 11).

The Cipres cultivar contained significantly the most total chlorophyll (156.60 mg·kg^{-1}·FW), and the Grolim cultivar contained significantly the least (115.20 mg·kg^{-1}·FW). This cultivar is usually grown for whitened spears, while the color of the spears in the light may change to light green, which was obtained in tests. Irrigation caused a significant increase in the tested compound in the plant (Table 11).

The Ramada and Grolim cultivars accumulated significantly the highest total carotenoids in the spears, 69.76 and 68.68 mg·kg^{-1}·FW, respectively, while the Plaverd cultivar accumulated significantly the lowest amount (60.03 mg·kg^{-1}·FW). The irrigation used significantly increased the content of this bioactive compound in the plant. A significant influence of both studied factors was also found. The Ramada cultivar from irrigated plots contained the highest amount of total carotenoids (70.60 mg·kg^{-1}·FW) (Table 11). Photosynthetic pigments such as chlorophyll and carotenoids are indicators of stress in plants [Ashraf and Harris, 2013]. Therefore, lower concentrations of these compounds indicate a more frequent occurrence of stress related to lack of hydration.

Antioxidant activity depends on the content of bioactive compounds in plants, such as polyphenols, vitamin C, carotenoids [Maeda at al., 2005]. Depending on the cultivar, asparagus stalks of the Grolim and Cipres cultivars were characterized by the significantly highest antioxidant activity (6.50, 6.39 mmol $Fe^{2+}kg^{-1}$). Irrigation resulted in a significant accumulation of compounds influencing the antioxidant activity of the tested asparagus spears. Significant interactions between the studied factors were also proven. The highest antioxidant activity was observed in the Cipres and Grolim cultivars from irrigated plots (6.55, 6.41 mmol·Fe^{2+}·kg^{-1}).

CONCLUSIONS

Drip irrigation of the European asparagus cultivars applied on a very light sandy soil in central Poland had a positive effect on summer stalks (2006–2007) and green spears (2007–2008). A significant increase in the height, number and diameter of summer stalks, as well an increase in the marketable yield, weight and number of green spears was observed for most of the cultivars. Water needs during the irrigation period were slightly higher in 2006 and amounted to 253 mm. The highest water deficits were obtained in 2006 as well. Both factors, the irrigation used and the asparagus cultivars significantly modified the antioxidant content in green spears of asparagus. The Rapsody cultivar accumulated significantly more, and the Grolim cultivar significantly less, total polyphenols in asparagus spears that were not irrigated. An inverse relationship was obtained in the Grolim cultivar with respect to the content of vitamin C, which accumulated the most of it under the influence of irrigation. The Ramada cultivar from irrigated plots contained significantly the highest amount of total carotenoids. In turn, the Cipres and Grolim cultivars from irrigated plots were characterized by the highest antioxidant activity.

REFERENCES

1. Ashraf M., Harris P.J.C. 2013. Photosynthesis under stressful environments: An overview. Photosynthetica, 51, 163–190. DOI: 10.1007/s11099-013-0021-6
2. Battilani A. 1997. Response of asparagus (*Asparagus officinalis* L.) to post-harvesting irrigation. Acta Horticulturae, 449(1), 181–187. DOI: 10.17660/ActaHortic.1997.449.24
3. Benzie I.F., Strain J.J. 1999. Ferric reducing/antioxidant power assay: Direct measure of total antioxidant activity of biological fluids and modified version for simultaneous measurement of total antioxidant power and ascorbic acid concentration. Methods in Enzymology, 299, 15–27. DOI: 10.1016/s0076-6879(99)99005-5
4. Benzie I.F.F. 2023. Evolution of dietaryantioxidants. Comparative Biochemistry and Physiology Part A. Molecular and Integrative Physiology, 136, 113–126. DOI: 10.1016/s1095-6433(02)00368-9
5. Brainard D.C., Był B., Hayden Z.D., Noyes D.C., Bakker J., Werling B. 2019. Managing drought risk in changing climate: Irrigation and cultivar impact on Michigan asparagus. Agricultural Water Management, 213, 773–781. https://doi.org/10.1016/j.agwat.2018.11.017
6. Campi P., Mastrorilli M., Stellacci, A.M., Modugno F., Palumbo A.D. 2019. Increasing the effective use of water in green asparagus through deficit irrigation strategies. Agricultural Water Management, 217, 119–130. https://doi.org/10.1016/j.agwat.2019.02.039
7. Cieślik E., Siembida A. 2011. Nutritional value and pro-healthy properties of asparagus (*Asparagus officinalis* L.). Postępy Fitoterapii, 12(4), 275-281. (in Polish)
8. Conversa G., Lazzizera C., Chiaravalle A.E., Miedico, O., Bonasia A., La Rotonda P., Elia A. 2019. Selenium fern application and arbuscular mycorrhizal fungi soil inoculation enhance Se content and antioxidant properties of green asparagus (*Asparagus officinalis* L.) spears. Scientia Horticulturae, 252, 176–191. https://doi.org/10.1016/j.scienta.2019.03.056
9. Cruz-Bautista F., Lopez-Cruz I.L., Rodríguez J.C., Ochoa-Meza A., Ruíz-García A., Er-Raki S. 2023. Irrigation optimization in green asparagus (*Asparagus officinalis* L.) using the AquaCrop model and evolutionary strategy algorithms. Irrigation and Drainage, 1–15. https://doi.org/10. 1002/ird.2853
10. Doorenbos J., Pruitt W.O. 1977. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper, 24, 156.
11. Drost D.T. 1996. Irrigation budget and plant growth of asparagus. Acta Horticulturae, 415, 343–350. DOI: 10.17660/ActaHortic.1996.415.48
12. Drost D.T. 1999. Soil water deficits reduce growth and yield of asparagus. Acta Horticulturae, 479, 383–390. DOI: 10.17660/ActaHortic.1999.479.52
13. Drost D.T., Wilcox-Lee D. 1997. Soil water deficits and asparagus: Bud size and subsequent spear growth. Scientia Horticulturae, 70, 145–153. https://doi.org/10.1016/S0304-4238(97)00042-3
14. Dziedziński M., Szczepaniak O., Szymanowska D., Szulc P., Bielec D., Kobus-Cisowska, J. 2019. Cultivation of szparaga (*Asparagus officinalis* L.) as raw material with functional properties. Part 2. Nutritional characteristics. Technika Rolnicza Ogrodnicza Leśna, (3), 5–8. (in Polish)
15. Elsaid F.G., Shati A.A., Sarhan M.A. 2015. Role of *Matricaria recutita* L. and *Asparagus officinalis* L. against the neurotoxicity of diazinon in rats. The Journal of Basic & Applied Zoology, 72, 26–35. https://doi.org/10.1016/j.jobaz.2015.02.002.
16. Ferreyra E.R., Peralta A.J.M., van Selles S.G., Fritsch F.N. Contador F.F. 1995. Asparagus crop (*Asparagus officinalis* L.) response to different water regimes during the first two establishment seasons. Agricultura Technica, 55(1), 1–8.
17. Fuentes-Alventosa J.M., Jaramillo-Carmona S., Rodríguez-Gutiérrez G., Rodríguez-Arcos R., Fernández-Bolaños J., Guillén-Bejarano R., Espejo-Calvo J.A. 2009. Jiménez-Araujo, A. Effect of the extraction method on phytochemical composition and antioxidant activity of high dietary fibre powders obtained from asparagus by-product. Food Chemistry, 116, 484–490. https://doi.org/10.1016/j.foodchem.2009.02.074
18. Guo Q., Wang N., Liu H., Li Z., Lu L., Wang C. 2020. The bioactive compounds and biological functions of *Asparagus officinalis* L — A review.

Journal of Functional Foods, 65, 103727. https://doi.org/10.1016/j.jff.2019.103727

19. Hartmann H.D. 1981a. Die Bewasserung bei Spargel und ihre Auswikung auf die Pflanze. Archive für Gartenbau, 29(4), 167–175.
20. Hartmann H.D. 1995. Possibility of predicting asparagus yields in central Europe. In: Proceedings of the 6th Int. Asparagus Symp*.,* Guelph, Canada, 318–32
21. Hartmann H.D. 1981b. The influence of irrigation on the development and yield of asparagus. Acta Horticulturae, 119, 309–316. https://doi.org/10.17660/ActaHortic.1981.119.34
22. Hartmann H.D., Hermann G., Kirchner-Ness R. 1990. Effect of weather during the vegetative period on the yield of asparagus in the following year. Gartenbauwissenschaft, 55(1), 30–34.
23. Jeznach J. 2009. Current trends in development of microirrigation. Infrastructure and Ecology of Rural Areas, 6, 83–94. (in Polish)
24. Kale Celik S. 2022. Deficit irrigation under water stress and salinity conditions: Fao-aquacrop model. Infrastruktura i Ekologia Terenów Wiejskich, 17(1)
25. Kaniszewski S. 2005. Technologia nawadniania warzyw. In: Proceedings Nawadnianie warzyw w uprawach polowych, Skierniewice, Poland, 5–19. (in Polish)
26. Kaufmann F. 1990. Principles of plant density for green asparagus harvested by different methods. Acta Horticulturae, 271, 227–233. DOI: 10.17660/ActaHortic.1990.271.30
27. Knaflewski M. 2005. Uprawa szparaga*.* Hortpress Warszawa
28. Kobus-Cisowska J., Szymanowska D., Szczepaniak O.M., Gramza-Michałowska A., Kmiecik D., Kulczyński B., Szulc P., Górnaś P. 2019, Composition of polyphenols of asparagus spears (*Asparagus officinalis* L) and their antioxidant potential. Ciência Rural, 49. https://doi.org/10.1590/0103-8478cr20180863
29. Lee S.K., Kadar A.A. 2000. Preharvest and postharvest facors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology, 20, 207–220. https://doi.org/10.1016/S0925-5214(00)00133-2
30. Low Dog T. 2009. The use of botanicals during pregnancy and lactation. Alternative Therapies in Health and Medicine, 15(1), 54–58.
31. Łabędzki L. 2006. Agricultural droughts. An outline of problems and methods of monitoring and classification. Water. Environment. Rural areas. Scientific Dissertations and Monographs, 17, 1–107. (in Polish)
32. Maeda T., Kakut H., Sonoda T., Motoki S., Ueno R., Suzuki T., Oosawa K. 2005. Antioxidation capacities of extracts from green, purple and white asparagus spears related to polyphenol concentration. HortScience, 40(5), 1221–1224). DOI: 10.21273/HORTSCI.40.5.1221
33. Martin S., Hartmann H.D. 1990. The content and distribution of carbohydrates in asparagus. Acta Horticulturae, 271, 443–446. DOI: 10.17660/ActaHortic.1990.271.62
34. Mastropasqua L., Tanzarella P., Paciolla C. 2016. Effects of postharvest light spectra on quality and health-related parameters in green *Asparagus officinalis* L. Postharvest Biology and Technology, 112, 143-151. DOI: 10.1016/j.postharvbio.2015.10.010
35. Mulder J.H., Lavrijsen P. 2008. First results of the "Third International Asparagus Cultivar Trial" planted in Horst, the Netherlands. Horticulturae (ISHS)*,* 776, 367–372. DOI: 10.17660/ActaHortic.2008.776.48
36. Papoulias E., Siomos A., Koukounaras A., Gerasopoulos D., Kazakis E. 2009. Effects of genetic, Pre- and Post-Harvest Factors on phenolic content and antioxidant capacity of white asparagus spears. International Journal of Molecular *Sciences*, 10, 5370–5380.
37. Pardo A., Arbizou, J., Suso M.L. 1997. Evapotranspiration and crop coefficients in white asparagus. Acta Horticulturae, 449(1), 187–192. https://doi.org/10.17660/ActaHortic.1997.449.25
38. Park M.H. 2016. Sucrose delays senescence and preserves functional compounds in *Asparagus officinalis* L. Biochemical and Biophysical Research Communications, 480(2), 241–247. DOI: 10.1016/j.bbrc.2016.10.036
39. Paschold P.J., Artelt B., Hermann G. 2004. The water need of asparagus (*Asparagus officinalis* L.) determined in a lysimeter station. Acta Horticulturae, 664, 529–536. DOI: 10.17660/ActaHortic.2004.664.67
40. Paschold P.J., Artelt B., Hermann G. 2008. Comparison of white asparagus cultivars (*Asparagus officinalis* L.) in Germany. Acta Horticulturae, 776, 379–385. https://doi.org/10.17660/ActaHortic.2008.776.50
41. Paschold P.J., Hermann G., Artelt B. 1999. Asparagus varieties tested over 6 years*.* Gemüse*.* 35(4), 261–266.
42. Paschold P.J., Hermann G., Artelt B. 1996. Comparison of international asparagus cultivars under Rhine-Valley conditions in Germany. Acta Horticulturae*,* 415, 257–262. https://doi.org/10.17660/ActaHortic.1996.415.36
43. Paschold P.J., Weithaler A. 2000. Eignung von Sensoren zum Steuern der Bewässerung bei Freilandgemüse. Zeitschrift für Bewässerungswirtschaft, 35(1), 51–62.
44. Pierzgalski E., Jeznach J. 2006. Measures for soil water control in Poland. J. Water and Land Development. 10, 79–89. DOI: 10.2478/v10025-007-0007-5
45. Pinkau H., Grutz E.M. 1985. Effect of nitrogen, sprinkler irrigation and length of harvesting period on the yield and quality of green asparagus. Archive fur Gartenbau. 33(4), 177–189.

46. PN-A-04019:1998. Food products.
47. Pressman E., Schaffer A.A., Compton D., Zamski E. 1994. Carbohydrate content of young asparagus plants as affected by temperature regimes. *J. Plant Physiol.* 143, 621–624. https://doi.org/10.1016/S0176-1617(11)81148-X
48. Pressman E., Schaffer A.A., Compton D., Zamski E.1 1989. The effect of low temperature and drought on carbohydrate content of asparagus. J. Plant Physiol. 134, 209–213. https://doi.org/10.1016/S0176-1617(89)80057-4
49. Rickman J.C., Barrett D.M., Bruhn C.M. 2007. Nutritional Comparison of Fresh, Frozen and Canned Fruits and Vegetables. Part 1. Vitamins C and B and phenolic compounds. Journal of the Science of Food and Agriculture, 87, 930–944. https://doi.org/10.1002/jsfa.2825
50. Rolbiecki R. 2013. Assessment of the needs and effects of micro-irrigation of asparagus (*Asparagus officinalis* L.) in an area particularly water-deficient. UTP, Bydgoszcz, Poland, 1–103. (in Polish)
51. Rolbiecki R., Rolbiecki S. 2008. Effect of surface drip irrigation on asparagus cultivars in central Poland. Acta Horticulturae**,** 776, 45-50. https://doi.org/10.17660/ActaHortic.2008.776.3
52. Rolbiecki R., Rolbiecki S., Figas A., Jagosz B., Prus P., Stachowski P., Kazula M.J., Szczepanek M., Ptach W., Pal-Fam F. 2021a. Response of chosen american *Asparagus officinalis* L. cultivars to drip irrigation on the sandy soil in Central Europe: growth, yield, and water productivity. Agronomy, 11, 864. https://doi.org/10.3390/ agronomy11050864
53. Rolbiecki R., Rolbiecki S., Figas, A., Jagosz B., Stachowski P., Sadan H.A., Prus P., Pal-Fam F. 2021b. Requirements and effects of surface drip irrigation of mid-early potato cultivar courage on a very light soil in Central Poland. Agronomy, 11(33). https://dx.doi.org/10.3390/ agronomy11010033
54. Singleton V.L., Orthofer R. 1999. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. In Methods in Enzymology; Abelson, J.N., Simon, M.I., Sies, H., Eds.; Academic Press: Burlington, MA, USA, 152–178.
55. Smirnoff N. 2000. Ascorbic acid: metabolism and functions of a multifaceted molecule. Current Opinion in Plant Biology, 3, 229–235.
56. Sterrett S.B., Ross B.B., Savage C.P. 1990. Establishment and yield of asparagus as influenced by planting and irrigation method. Journal of the American Society for Horticultural Science, 115(1), 29–33.
57. Sullivan S,A., Tran A.Q.M., Xu G., Yin, Y., Zhou C., Bae-Jump V.L. 2017. Asparagus polysaccharide inhibits cell proliferation, adhesion and invasion in endometrial cancer cells. Abstracts/Gynecologic Oncology, 133. https://doi.org/10. 1016/j.ygyno.2017.03.312
58. Szczepaniak O., Dziedzinski M., Szymanowska D., Szulc P., Bielec D., Kobus-Cisowska J. 2019. Cultivation of szparaga (*Asparagus officinalis* L.) as raw material with functional properties. Part 2. Nutritional characteristics. Technika Rolnicza Ogrodnicza Leśna (2), 2–6. (in Polish)
59. Takács-Hájos M., László Zsombik L. 2015. Total polyphenol, flavonoid and other bioactive materials in different asparagus cultivars. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 43(1), 59–63 DOI:10.15835/nbha4319720. https://doi.org/10.15835/nbha4319720
60. Wellburn A.R. 1994. The spectral determination of chlorophyll a and b, as well as total carotenoids, using various solvents with Spectrophotometrs of different resolution. Journal of Plant Physiology, 144, 307–313. https://doi.org/10.1016/S0176-1617(11)81192-2
61. Žebrauskienė A., Paulauskienė A., Abramavičienė R. 2013. Investigation of chemical composition of introduced cultivars of asparagus (*Asparagus officinalis* L.) spears. The Sixth International Scientific Conference Rural Development Proceedings, 6, 2, 276–287. https://doi.org/10.1016/j.foodres.2022.111992
62. Żakowicz S. 2010. Fundamentals of irrigation technology for reclaimed municipal waste dumas. Scientific Dissertations and Monographs. SGGW: Warszawa, Poland. (in Polish)
63. Żarski J. 2011.Trends in changes of climatic indices for irrigation needs of plants in the region of Bydgoszcz. Infrastructure and Ecology of Rural Areas, 5, 29–37. (in Polish)