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Effect of Nitrogen Fertilizer Rates on Physico-Chemical Characteristics of Onion Bulbs (*Allium cepa* L. var. *cepa*)

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Abstract

Onion is one of the most important vegetable bulb crops in the world. A field experiment was carried out at the experimental fields of the Agricultural Institute of Slovenia in 2017 with the aim to examine the effect of three nitrogen (N) fertilization rates on the physico-chemical characteristics of bulbs of five onion varieties. Three autochthonous and two hybrid onion varieties were evaluated. During the growth 0, 162 and 324 kg Nha^{-1} were applied. The number of fleshy scale leaves, bulb weight, height, diameter and firmness were determined on onion bulbs. In addition, the total soluble solids and total sugars were analysed. Both factors, i.e. variety and N fertilization rate, significantly affected the number of fleshy scale leaves, while N fertilisation rate also affected bulb firmness and the variety influenced the content of total soluble solids and bulb height. Hybrid varieties had lower total soluble solids compared to autochthonous varieties.

Key words: firmness, nitrogen fertilization, physical parameters, onion, total sugars

Introduction

Onion (*Allium cepa* L. var. *cepa*) is one of the most important vegetable bulb crops cultivated for more than 4000 years (Jurgiel-Malecka et al., 2015; Kumar et al., 2007; Mallor Giménez et al., 2011). In Slovenia, it is commonly grown in every garden and cultivated for the market.

The production has been increasing over the last years; in 2017 onion was cultivated on 444 ha with a total production of 9.709 t of which 6.613 t was produced for the market and the rest for self-supply (SI-STAT, 2019).

These quantities are encouraging in comparison with previous years, but they are far from covering the needs of the onion market. The average yield varies between 20 – 30 t $ha^{-1}$and is slightly lower than the average yield in the EU, which is about 37 t ha^{-1} (EUROSAT, 2019). Anyhow, much higher (double and higher) yields are achieved in some countries around the world, i.e. 66 t ha^{-1} in the Republic of Korea, 67 t ha^{-1} in USA, 57 t ha^{-1} in Australia, 52 t ha^{-1} in Netherlands and Spain, and 49 t ha^{-1} in Sweden (FAOSTAT, 2019).

Besides climatic conditions, the agricultural practice including N fertilization and the selection of varieties considerably affects the onion yield. According to Brewster (1994) onion yields typically increase with increases in N application in the range from 0 to 150 kg ha^{-1} and thereafter level off. Also, nitrogen application in onion production significantly influences the flavour, development and quality of bulbs (Randle, 2000).

Several landraces of bulb onions have been developed over the decades in different onion growing regions in Slovenia. Lately a few autochthonous varieties have been selected form these populations. The most widespread is the 'Ptujska rdeča' variety, which is Protected by Geographical Indication (PGI) under the name Ptujski lük and grown in the traditional way from the sets in the region of east Slovenia around the town Ptuj since 2011.

It is the first Slovenian PGI certified vegetable. In 2018 four autochthonous onion varieties, i.e. 'Belokranjka', 'Ptujska rdeča', 'Tera' and 'Ivica rdeča' were registered in the national variety catalogue (National List of Varieties, 2018).

Onions are produced for its bulbs which consist of inner fleshy scale leaves and outer tunics. The quality of the onion bulbs which is important for the acceptability of consumers is influenced by many factors, such as production technology, weather conditions during the growth, pre- and post-harvest handling and storage conditions (Petropoulos et al., 2016; Lee, 2010). In addition, the physical parameters, mechanical properties and chemical composition of the bulbs are as well affected by those factors (Mallor Giménez et al., 2011; Sinclair et al., 1995; Bahnasawy et al., 2004).

The objective of the present study was to find out how application of different rates of N affects some quality-related physical parameters (i.e. bulb weight, height and diameter, height/diameter ratio, number of fleshy scale leaves, bulb firmness) and chemical properties (i.e.total soluble solids, total sugars) of bulbs of different onion varieties.

Material and Methods

A field experiment with five onion varieties was performed in the experimental fields (304 m a.s.l.; 46.151°N 14.562°E) of the Infrastructure Centre Jablje at the Agricultural Institute of Slovenia in 2017. The experiment was designed as a split plot in three replicates with N fertilization as the main factor (three rates) and the onion variety as a sub-factor (five varieties). Three autochthonous open pollinated ('Ptujska rdeča', 'Tera', 'Belokranjka') and two hybrid onion varieties ('Talon', 'Tamara'), which are most widespread in Slovenia, were evaluated. 'Ptujska rdeča' forms medium-sized flat bulbs with white fleshy scale leaves and pink-brown tunics. 'Tera' forms middle-sized flat bulbs with white fleshy scale leaves and dark-red epidermis and dark-red tunics. 'Belokranjka' is of oblong shape with convex bulbs and white fleshy scale leaves and yellowish-brown tunics. 'Talon' is a medium-early thick hybrid variety with high-yield suitable for storage. 'Tamara' is a medium-size hybrid variety suitable for long-term storage. Both hybrid varieties form large round bulbs with white fleshy scale leaves and brown tunics.

Onion seedlings were produced in polystyrene growing plates with 160 cells in a heated greenhouse. Seeding was carried out on 15 February, transplanting of seedlings to open field on 5 April and harvesting of onion bulbs on 14 August. The seedlings were planted in three-row beds at a 30 cm distance between the rows and 10 cm within the rows, giving the density of 200,000 plants ha^{-1}. The size of each plot was 4.5 m^2. Before the crop establishment, 20 t ha^{-1} of bovine manure was applied in autumn prior to field ploughing. In spring, before transplanting, 28 kg N ha^{-1} N, 80 kg P_2O_5 ha^{-1} and 240 kg K_2O ha^{-1} was added. During the growth three N rates were applied in split application in the form of ammonium nitrate as follows: without N fertilization (0 kg Nha^{-1}), 3-times 54 kg Nha^{-1} (fertilization with 162 kg Nha^{-1}) and 3-times 108 kg Nha^{-1} (fertilization with 324 kg Nha^{-1}). Nitrogen was added three, six and nine weeks after transplanting. The experiment was cultivated in accordance with prevalent agricultural practice. Harvested onion bulbs were stored in dry and dark environment until the analysis. All measurements of physical parameters and chemical properties were carried out on marketable onion bulbs at the beginning of November. For measurement of physical parameters six marketable bulbs were selected from each treatment and the following parameters determined: bulb weight (g), bulb height (cm), bulb diameter (cm), number of fleshy scale leaves and total soluble solids (°Brix) using a digital refractometer (Atago Palette PR-100).

The bulb shape index (BSI) was calculated as the height/diameter ratio (Bahnasawy et al., 2004). Bulb firmness (kg cm^{-2}) was measured at the equatorial axis of each of six onion bulbs without tunics at four different points with a flat bottom probe (d=11.2 mm and penetration depth 8 mm) using an electronic penetrometer (PTS 01 TRC-HBM). For determination of total sugars, the bulk sample of six bulbs was lyophilized and homogenized with a ball mill (Retsch MM400).

The total sugars were determined according to the Luff-Schoorl method (Commission Regulation EC No. 152/2009) by which the reducing and total sugars in the sample are determined after inversion and expressed as g glucose per kg of dry matter (DM).

The results were statistically evaluated using the Statgraphics Centurion XVI (Statgraphics Centurion, 2009). The statistical significance of the effect of each factor was determined by multifactor ANOVA and, in cases where the interaction was not significant, the significance differences among the factors levels determined by LSD test. Besides, the statistical significance of the effect of each treatment (combination of variety and N fertilization level) was determined by ANOVA and the differences among the mean values by Duncan's multiple range tests. All tests were performed at the 95 % confidence level ($P < 0.05$). Correlations between physical and chemical characteristics were determined by the Pearson's correlation test using the R-commander (Rcmdr) program.

Results and Discussion

The results of physical parameters of onion bulbs from different treatments, i.e. five onion varieties grown at three different N fertilization rates (0, 162 and 324 kg Nha^{-1}) are presented in Tab. 1. By increasing N rate the following parameters: bulb weight, height and diameter, increased in all varieties, except in 'Belokranjka'. However, the differences were not always statistically significant. Both hybrid varieties 'Tamara' (mean 313.9 g) and 'Talon' (mean 268.6 g) had significantly higher bulb weight compared to autochthonous varieties 'Belokranjka' (mean 201.1 g), 'Ptujska rdeča' (mean 182.0 g) and 'Tera' (mean 165.4 g). The bulb height was the highest for 'Belokranjka' (> 10.0 cm) and the bulb diameter for 'Tamara' (mean 8.6 cm). The number of fleshy scale leaves at 'Tamara' and 'Talon' was statistically significantly higher than in all autochthonous varieties. Regarding different N fertilization rates, the highest number of fleshy scale leaves was determined for the treatment without N fertilization.

A closer look at single factor combination reveals that on the level of each variety the N fertilisation did not influence the number of fleshy scale leaves at both hybrid varieties ‘Tamara and ‘Talon’, while at all 3 autochthonous varieties there is a trend of decreasing of flesh scale leaves with increasing N rate, but the differences are statistically significant only for the variety ‘Ptujska rdeča’. The height/diameter ratio of the bulbs determines the bulb shape index (BSI). The shape of the onion is oval when it is BSI > 1.5, and spherical when it is BSI < 1.5. Among all varieties in the experiment, only 'Belokranjka' has oval shaped bulbs while other varieties have spherical. These data are in agreement with the previous report on various genetic resources and varieties of onions (Mallor Giménez et al., 2011; Bahnasawy et al., 2004; Leilah et al., 2003).

Tab. 1. Physical parameters of five onion varieties grown at three nitrogen fertilization rates

Морфолошки параметри пет сорти црног лука при гајењу са три различита нивоа ђубрења азотом

Variety	N fertilization rate ($kgha^{-1}$)	Bulb weight (g)	Bulb height (cm)	Bulb diameter (cm)	Bulb shape index (BSI)	Number of fleshy scale leaves
'Tera'	0	153.67 ± 27.78	4.73 ± 0.45 b	7.80 ± 0.47	0.61 ± 0.06	8.33 ± 1.63
	162	153.67 ± 42.87	4.99 ± 0.45 ab	7.61 ± 0.92	0.66 ± 0.06	7.83 ± 1.47
	324	189.00 ± 39.75	5.44 ± 0.44 a	8.20 ± 0.61	0.66 ± 0.05	7.33 ± 1.51
'Talon'	0	202.00 ± 72.19 a	7.06 ± 0.92 a	7.32 ± 0.74 a	0.96 ± 0.05	9.00 ± 0.63
	162	288.33 ± 68.82 ab	7.73 ± 0.72 ab	8.42 ± 0.80 b	0.92 ± 0.13	9.33 ± 0.52
	324	315.33 ± 26.49 b	8.13 ± 0.29 b	8.61 ± 0.33 b	0.95 ± 0.05	9.50 ± 0.55
'Ptujskardeča'	0	157.67 ± 20.45 a	4.96 ± 0.31	7.78 ± 0.37 a	0.64 ± 0.05	8.67 ± 0.82 b
	162	180.00 ± 22.13 ab	4.95 ± 0.35	8.18 ± 0.36 ab	0.61 ± 0.05	7.17 ± 0.98 a
	324	208.33 ± 47.59 b	5.09 ± 0.35	8.70 ± 0.72 b	0.59 ± 0.04	6.67 ± 0.82 a
'Belokranjka'	0	212.67 ± 58.63	10.22 ± 1.09	6.82 ± 0.87	1.52 ± 0.23	8.50 ± 1.05
	162	208.33 ± 25.41	10.00 ± 1.19	6.99 ± 0.24	1.43 ± 0.15	8.17 ± 0.75
	324	182.33 ± 46.07	10.10 ± 1.57	6.51 ± 0.60	1.55 ± 0.22	6.83 ± 1.47
'Tamara'	0	325.33 ± 21.53	8.17 ± 0.67	8.67 ± 0.20	0.94 ± 0.09	9.67 ± 0.82
	162	282.67 ± 19.75	7.74 ± 0.23	8.42 ± 0.33	0.92 ± 0.04	9.33 ± 0.82
	324	333.67 ± 80.95	8.25 ± 0.76	8.72 ± 0.55	0.95 ± 0.06	9.50 ± 0.84

Note: Data are means ±standard deviation (n=6). Mean values with different letters (a,b) in columns for individual variety are significantly different ($P < 0.05$; differences between N fertilization rates).

The differences in the bulb firmness between the varieties were not statistically significant. N fertilization rates significantly influenced the bulb firmness so that the bulbs from treatment without N fertilization had the highest firmness (12.3 kg cm^{-2}), followed by fertilization with 162 kg N ha^{-1} (11.9 kg cm^{-2}) and fertilization with 324 kg N ha^{-1} (11.1 kg cm^{-2}) where the bulbs were statistically significantly less firm than at the other two treatments.

This trend was observed for all onion varieties, although the differences were significant only for 'Tera' (Fig. 1).

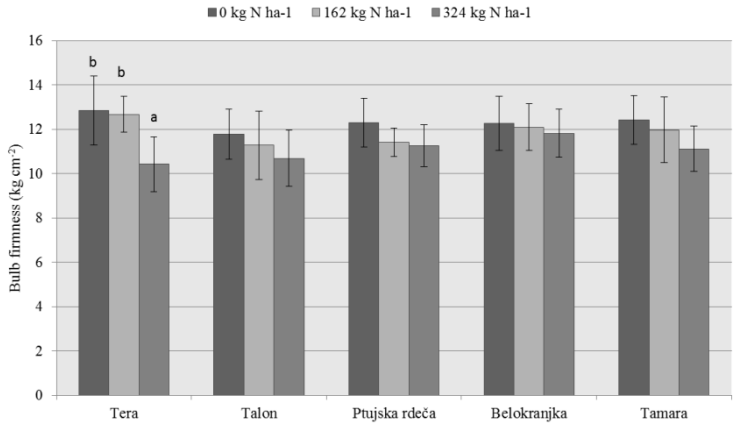

Fig. 1. Bulb firmness of five onion varieties grown at three nitrogen fertilization rates
Чврстоћа луковица пет сорти црног лука гајених при три различита нивоа ђубрења азотом

The highest variety mean value for total soluble solids (data not shown, Fig. 2) was found for 'Tera' (11.8 °Brix), followed by 'Ptujska rdeča' (11.7 °Brix), 'Belokranjka' (10.6 °Brix), Tamara (8.7 °Brix) and Talon (7.8 °Brix).

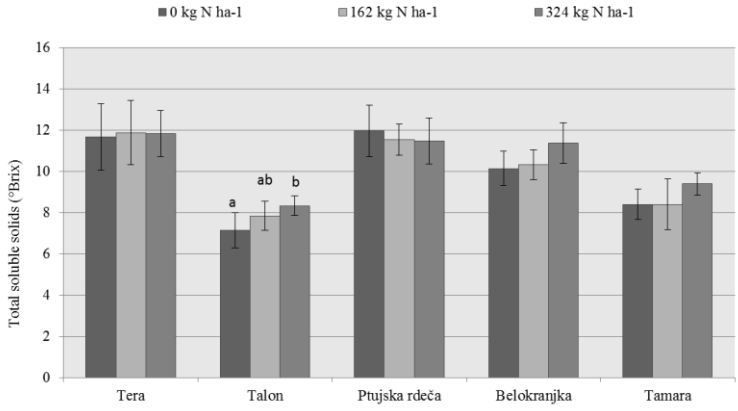

Fig. 2. Total soluble solids in five onion varieties grown
at three nitrogen fertilization rates
Укупне растворљиве чврсте материје у пет сорти црног лука гајених при три различита нивоа ђубрења азотом

The autochthonous varieties had significantly higher total soluble solids compared to hybrids. The differences in the total soluble solids between the N fertilization rates were not statistically significant. The differences between N fertilization rates were significant only for 'Talon' ($P < 0.05$). Previous studies on onion genetic sources reported slightly lower mean values for bulb firmness and total soluble solids (Mallor Giménez et al., 2011; Petropoulos et al., 2016).

The total sugars mean value of all analysed bulbs of onion varieties was 634 g glucose kg^{-1}DM. The highest mean values of total sugars were found for 'Ptujska rdeča' and 'Tera' (> 650 g glucose kg^{-1}DM) and the lowest for 'Belokranjka' (Fig. 3). Among different N fertilization rates the bulbs grown without N fertilization (680 g glucose kg^{-1}DM) reached the highest mean values for total sugars, followed by fertilization with 324 kg N ha^{-1} (637 g glucose kg^{-1}DM) and fertilization with 162 kg N ha^{-1}(614 g glucose kg^{-1}DM).

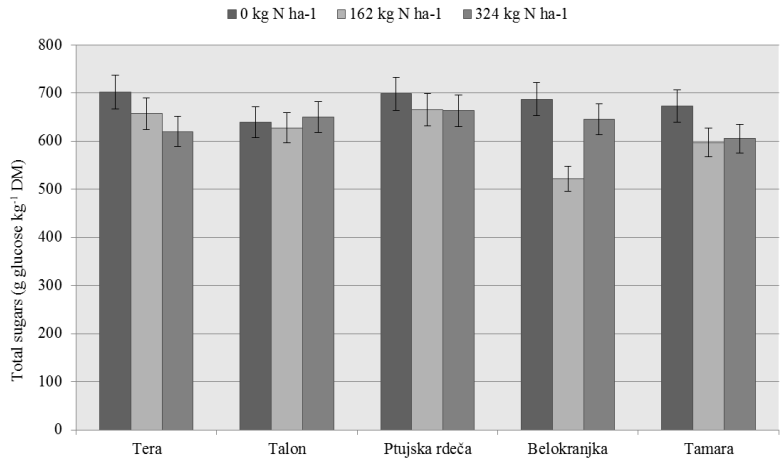

Fig. 3. Total sugars in five onion varieties grown at three nitrogen fertilization rates

Укупни шећери у пет сорти лука гајених при три различита нивоа ђубрења азотом

Correlations between all investigated physico-chemical characteristics were determined. The highest correlation was found between the total soluble solids and number of fleshy scale leaves, i.e. -0.755 ($P < 0.01$**). A high correlation was also determined between the bulb weight and bulb diameter 0.693 ($P < 0.001$**), the bulb weight and a number of fleshy scale leaves 0.674 ($P < 0.01$**) and the bulb weight and total soluble solids -0.599 ($P < 0.05$*).

Conclusion

Nitrogen (N) fertilization rate significantly affects the bulb firmness and number of fleshy scale leaves, meaning that on average both parameters have decreased with increasing N rate in all varieties. The variety has a significant effect on the number of fleshy scale leaves, total soluble solids and the bulb height. The hybrid varieties have a significantly higher number of fleshy scale leaves than autochthonous varieties. The 'Ptujska rdeča' variety has the highest total soluble solids while 'Talon' has the lowest. ‘Belokranjka’ has significantly the highest bulbs and ‘Ptujska rdeča’ and ‘Tera’ the flattest. On the basis of the bulb shape index (BSI) the 'Belokranjka' variety has an oval bulb shape while the varieties 'Ptujska rdeča', 'Tera', 'Talon' and 'Tamara' have a spherical bulb shape. For bulb weight and diameter the interactions between the N rate and varieties were determined. A significant correlation was determined between the following characteristics: total soluble solids and number of fleshy scale leaves, bulb weight and bulb diameter, bulb weight and a number of fleshy scale leaves, bulb weight and total soluble solids.

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Утицај нивоа ђубрења азотом на физичко-хемијске карактеристике луковица црвеног лука (*Allium cepa* L. var. *cepa*)

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Сажетак

Црвени лук је једна од најзначајнијих биљних врста у свијету. На огледним пољима Пољопривредног института Словеније у 2017. години спроведен је пољски оглед са циљем испитивања утицаја три нивоа ђубрења азотом (N) на физичко-хемијске карактеристике луковица пет сорти лука. Оглед је спроведен са три аутохтоне и двије хибридне сорте лука. Током раста, азот је примјењен у три различита нивоа, тј. 0, 162 и 324 kg N/ha. На луковицама су одређени: број меснатих листова, маса, висина, пречник и чврстоћа луковице. Поред тога, утврђен је удио укупних растворљивих материја и укупних шећера. Оба фактора, тј. сорта и ниво ђубрења азотом, значајно су утицали на број меснатих листова, док је ниво ђубрења азотом утицао још на чврстоћу луковица а сорта на удио укупних растворљивих материја и висину луковица. Хибридне сорте су имале мањи удио укупних растворљивих материја у поређењу са аутохтоним сортама.

Кључне ријечи: чврстоћа, ђубрење азотом, физички параметри, црвени лук, укупни шећери

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