CHANGES IN YIELD PARAMETERS AND POLYPHENOL CONTENT IN RESPONSE TO DIFFERENT PLANT SPACING IN EDIBLE HIBISCUS PRODUCTION

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Abstract

The aim of the study was to verify the effect of plant spacing on the yield parameters and quality of edible hibiscus fruits, known as okra. The results were compared with other authors who studied the connections between plant spacing and other production parameters. Two varieties ('Baby bubba´ and ´Clemson spineless´) and different spacing effect (S1 = 0.6 x 0.45m; S2 = 0.5 x 0.45m; S3 = 0.6 x 0.3m; S4 = 0.5 x 0.3 m) on average fruit weight, yield per plant, yield per hectare and content of total polyphenols were tested in work. The average fruit weight of cultivar ´Baby bubba´ variety was ranged from 25.7 g (S1) to 28.7 g (S2). The yield per plant was ranged from 308.2 g (S1) to 345.0 g (S2). The yield per hectare was showed by significantly different results; the highest okra yield was found in the variant of spacing S4 (21.1 t.ha^{-1}) and the lowest yield was found in the spacing variant S1 (11.3 t.ha^{-1}). The content of total polyphenols in okra fruits was significantly highest in S1 spacing (16519.6 mg GAE.kg^{-1} DM), compared to other spacing variants. In ´Clemson spineless´ okra cultivars, slightly different results were found. The average fruit weight of okra was ranged from 19.2 g (S4) to 25.8 g (S2). The yield per plant was ranged from 230.9 g (S4) to 309.3 g (S2). The effect of plant spacing in this cultivar was similar to results of yield in the cultivar ´Baby bubba´. The yield per hectare was ranged from S1 (10.8 t.ha^{-1}) to S4 variant (15.3 t.ha^{-1}). The highest content of polyphenols was also found in the spacing S1 (17694.8 mg GAE.kg^{-1} DM). Obtained results showed on the significant effect of plant spacing and grown cultivar on the yield parameters and polyphenol content. Results can be usable for potential growers of okra in conditions of Slovak Republic, or Middle-Europe generally.

Keywords: *okra, spacing, yield parameters, polyphenols*

1. INTRODUCTION

The Edible Hibiscus (*Abelmoschus esculentus* L. Moench.), most often marked as okra, is plant of *Malvaceae* family, well known by many local names as Lady's finger, Bhindi, Bamya, Gumbo, Okura, Kacang Bendi etc. (Tiwari et al. 1998; Jwar & Neghamish 2022).

The origin of this crop is East Africa, probably Ethiopia, but nowadays it is grown in all countries with tropical and Mediterranean climates (Doymaz 2005). Faostat data states that okra was grown on more than 2.5 mil. hectares in 2020 with total production more than 10.5 mil. tonnes worldwide. The highest producers of okra in 2020 was India (4.6 mil. tonnes), followed by countries from Africa (Nigeria, Sudan, Mali, Ivory Coast, Egypt, Ghana, Niger) and Asia (Iraq, Pakistan). In Europe, Albania can be marked as the highest producer of okra, but with minimal ratio compared to mentioned countries (FAO 2022). In Slovakia, as well as in other European countries, okra is cultivated only as a local garden crop.

Okra is traditional vegetable crop grown for its fresh immature, semi-mature and mature beaked pods (fruits), fresh leaves, buds, flowers, stems and seeds (Diizyaman 1997; Raymond 2011; Mihretu, Garedew & Debela 2014). Immature, semi-mature pods and leaves are used as cooked green vegetable (Raymond 2011); the mature fruit has high mucilage content which binds cholesterol and bile acid carrying toxins dumped into it by the liver (Gemede et al. 2015). Okra pods are rich in vitamin A, vitamin B, vitamin C, amino acids, Ca, K and other mineral substances; seeds are good source of oil which is reach in unsaturated fatty acids (Kumar, Kumar & Nadendla 2003; Hossain et al. 2006). Arapitsas (2008) states that okra is rich in polyphenolic compounds; seeds are mainly composed by

oligomeric catechins and flavonol derivatives. Skin polyphenolic profile is composed principally by hydroxycinnamic and quercetin derivatives.

The okra plant is also good source of polysaccharides that have a proven hypoglycemic effect (Liu et al. 2018). In Turkey, ripe okra seeds are roasted, ground and used as a coffee substitute (Çalisir et al. 2005). The stems contain crude fiber, used in the paper industry. They have comparable properties to lignocellulosic fibers and show some potential as reinforcement in polymer matrix composites (De Rosa et al. 2010; Kumar, Kumar & Nadendla 2003). From an economic point of view, this crop proves to be a good raw material to produce biofuels, crude vegetable oil and other industrial products (Anwar et al. 2010; De Rosa et al. 2010; Anastasakis, Kalderis & Diamadopoulos 2009; Agarwal, Srinivasan & Mishra 2001).

Due to irreplaceable properties of okra, new growing methods are testing in order to optimization of its yield. Okra yield can be affected by many factors including seed quality, nutrition, climatic conditions, growing practices or picking interval (Kusvuran 2012; Talukder et al. 2003). One of the most important factor within okra growing technology is the plant spacing. A suitable plant spacing can lead to the optimization of okra yields, on the contrary, an inappropriately selected spacing can lead to a relatively low yield and poor quality fruit (Absar & Siddique 1982; Moniruzzaman, Uddin & Chaudhury 2007).

In literature source, different spacing of okra plants is recommended. The plant spacing (plant density) in wide range (0.9 - 0.3 x 0.6 - 0.3 m) has been observed in various studies with okra, in which its high effect on vegetative growth, fruit quality and yield parameters of okra plants were found (Firoz et al. 2007; Paththinige, Ranaweera Banda & Fonseka 2008; Maurya, Bailey & Chandler 2013). From this reason, aim of this study was to verify the optimal plant spacing for okra production in Slovak Republic.

2. MATERIALS AND METHODS

2.1. Materials

Within experiment, two cultivars of okra were used, concretely 'Clemson spineless' and 'Baby bubba'.

The 'Clemson spineless' cultivar is characterized by green leaves and long curved ribbed fruits (pods) 8-9 cm long. The seed producer states that the growing season from sowing to harvest maturity is 56 days. The crop requires high sunlight. The fruits are fleshy and delicate in taste, used as an ingredient in soups, for stews, it can be grilled and stewed (Amoatey et al. 2015; Burpee 2021).

The 'Baby bubba' cultivar is characterized by high yields. The plant requires direct sunlight. The growing season from sowing to first harvest is 53 days. The fruits are 5 - 7.5 cm long (Burpeeeurope 2021).

2.2. Methods

The study was carried out as a field experiment on an experimental plot with an area of 49 m^2. Experiment was situated in the village Jelka in south-western part of Slovak Republic. Each okra cultivar was sown in 4 variants with 3 repetitions (repetition: 6 plants). The variants of tested plant spacing were following:

- S1: 0.6 x 0.45m (recounted plant density per hectare: 37 037 plants.ha^{-1}),
- S2: 0.5 x 0.45m (44 444 plants.ha^{-1}),
- S3: 0.6 x 0.3m (55 556 plants.ha^{-1}),
- S4: 0.5 x 0.3m (66 667 plants.ha^{-1}).

The seed was sown on 15th March 2020 in the greenhouse of the SUA Botanical Garden in Nitra. Subsequently, okra seedlings were planted in the experimental area on 17th May 2020. Based on the performed soil analysis, LAD 27 (27% N) fertilizer was applied to the required nitrogen supply for okra growing (150 kg.ha^{-1}). Counted fertilizer dose was divided to the application in 3 terms: 29th May 2020, 15th June 2020 and 30th June 2020.

Okra fruits were harvested from 22nd June 2020 to 21st August 2020 depending on the required maturity of the fruit. Crispy light green fruits long approximately 50 mm were manually harvested. The harvest was done for each repetition separately.

Immediately after harvest, okra fruits were weighted. According to weight and number of fruits, average weight of fruits and yield per plant were counted. Sequentially, yield per hectare was recounted according to plant density in each plant spacing variant.

The total polyphenol content in okra fruits, harvested on 23th July 2022, was determined by spectrophotometric method using a Folin-Ciocalteu reagent in lyophilized samples at Institute of Food FBaFC SUA in Nitra. Lyophilized samples were prepared by the Institute of Nutrition and Genomics FAaFR SUA in Nitra.

Obtained experimental results were evaluated by Anova analysis of variance at the significance level of $p = 0.05$.

3. RESULTS

The average weight of okra fruit in the 'Baby bubba' cultivar was ranged from 25.7 g (S1) to 28.7 g (S2). The highest yield per plant was also found in the same spacing variant S2 (345.0g). Differences in values of both parameters among spacing variants were evaluated as statistically non-significant. On the contrary, yield of okra fruits was the highest in the variant S4 (21.1 $t.ha^{-1}$). Significant differences of yield per hectare were found between all spacing variants. The lowest values of all quantitative parameters were found in the variant with the widest spacing S1; however, content of total polyphenols (TPC) in okra fruits was the significantly highest in this variant (16519.6 mg $GAE.kg^{-1}$ DM).

In the 'Clemson spineless' cultivar, values of AW were ranged from 19.2 g (S4) to 25.8 g (S2). The yield per plant was achieved from 230.9 g (S4) to 309.3 g (S2). Differences in values of both parameters among S3 or S4 and S1 or S2 were evaluated as statistically significant. From aspect of okra yield per hectare, the highest value was found in the closest spacing variant S4 (15.3 $t.ha^{-1}$). In both tested cultivars, the yield per hectare was increasing with decreasing plant distance in spacing variants. The statistically significant differences of TPC in okra fruits were showed among all tested spacing variants.

The influence of cultivar was showed by statistically significant differences in all parameters of okra fruits. In okra cultivar 'Baby bubba', higher values of AW (+12.1%), yield per plant (+21.1%) and hectare (+24.2%) were found compared to the cultivar 'Clemson spineless'. On the contrary, okra cultivar 'Clemson spineless' was showed as a richer source polyphenols compared to the cultivar 'Baby bubba' (+7.2%).

	Spacing [m]	Average fruit weight [g]	Yield per plant [g]	Total yield [$t.ha^{-1}$]	Polyphenols [mg $GAE.kg^{-1}$ DM]
Baby bubba	S1	25.7 ±1.76^{a}	308.2 ±21.12^{a}	11.3 ±0.77^{a}	16519.6 ±80.87^{d}
	S2	28.7 ±1.27^{a}	345.0 ±15.21^{a}	15.2 ±0.67^{b}	16136.1 ±121.58^{c}
	S3	27.2 ±2.32^{a}	325.8 ±27.85^{a}	17.9 ±1.53^{c}	15591.2 ±82.69^{b}
	S4	26.6 ±1.49^{a}	319.2 ±17.87^{a}	21.1 ±1.18^{d}	15142.6 ±67.56^{a}
Clemson spineless	S1	24.6 ±1.67^{b}	295.1 ±20.09^{b}	10.8 ±0.74^{a}	17694.8 ±195.31^{d}
	S2	25.8 ±1.37^{b}	309.3 ±16.46^{b}	13.6 ±0.72^{b}	17338.9 ±134.12^{c}
	S3	19.7 ±1.31^{a}	236.2 ±15.71^{a}	13.0 ±0.86^{b}	16806.4 ±87.85^{b}
	S4	19.2 ±1.41^{a}	230.9 ±16.88^{a}	15.3 ±1.12^{c}	16120.6 ±78.00^{a}

Table 1. Effect of plant spacing on quantitative parameters and polyphenol content of okra fruits

Note: Same letters (a) within the same column means statistically non-significant difference (at 95.0% confidence level) within one cultivar. Different letters (a; b) within the same column means statistically significant difference (at 95.0% confidence level) within one cultivar.

	Average fruit weight [g]	Yield per plant [g]	Total yield [t.ha^{-1}]	Polyphenols [mg GAE/kg DM]
Baby bubba	27.0 ±1.90^{b}	324.5 ±22.74^{b}	16.4 ±3.88^{b}	15847.4 ±552.53^{a}
Clemson spineless	22.3 ±3.26^{a}	267.9 ±39.18^{a}	13.2 ±1.83^{a}	16990.2 ±629.84^{b}

Table 2. Effect of cultivar on quantitative parameters and polyphenol content of okra fruits

Note: Same letters (a) within the same column means statistically non-significant difference (at 95.0% confidence level) within one cultivar. Different letters (a; b) within the same column means statistically significant difference (at 95.0% confidence level) within one cultivar.

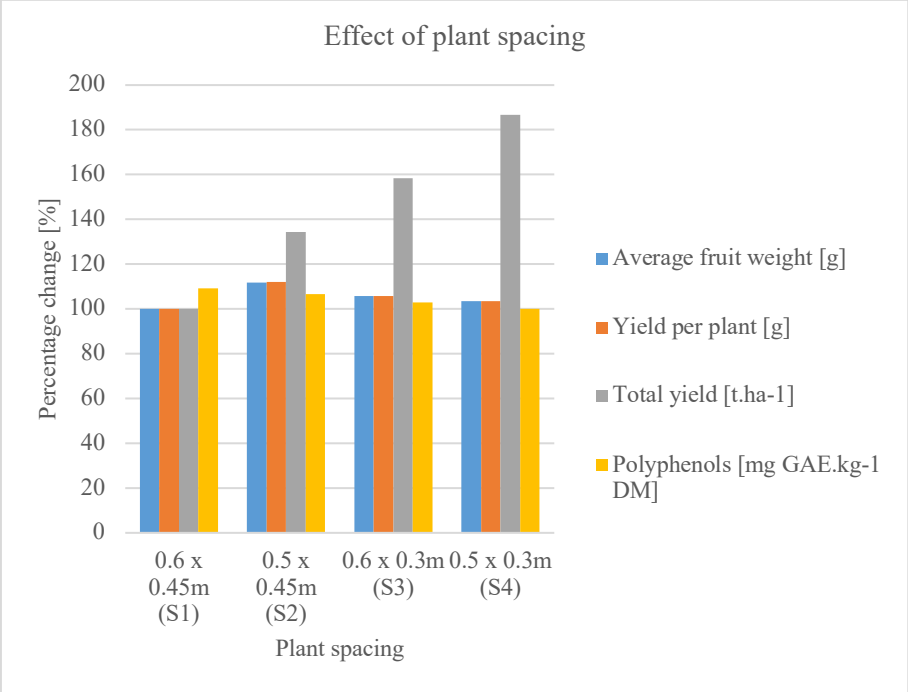


Fig. 1. Effect of plant spacing on evaluated parameters of okra

4. DISCUSSION

Various scientific studies focused on the effect of plant spacing on crop-forming parameters have presented similar results. Similarly, in our work we find results that confirm the hypotheses of other authors.

In our study, the highest yield per hectare was found in the variant with widest plant spacing and its lowest value in the variant with closest plant spacing. Maurya, Bailey & Chandler (2013) tested effect of three different plant spacing in experiment with okra cultivar 'Clemson spineless' (0.3 x 0.45m; 0.6 x 0.3m; 0.6 x 0.45m). Authors also found that the increase of okra yield per hectare was directly connected with higher plant density. Moniruzzaman, Uddin & Chaudhury (2007) tested the effect of four okra spacing variants (0.6 x 0.3 m; 0.6 x 0.4 m; 0.6 x 0.5 m; 0.6 x 0.6 m) on okra seed yields and they found that hectare seed yield decreased with a wider spacing (0.6 x 0.5 m; 0.6 x 0.6 m). Authors found that reduction in plant density was showed by an increase of fruit number and yield of okra seed per plant.

The same effect was also found in our study and studies of several authors. Paththinige et al. (2008) presented that total okra yield is increasing with increasing plant density per area. Authors tested four different spacing variants of okra plants (0.9 x 0.6 m; 0.6 x 0.45 m; 0.45 x 0.45 m; 0.45 x 0.3 m) and the highest yield per hectare was found in the spacing variant '0.45 x 0.3 m' spacing and the lowest value in the variant '0.9 x 0.6 m'. On the contrary, weight of okra fruit was increased due to the wider plant spacing. Maurya, Bailey & Chandler (2013) also found that the wider spacing resulted in higher AW and yield per grown area. According to the study of Brar & Singh (2016), the lower plant density (spacing 0.15 m in row) was revealed by significant increase (+11.3%) in fresh weight of okra fruits compared to the spacing of 0.20 m in row.

Results of study realized by Firoz et al. (2007) confirmed fact that closer spacing is showed by higher yield of okra fruits per hectare. Authors found its significantly highest value in the spacing 0.6 x 0.5m (+48.1%) compared to spacing variant '0.6 x 0.4 m' (+18.8%) and '0.6 x 0.3 m' (the lowest value determined as a control value). Similar results were also presented in the study of Falodun and Ogedegbe (2016) who found the highest yield of okra fruits per hectare by using of closer spacing. Its values were increased in following variant order: 0.70 x 0.30 m < 0.60 x 0.30 m < 0.50 x 0.30 < 0.40 x 0.30 m.

In our experimental work, the statistically significant influence of plant spacing on the content of total polyphenols (TPC) in okra fruits was found. Values of TPC was increased with the expanding plant spacing. It is expected that increase of TPC in okra fruits could be result of higher sunlight intensity among plants. This fact was found and mentioned in several studies with various vegetable species. Khandaker, Ali & Oba (2008) observed the effect of different sunlight level on TPC in leaves of *Amaranthus tricolor* L. A statistically significant effect was revealed in open sunlight, where the highest value of TPC was found compared to variant where sunlight was reduced by white nets. Pérez-Lopéz et al. (2018) studied the effect of light intensity and CO_2 concentration on the TPC in lettuce (*Lactuca sativa* L). Authors found that increase of light intensity, at the same CO_2 concentration, was resulted in higher TPC in lettuce leaves. Løvdal et al. (2010) realized the study focused on the effect of two levels of light on the content of phenolic substances in tomato leaves. Authors noticed a significant differences in the content of individual phenolic compounds in variant with higher light intensity compared to the control, e. g. flavanols (+110.5%) or anthocyanins (+31.6%). According to Di Stefano et al. (2020), direct sunlight should regulate the biosynthesis of phenolic compounds in crop products by altering the expression of genes that code enzymes of the biosynthetic pathways. Authors found positive effect of light intensity on the content of phenolic substances in pomegranate (*Punica granatum* L.) fruits. Result of higher intensity is variable dependent on the type of phenolic substances.

Results of our study showed fact that cultivar is one of the most important factors influencing on the yield and quality of okra production (table 2). It has been also demonstrated in previous studies with okra (Prasad, Manesh & Neha, 2016; Singh, Singh & Meraj, 2018; Šlosár et al., 2019) and other vegetable crops, e. g. sweet pepper (Boyhan et al., 2019), tomato (Sekara et al., 2019), onion (Wohleb & Waters, 2016) or carrot (de Carvalho, da Silva & Magalhães, 2020).

Within study of Maurya, Bailey & Chandler (2013), the same spacing variant, like in our experiment, were used in the cultivar 'Clemson spineless ', concretely 0.6 x 0.45 m (S1) and 0.6 x 0.3 m (S3). The higher weight of okra fruits was reached in our study (S1 difference = +6.2%; S3 = 1.9%). On the contrary, Maurya, Bailey & Chandler (2013) found higher yield per plant (S1 = +40.8%; S3 = +40.3%) and yield per hectare (S1 = +42.5%; S3 = +41.7%) compared to our study. It is obvious that growing locality should also has significant impact to the yield of okra fruits. We did not find any experimental results regarding to the use of the same spacing variants in cultivar 'Baby bubba', thus, it is not possible to compare our results exactly for this cultivar.

5. CONCLUSION

Results of this study showed that plant spacing has a significant effect on quantitative and qualitative parameters of okra yield. From aspect of average fruit weight and yield per plant, a wider spacing could be used (0.6 x 0.45 m or 0.5 x 0.45 m). This fact can be interesting for smaller growers. Within large-scale production, significant parameter is yield of crops per hectare. The aim of producers is to ensure

the highest possible yield and profit. In this case, using of closer spacing (0.6 x 0.3 m or 0.5 x 0.3 m), could be recommended. Nowadays, interest about human nutrition and nutrition value of products is continuously increasing. From aspect of higher polyphenol content in okra fruits, wider spacing should be used (0.6 x 0.45 m or 0.5 x 0.45 m). Fruit formation and their quality is obviously closely related to the intensity of sunlight. Our results, after comparison with various studies, show that lower plant density causing higher sunlight intensity among plants is tending to induce higher content of pohyphenols as secondary metabolites.

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