TÜBİTAK

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2016) 40: 465-473
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doi:10.3906/tar-1501-99

Selected yield and qualitative parameters of broccoli in dependence on nitrogen, sulfur, and zinc fertilization

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Received: 22.01.2015 • **Accepted/Published Online:** 19.02.2016 • **Final Version:** 18.05.2016

Abstract: The effect of nitrogen (N), sulfur (S), and zinc (Zn) fertilization on the yield quantity and selected qualitative parameters of broccoli was studied in an experiment carried out in Nitra (Slovak Republic) during 2011 and 2012. In this experiment, the following fertilization treatments were tested: control; $N_{200}S_{80}$ (fertilized to the supply level: 200 kg N ha^{-1} and 80 kg S ha^{-1}); $N_{200}S_{100}$ (supply level: 200 kg N ha^{-1} and 100 kg S ha^{-1}), and $N_{200}S_{100}$Zn (supply level: 200 kg N ha^{-1} and 100 kg S ha^{-1} + foliar zinc application). Compared to the control treatment, higher broccoli yield was shown at all fertilized treatments. The most significant increase in yield quantity was found at $N_{200}S_{100}$Zn, i.e. about 59% higher than the control. Application of $N_{200}S_{100}$Zn was the most suitable fertilization from the standpoint of broccoli quality. The foliar Zn spraying led to a statistically highly significant increase of sulforaphane in broccoli (about 41.1%) compared to the control. The applied N and S fertilization tended to decrease the vitamin C content in broccoli (about 9.2%) against the control. On the other hand, Zn application resulted in a return of the vitamin C content, nearly to its level in control. The results confirmed the well-known fact that nitrogen fertilization leads to nitrate accumulation in vegetables. However, the results of this research indicate that nitrogen fertilization combined with zinc application should be expressed mainly by lower nitrate accumulation in the edible parts of broccoli. The experimental data are interesting, and in terms of growing vegetables for consumption with enhanced quality, promising. This is notable because the formation of many serious diseases is increasing.

Key words: Broccoli, fertilization, nitrates, sulforaphane, vitamin C

1. Introduction

Broccoli (*Brassica oleracea* L. var. *italica*) is one of most important cole crops in the world. The health benefits of broccoli are partly associated with secondary plant compounds known for their antioxidant activity (Jones et al., 2006).

Prominent components of broccoli are glucosinolates (β-thioglucoside-N-hydroxy-sulfates) which are present in all members of the family *Brassicaceae*. Glucosinolates (GLS) and products of their breakdown are known for antifungal, bactericidal, nematicidal, and allelopathic properties (Fahey et al., 2002). The GLS content is extremely variable according to species (Verkerk et al., 2009), variety (Sivakumar et al., 2007), part of the *Brassica* vegetable plant (Borowski et al., 2008), vegetation period (Turhan et al., 2011), and other factors (e.g., fertilization and climate conditions). From the glucosinolates group, broccoli contains mostly sulforaphane, which has proven anticancer activity. It was identified as a product of enzymatic or acid hydrolysis of corresponding glucoraphanin (Anilakumar, 2006). SF is connected with a reduced risk of prostate and lung cancer (Spitz et al., 2000; Joseph et al., 2004). It suppresses and kills *Helicobacter pylori*, which is responsible for ulcer disease and is considered an agent in many cases of stomach cancer (Fahey et al., 2002). Lin et al. (2002) state that sufficient vitamin C intake has similar beneficial properties for *Helicobacter pylori* suppression (Lin et al., 2002).

Vitamin C (ascorbic acid) is a very effective antioxidant due to its properties. It can act as an anticarcinogenic agent and reduces the risk of cardiovascular diseases (Du et al., 2012). The potential antioxidant effect of vitamin C has been the subject of many studies. Iqbal et al. (2004) indicate that vitamin C prevents cancer formation by inhibiting nitroso compounds in the stomach and stimulating the immune system. Vitamin C content depends on several factors, e.g., species and variety (Valšíková et al., 2010) or manner of postharvest processing and treatment before storage (Nursal Tosun and Yücecan, 2007).

Nitrates (NO_3^-) are natural substances in plants, and they are not toxic by themselves. The potential toxicity

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of higher nitrate levels in vegetables or other foods consists in their reduction to disease-causing nitrites called methemoglobinemia (Du et al., 2007). Nitrates accumulate in plant tissues in larger amounts if plants are not able to use the applied nitrogen for creation of amino acids and sequentially proteins, i.e. plant metabolism is not able to reduce the nitrates into the assimilable form (Bryan et al., 2012). Santamaria (2009) classifies broccoli among vegetable species with a moderate nitrate content (500–1000 mg NO_3^- kg^{-1} of fresh weight).

Several studies in different agricultural crops indicate that sulfur and zinc fertilization could lead to an increase in crop quality. On the other hand, the impact of fertilization on the quality of broccoli, or vegetable species in general, has not been sufficiently proven, and findings from previous experiments are variable. Thus, the goal of this research was to determine the effect of nitrogen (N), sulfur (S), and zinc (Zn) fertilization on the yield quantity and sulforaphane, vitamin C, and nitrate accumulation in broccoli florets.

2. Materials and methods

2.1. Plant material and experimental design

The small-plot field experiment with broccoli was established in the botanical garden of the Slovak University of Agriculture in Nitra in 2011–2012. The experimental area is situated at 144 m above sea level. The climate of experimental area is characterized by warm and dry summers and slightly warm and dry, or very dry, winters. According to the climatic normal (1951–2000) for Nitra, the mean annual temperature is 9.9 °C, and the mean rainfall is 548 mm (Table 1).

Within the experiment a middle-late broccoli cultivar, Tiburon F1 (Bejo Zaden BV, Warmenhuizen, Netherlands), that forms firm and finely granular florets of dark green was tested. Seedlings were planted on 24 June 2011 and 30 June 2012. Each fertilization treatment was examined at four replications. In each replication (4 m^2), 16 seedlings were planted at a spacing of 0.5 × 0.5 m. Within the experiment, 256 seedlings were planted each year. The width of loosening and protection against weeds was by manual hoeing. Chemical protection against several insects (*Brevicoryne brassicae*, *Pieris brassicae*, *Mamestra brassicae*, *Delia brassicae*, *Aleyrodes proletella*, and *Phyllotreta* spp.) was conducted.

The harvest of broccoli florets was gradual, in relation to their maturation. The broccoli florets were harvested including an edible part of stalk with length of 10 cm. The total broccoli yield consisted of yield from partial harvests from 3 dates in particular fertilization treatments in each experimental year. The broccoli was harvested on 26 August, 30 August, and 2 September 2011 and on 3 September, 7 September, and 12 September in 2012.

Table 1. Mean monthly rainfall (mm) and temperature (°C) in 2011 and 2012 and long-term mean (1951–2000), Nitra, Slovakia.

Month	Rainfall (mm)			Temperature (°C)		
	2011	2012	Long-term	2011	2012	Long-term
January	25	61	29	–0.9	1.4	–1.4
February	6	24	30	–0.6	–2.5	0.5
March	27	3	32	5.9	7.4	4.8
April	13	36	42	12.7	11.2	10.4
May	48	20	56	15.8	17.3	15.2
June	91	70	66	19.8	20.9	18.3
July	122	61	59	19.7	22.8	20.0
August	152	7	54	20.9	21.5	19.7
September	92	33	43	17.7	17.0	15.5
October	37	76	41	9.9	10.5	10.2
November	1	35	52	3.0	7.5	4.6
December	42	44	43	2.2	–0.9	0.5
Total	656	470	548	-	-	-
Mean	-	-	-	10.5	11.2	9.9

2.2. Fertilization treatments

In this research, the effect of N, S, and Zn application on the quantity and quality of broccoli yield was tested. Fertilization treatments were as follows:

0: control (without application of fertilizers),

$N_{200}S_{80}$: application of nitrogen and sulfur at the supply level N:S = 200:80 kg ha^{-1},

$N_{200}S_{100}$: application of nitrogen and sulfur at the supply level N:S = 200:100 kg ha^{-1},

$N_{200}S_{100}Zn$: application of nitrogen and sulfur at the supply level N:S = 200:100 kg ha^{-1} + foliar zinc application (0.75 L of Zinkuran SC fertilizer ha^{-1}).

The doses of N and S were calculated on the basis of agrochemical soil analysis at a depth of 0–0.30 m before the establishment of the experiment (Table 2).

In the experiment, fertilizers CAN 27 (calcium ammonium nitrate; 27% N; Duslo, a. s., Šaľa, Slovak Republic) and DASA 26/13 (26% N and 13% S; Duslo, a. s., Šaľa, Slovak Republic) were used for N and S supply. The fertilizer DASA 26/13 was applied 3 weeks before planting. The calculated dose of LAD 27 was applied twice at 3 (50%) and 6 weeks (50%) after planting. The Zn was applied in the form of ZINKURAN SC fertilizer (36% Zn; Arysta LifeScience Slovakia s.r.o., Nové Zámky, Slovak Republic). Foliar ZINKURAN SC solution was applied 4 weeks after plating.

2.3. Determination of qualitative parameters of broccoli

Analyses for determination of the examined qualitative substances were performed in samples prepared from broccoli florets harvested on 30 August 2011 and 7 September 2012. For sample preparation, broccoli florets were harvested from different points in each treatment replication. The average sample from each treatment replication was prepared from 6–7 florets of broccoli, and it was taken from several points along the floret and stalk. Samples prepared for sulforaphane determination were sequentially lyophilized at −58 °C. Analyses of ascorbic acid and nitrate content were performed with fresh samples of broccoli.

All qualitative parameters were measured by high pressure liquid chromatography (HPLC) at a certified laboratory. The analyses of sulforaphane, vitamin C, and nitrate content were according to methods previously described by Sivakumar et al. (2007), Stan et al. (2014), and Hegedűs et al. (2010).

2.4. Statistical analysis

A statistical analysis was performed using Statistica 6.0 for Windows. Obtained results were evaluated by analysis of variance (ANOVA), and average values were tested by Tukey's HSD test performed at the significance level of 95%.

3. Results

3.1. Weight of broccoli florets

Average weight of broccoli florets is an important quantitative parameter for calculation of total yield as well as income for broccoli producers. The average weight of broccoli florets ranged from 201.3 g (control) to 319.9 g ($N_{200}S_{100}Zn$). Variance analysis revealed a statistically significant increase in value at all fertilized treatments compared to the control treatment (Table 3). The weight of broccoli florets was higher in 2011 than in 2012. Its value was ranged from 205.5 g (control) to 326.1 g ($N_{200}S_{100}Zn$) in 2011. In 2012, floret weight varied from 197.1 g (control) to 313.8 g ($N_{200}S_{100}Zn$).

3.2. Total broccoli yield

The application of N, S, and Zn had a positive impact on the total broccoli yield. At all fertilized treatments, a statistically significant increase in its value was shown compared to the unfertilized/control treatment in both experimental years. The analysis of variance also detected a statistically significant increase in broccoli yield at treatments $N_{200}S_{100}$ and $N_{200}S_{100}Zn$ compared to the treatment with a lower level of sulfur ($N_{200}S_{80}$) in both experimental years. The additional application of zinc ($N_{200}S_{100}Zn$) led to a statistically significant increase in broccoli yield compared to the $N_{200}S_{100}$ treatment only in 2011. On the other hand, yield increase among the aforementioned treatments was not statistically significant in 2012 (Table 3).

The total broccoli yield was higher in 2011 than in 2012. The yield of broccoli florets varied from 8.21 t ha^{-1} to 13.04 t ha^{-1} in 2011. In 2012, the broccoli yield ranged from 7.89 t ha^{-1} to 12.56 t ha^{-1}. After application of $N_{200}S_{100}Zn$, broccoli

Table 2. Agrochemical soil analysis (depth: 0–0.30 m) before experiment establishment.

Year	pH/KCl	Content of nutrients in mg kg^{-1} of soil						% of humus
		Nmin*	P	K	S	Ca	Mg	
2011	6.96	46.8	130	575	32.5	7300	662.5	3.79
2012	6.67	30.4	128	530	37.5	6370	654	3.76

*Mineral (inorganic) nitrogen.

Table 3. The effect of fertilization on broccoli floret yield.

Treatment	Total yield (t ha^{-1})			Weight (g)		
	2011	2012	Average	2011	2012	Average
0	8.21a	7.89a	8.05	205.5a	197.1a	201.3
$N_{200}S_{80}$	11.73b	11.37b	11.55	293.4b	284.2b	208.8
$N_{200}S_{100}$	12.68c	12.22c	12.44	317.1c	304.9c	311.0
$N_{200}S_{100}Zn$	13.04d	12.56c	12.80	326.1d	313.8c	319.9

Different letters between rows show statistically significant differences at the level α = 0.05.

yield was 58.8% (2011) or 59.1% (2012) higher compared to the control treatment. The average broccoli yield for all treatments in 2011 (11.4 t ha^{-1}) was 3.5% higher than in 2012 (11.01 t ha^{-1}).

3.3. Sulforaphane content

The N, S, and Zn fertilization tended to lead to higher sulforaphane content in broccoli florets. A statistically significant increase in SF content was shown at all fertilized treatments in comparison with the control treatment (Table 4).

The SF content varied from 52.3 mg kg^{-1} (control) to 73.8 mg kg^{-1} of fresh weight ($N_{200}S_{100}Zn$). The difference between the aforementioned treatments was 41.1%. The zinc application ($N_{200}S_{100}Zn$) had a statistically significant impact on the SF content compared to N-S treatments ($N_{200}S_{80}$ and $N_{200}S_{100}$).

3.4. Vitamin C content

On the other hand, the application of N, S, and Zn had a negative impact on the content of vitamin C in broccoli (Table 4).

Vitamin C content varied from 748.3 mg kg^{-1} ($N_{200}S_{100}$) to 824.4 mg kg^{-1} (control) of FW. At this treatment, the vitamin C content was about 9.2% lower compared to the control treatment. Differences among fertilized treatments were evaluated as statistically nonsignificant.

3.5. Nitrate content

The application of N fertilizers resulted in an increased accumulation of nitrates in broccoli florets. At all fertilized treatments, a statistically significant increase in nitrate content was detected in contrast to the control treatment (Table 4).

The nitrate content ranged from 474.4 mg kg^{-1} (control) to 632.8 mg kg^{-1} of fresh weight ($N_{200}S_{80}$). At the treatment $N_{200}S_{80}$, the nitrate content was about 33.4% higher in comparison with control. The test of contrasts for obtained results revealed a statistically significant decrease in nitrate content at the treatment $N_{200}S_{100}Zn$ compared to the $N_{200}S_{80}$ treatment. The difference between treatments $N_{200}S_{80}$ and $N_{200}S_{100}$ was evaluated as statistically nonsignificant.

4. Discussion

Nitrogen (N) and sulfur (S) belong to basic macronutrients responsible for yield quantity and quality of *Brassica* vegetable species. Their deficiency is a major nutritional problem that results in decreased crop yield and quality (Schonhof et al., 2007). Plants also require the proper balance of zinc (Zn) for normal growth and optimum yield, and its deficiency causes diminishing quality in many agricultural crops (Sadeghzadeh, 2013). Magen (2008) emphasizes that balanced fertilization is one of the basic conditions for larger yields and better quality of crops grown.

Table 4. The effect of fertilization on the content of sulforaphane, vitamin C, and nitrates in mg kg^{-1} of fresh weight.

Treatment	Sulforaphane (mg kg^{-1})			Vitamin C (mg kg^{-1})			Nitrates (mg kg^{-1})		
	2011	2012	Average	2011	2012	Average	2011	2012	Average
0	45.4	59.1	52.3a	789.6	859.1	824.4a	461.1	478.7	474.4a
$N_{200}S_{80}$	59.4	70.8	65.1b	756.4	825.3	790.9b	621.2	644.4	632.8c
$N_{200}S_{100}$	54.3	65.4	59.9b	689.5	807.0	748.3b	599.0	611.6	605.3c
$N_{200}S_{100}Zn$	69.7	77.9	73.8c	784.4	839.2	811.8b	559.1	583.7	571.4b

Different letters between rows show statistically significant differences at the level α = 0.05.

The previous experiment by Šlosár and Uher (2013) indicated that combined N and S fertilization ($N_{200}S_{60}$) resulted in higher yield and increased accumulation of selected qualitative parameters in broccoli. In the current research, the effect of increased S supply (80 kg ha^{-1} and 100 kg ha^{-1}) and Zn application on broccoli yield was tested.

Results obtained from this experiment confirmed that N is a limiting nutrient necessary for achievement of optimal yield quantity in broccoli and in vegetable species generally. This was also presented in the previous studies of many authors. Erdem et al. (2010) examined the effect of increasing N dose (150, 200, and 250 kg ha^{-1}) on broccoli yield. The dose of 150 kg N ha^{-1} was the optimal fertilization treatment, about 46.0% higher than the control treatment. Giri et al. (2013) found that application of 200 kg N ha^{-1} resulted in a statistically significant increase in broccoli yield (about 143%). Hussain (2012) stated that raising the nitrogen dose led to a gradual increase in broccoli floret yield. S and Zn were also shown as important nutrients in terms of yield formation. The higher S supply participated in a slight increase in broccoli yield compared to treatment with lower S supply. This statement is in accordance with results obtained in experiments by Elwan and Abd El-Hamed (2011) and Pék et al. (2012), who also found that increasing S doses tended to lead to higher broccoli yield. De Pascale et al. (2007) examined the effect of S fertilization on yield in friariello (*Brassica rapa* L. subsp. *sylvestris* L. Janch. var. *esculenta* Hort.). The authors found that S application resulted in a higher yield (up to 17.6%) compared to treatment without a S dose. The effect of Zn fertilization on the yield quantity of vegetable species is not clear. However, the experiments of several authors (Yin et al., 2004; Feng et al., 2005) indicated that zinc application was profitable for the growth of broccoli and sweet corn, which should be sequentially expressed as increased vegetable yield. It was demonstrated in the case of a broccoli experiment presented by Abd El-All and El-Shabrawy (2013). Singh and Tiwari (2013) stated that rising zinc doses resulted in a gradually increasing yield in tomato fruits. Kazemi (2013) found that zinc application (100 mg L^{-1}) led to significantly higher yield in tomato compared to the control treatment. The difference in yield quantity among the aforementioned treatments was 63.6%. The positive impact of Zn application on the yield was also found in experiments with other agricultural crops, e.g., wheat or maize (Chaab et al., 2011; Aslam et al., 2014). Solanki et al. (2010) showed the variable impact of Zn fertilization on the yield of carrot, cauliflower, and onion. The authors found that application of Zn sulfate (up to 30 kg ha^{-1}) significantly increased the yield quantity of examined vegetable crops, whereas lower yield was detected at a higher Zn level (60 kg zinc sulfate ha^{-1}).

Experimental results indicated the marked role of S and Zn fertilization on sulforaphane accumulation in broccoli florets. Several reports also showed that S and Zn application can alter the concentration and composition of glucosinolates (GLS) in *Brassica* species (Hu et al., 2011; Sadeghzadeh, 2013). Schonhof et al. (2007) found that S fertilization in combination with optimal N supply tended to increase the content of sulforaphane in broccoli florets. Abd El-All (2014) tested the impact of two different sulfur doses (75 kg S ha^{-1} and 150 kg S ha^{-1}) on the sulforaphane content in broccoli. The author found the supply level of 150 kg S ha^{-1} was the optimal treatment for sulforaphane accumulation in broccoli. Similar results was presented by Rosen et al. (2005) and De Pascale et al. (2007), who showed the positive effect of S fertilization on GLS content in experiments with cabbage and turnip. These results contrast with those of Aires et al. (2006), who revealed a possible detrimental impact of S fertilization on the GLS content in broccoli. Zinc appears to be an important micronutrient for sulforaphane content in *Brassica* species. Liang et al. (2006) examined the effect of six micronutrients on broccoli quality, and Zn application was only expressed in the form of higher sulforaphane content. Coolong and Randle (2004) found a direct correlation of Zn application to the content of glucoraphanin, a sulforaphane precursor, in the hydroponic culture of *Brassica rapa*. Its value gradually increased depending on increasing Zn doses in the nutrient solution. A similar statement was presented by Abd El-All (2014) who found that Zn fertilization (200 ppm) resulted in a statistically significant increase in sulforaphane content in broccoli.

In the experiment, nitrogen fertilization in combination with sulfur and zinc tended to decrease vitamin C content in broccoli florets. However, opinions regarding the influence of nitrogen and sulfur fertilization on vitamin C content are very different. Xu et al. (2010) found that applied nitrogen fertilization tended to lead to a decrease in acid ascorbic content in broccoli florets. On the other hand, Ducsay and Varga (2004) showed that nutrient optimization resulted in higher vitamin C content in Chinese cabbage. Elwan and El-Hamed (2011) found that the impact of S fertilization on the content of vitamin C in broccoli was variable and statistically nonsignificant. According to the comparison of vitamin C content between treatments $N_{200}S_{100}$ and $N_{200}S_{100}Zn$, zinc appears to be a nutrient which could lead to an increase in vitamin C content in the edible parts of broccoli or vegetable crops in general. This is in accordance with a study published by Abd El-All and El-Shabrawy (2013), who stated the positive impact of zinc fertilization on vitamin C content in broccoli. Kumari (2012) found that a zinc dose of 100 ppm was expressed as an increase in vitamin C content in tomato (about 36.9%) in comparison with the control treatment. The cumulative impact of zinc fertilization was also reported by Kazemi (2013), who found the gradual rise in vitamin C content depended on increasing zinc doses in an experiment with tomato. In the treatment with a higher zinc dose (100 mg L^{-1}), a statistically significant increase in vitamin C (about 29.3%) was detected compared to the treatment with a lower zinc dose (50 mg L^{-1}). The positive impact of increasing zinc doses on vitamin C content was also stated by Kumar (2009) and Singh and Tiwari (2013).

According to results from our experiment, the applied nitrogen fertilization tended to lead to an increase in accumulation of nitrates in broccoli florets. Nevertheless, the maximum acceptable amount of nitrates in *Brassica* vegetable species (700 mg kg^{-1} of FW), according to the Food Codex of the Slovak Republic (SVFA SR, 2014), was not exceeded. Increasing nitrate accumulation in vegetables as a result of nitrogen fertilization was shown in various studies. Babik and Elkner (2002) stated that increasing the level of nitrogen fertilization (100, 200, 400, and 600 kg N ha^{-1}) led to a statistically significant increase in nitrate content in broccoli florets. Varga et al. (2004) found that nitrogen application at the supply level of 300 kg N ha^{-1} resulted in higher content of nitrates in broccoli (about 27.5%) compared to the unfertilized treatment. Fabek et al. (2012) tested the effect of different nitrogen supply levels on nitrate accumulation in broccoli. The authors detected an increase in nitrate content of about 20.5% (120 kg ha^{-1}) and 64.5% (240 kg ha^{-1}). Similar results on the cumulative impact of nitrogen fertilization were attained in research studies in other vegetable species (Karaman et al., 2000; Smolen and Sady, 2009; Ahmadil et al., 2010). According to Campbell (1999) and Swamy et al. (2005), sulfur is an essential constituent of enzymes involved in N metabolism: nitrate reductase and nitrite reductase. Its availability could lead to an increase in assimilation of what is contributed to the lower nitrate content, as it was also found in the treatment with a higher sulfur supply in the current experiment. Moreover, a decreasing nitrate content dependent on sulfur application was presented by Elwan and Abd El-Hamed (2011) in a broccoli experiment. After foliar sulfur application (0.5% solution), the nitrate content decreased from 644.8 mg kg^{-1} to 630.5 mg kg^{-1} of FW. However, sulfur fertilization can be expressed by a more notable and statistically significant decrease in nitrate content, as in the experiment with friariello (De Pascale et al., 2007). Sulfur application also resulted in lower nitrate content in other horticultural crops, e.g., onion (Lošák et al., 2010), spinach, pepper (Smatanová et al., 2004), and kohlrabi (Lošák et al., 2008). According to Cakmak (2008), zinc is required for the basic processes of plant life, including photosynthesis and nitrogen assimilation; thus, it plays a key role in crop growth. Kazemi (2013) found that gradually increasing the zinc dose (0, 50,, and 100 mg L^{-1}) resulted in a statistically highly significant increase in nitrate reductase activity (about 172.4%). The increase in nitrate reductase activity after zinc application is a very important factor due to the lower nitrate content in the edible part of the vegetable. It was confirmed by Wang et al. (2001), who found a significant decrease in nitrate content in celery of about 28.6% and 29.5% as a result of zinc application at different doses.

The sulforaphane, vitamin C, and nitrate contents of broccoli were also affected by climatic conditions in 2011 and 2012. The average air temperature within the harvest period (August/September) was the same in both experimental years (19.3 °C). The rainfall sum within the harvest period was markedly higher in 2011 (244 m) than in 2012 (40 mm). The values of all examined qualitative parameters were higher in 2012 than in 2011. Similar findings confirming the impact of climate on broccoli quality were presented by various authors. Ciska et al. (2000) found that lower rainfall was expressed by higher glucosinolate (GLS) in several *Brassica* vegetables, because GLS concentration was not diluted by high rainfall intake. Pék et al. (2012, 2013) stated that sulforaphane content in broccoli increased as a result of lower rainfall intake or drought stress during the vegetation period. Erken and Öztokat Kuzucu (2013) tested several levels of water deficit on vitamin C content at different growth stages of broccoli. The authors found that decreasing water supply before harvest resulted in increasing vitamin C content in broccoli florets. Wojciechowska et al. (2005) found that nitrate content in broccoli was closely dependent on the sum of rainfall during the harvest period in June in 1999, 2000, and 2001. In 1999, the rainfall sum was higher (200 mm) than in 2000 (100 mm) and 2001 (80 mm). The nitrate content was markedly lower in 2001 (1399.3 mg NO_3^- kg^{-1} FW) than in 1999 (705.8 mg NO_3^- kg^{-1} FW).

5. Conclusion

Fertilization is a substantial element in the cultivation technology of all crops. In this study, all tested nutrients (N, S, and Zn) were very important for yield and qualitative parameters in broccoli. Among all applied nutrients, the zinc foliar application provided the most beneficial impact on yield quantity, sulforaphane, vitamin C, and nitrate contents in broccoli.

Acknowledgments

This paper was supported by grants from the Scientific Grant Agency (VEGA 1/0105/14) and the Culture and Education Grant Agency (KEGA 038SPU-4/2014) of the Ministry of Education, Science, Research, and Sport of the Slovak Republic.

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