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ORIGINAL PAPER

YIELDS AND THE COMPOSITION OF ROOTS OF SUGAR BEET VARIETIES TOLERANT TO THE BEET CYST NEMATODE*

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Abstract

Breeding sugar beet varieties resistant and tolerant to *Heterodera schachtii* Schmidt is one of the ways to reduce the occurrence of this pest in soil. Tolerant varieties should have a high value. Yields of roots must be high and of good technological quality. In 2013-2015, the research unit of Nordzucker Polska S.A. together with the Department of Plant Production and Experimentation of the Bydgoszcz University of Science and Technology carried out a one-factor field experiment at the village of Błoto, Kujawsko-Pomorskie Province, Poland. The purpose of the study was to compare the root yield, the internal technological quality of roots, and the technological yield of sugar from three beet cyst nematode (BCN) tolerant sugar beet varieties: Charly, Perruche, and Sława KWS, and two conventional varieties, grown in fields with a high BCN cyst count (657-1140 cysts 100 g^{-1} soil). Yields and technological quality of roots during the study period depended on a variety of sugar beet. The tolerant variety Perruche was the highest yielding one in terms of average yields over the whole period. In two out of the three years of the experiment, there was also a significant relationship between the sugar content in beet roots and their variety. In 2013 and 2015, the sugar yield of at least one BCN-tolerant variety, i.e. the varieties Sława KWS and Charly respectively, was significantly higher than the yield of a conventional variety, which was worse in this respect. In 2014, the technological yield of sugar from each tolerant variety was higher than the yield obtained from the conventional varieties.

Keywords: BCN-tolerant varieties, roots yield, technological sugar yield, polarisation, molasses-forming components.

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INTRODUCTION

Root crops are an important component of crop rotations, affecting other elements of agricultural practice, such as fertilization and soil properties (Suwara, Szulc 2011). The beet cyst nematode – BCN (*Heterodera schachtii* Schmidt) is one of the most dangerous agrophages of sugar beet. Its incidence in soil is aided by a close relationship with host plants, such as beet and the *Brassicaceae* plants, as well as the presence of host weeds from the *Chenopodiaceae* and *Brassicaceae* families in the field (Daub, Westphal 2012). BCN causes beet root deformation, a decrease in size and weight, and large harvest losses. Other effect of its presence in soil are worse technological quality of roots and decreased sugar yield (Fatemy et al. 2007, Deumelandt et al. 2010, Kenter et al. 2014).

The control of this pest involves mainly the observance of crop rotation principles, elimination of host plants, and rotation with plants which hold a BCN population in check. This purpose is also served, to different degrees, by breeding BCN-killer varieties of white mustard, oil radish and phacelia as the main or stubble crop (Szymczak-Nowak, Nowakowski 2002, Niere 2009, Heinrichs 2011). An effective method of pest reduction and limiting the effects of its presence in sugar beet fields is by growing resistant and tolerant beet varieties (Raaijmakers 2014, Hauer et al. 2016).

The national register of cultivars and the EU catalogue contain numerous sugar beet varieties, with new ones being added year after year, including BCN-tolerant ones. The presence of this trait in beet is one of the objectives of breeding programmes. The varieties must also possess other desirable properties which determine the quantity and quality of the raw material (Richardson 2012). It can therefore be assumed that the current sugar beet varieties which are BCN-tolerant permit high root yields and have quality traits that guarantee a high technological yield of sugar.

The purpose of the research was to compare the yields of roots, their internal technological quality and the technological sugar yields of three BCN -tolerant varieties and of two conventional varieties, grown under conditions of a high BCN cyst count in the soil in northern Poland.

MATERIAL AND METHODS

In 2013-2015, the agricultural experimentation unit of Nordzucker Polska S.A., member of the Nordzucker Group, and the Department of Plant Production and Experimentation of the Bydgoszcz University of Science and Technology carried out a one-factor field experiment at the village of Błoto (53,14° N; 18,21° E), situated in Kujawsko-Pomorskie Province in northern Poland. The yield and quality of roots of 5 sugar beet varieties were evaluated, in 4 replicates, in a randomised block design. Every year, three BCN-tolerant varieties: Charly (bred by Strube GmbH & Co. KG) , Perruche (SAS Florimond Desprez Veuve & Fils) and Sława KWS (KWS Saat SE), and two conventional varieties without the BCN tolerance trait, for the purposes of this paper referred to as Conventional 1 and Conventional 2, were sown into Mollic Fluvisol (good wheat soil complex in the Polish classification system). In the subsequent years, the following varieties: Primavera (KWS Saat SE) and Melodia (Kutnowska Hodowla Buraka Cukrowego sp. z o.o., Poland), Janka (Kutnowska Hodowla Buraka Cukrowego sp. z o.o., Poland) and Natura KWS (KWS Saat SE), Syzyf (Kutnowska Hodowla Buraka Cukrowego sp. z o.o., Poland) and Nevenka (KWS Saat SE) were tested, respectively. The counts of BCN eggs and larvae in early spring, before the sowing, were between 657 and 1140 per 100 g soil, depending on the year. Their numbers were calculated at the Toruń Agricultural Experiment Station of the Plant Protection Department of the National Research Institute (IOR PIB TSD Toruń, Poland).

Sugar beet was cultivated using the standard technology. Seeds were sown in rows at 45 cm distance, spaced at 7.7 cm in a row. After correcting the population density, the plants were spaced at 18 cm in a row. Nitrogen fertilisation was applied at 110 kg N ha^{-1}, while phosphorus and potassium fertilisation was dosed according to the nutrient content in a given year, on average 30 kg P ha^{-1} and 100 kg K ha^{-1}. Monocotyledonous and dicotyledonous weeds were removed in 4 treatments with a shared total dose herbicides: Betanal Maxx Pro 209 OD (phenmedipham 60 g dm^{-3}, desmedipham 47 g dm^{-3}, ethofumesate 75 g dm^{-3}, lenacil 27 g dm^{-3}), Goltix 700 SC (metamitron 700 g dm^{-3}), Venzar 500 SC (lenacil 500 g dm^{-3}), at 4.0 dm^3 ha^{-1}, 4.0 dm^3 ha^{-1} and 0.9 dm^3 ha^{-1}, respectively. The root yield and its internal technological quality were determined, i.e. the sugar content (polarisation), plus the potassium, sodium and α-amino nitrogen content, during the harvest. The root quality analysis was performed on an automatic Venema line at the KHBC's agricultural experimentation station (AES) in Straszków, Poland. Also, the technological sugar yield was calculated from the algorithm (Reinefeld et al. 1974, Stępień et al. 2010):

$$W = P - [0{,}343(K+Na) + 0.094N\ \alpha\text{-amin.} + 0.29],$$

where: W – purified sugar yield, P – sucrose content percentage, K, Na, α-amin. N – mval (milliequivalent) in 100 g mush, 0.094 – experimental correction, 0.29 – correction for undetermined losses.

The results from every study year and their synthesis for the period of three years were elaborated using statistical methods. The analysis of variance was carried out according to the single-factor experiment model. The significance of the influence of a variety on the individual parameters was estimated using an F-test, while the significance of the differences among the varieties was estimated using the Tukey's test at a level of P = 0.05 ($LSD_{p\,=\,0{,}05}$). A Statistica 7.0 (StatSoft Inc, Tulsa, USA) statistical software package was used for the calculations.

RESULTS

The period that directly preceded the sowing and vegetative growth and development of sugar beet in individual years varied in terms of total precipitations and average air temperatures. The differences were even more profound for individual months of the year (Table 1). The biggest shortage of

Table 1

Sum of precipitations and air temperatures in the growing season of sugar beet

Month	Precipitation (mm)				Air temperature (°C)			
	2013	2014	2015	2000-2015	2013	2014	2015	2000-2015
March	40.1	74.6	34.5	38.7	-1.5	7.5	6.3	3.2
April	19.0	35.5	18.1	29.3	7.7	11.1	8.9	8.9
May	87.0	81.1	35.0	69.2	15.3	13.6	12.7	14.1
June	46.6	43.2	47.3	59.1	17.4	16.3	15.7	16.6
July	46.6	60.8	51.5	62.2	17.4	21.9	18.9	19.1
August	73.3	49.5	7.5	79.2	19.2	17.9	21.7	18.4
September	40.3	25.2	25.7	44.6	12.0	15.1	14.5	13.3
October	23.8	12.4	31.6	35.6	9.4	9.9	7.7	8.9
Sum	376.7	382.3	251.2	417.9	-	-	-	-
Average	-	-	-	-	12.1	14.2	13.3	12.8

rainfall compared to its long-period average sum occurred in 2015, especially in August and May. The average air temperature in many months was higher than the average; on the other hand it was lower than the average in March, April, July and September 2013, May, June and August 2014, and in May, June, July and October 2015.

In soils infected with eggs and larvae of BCN, the root yield of individual varieties and the differences between the yields of tolerant and conventional varieties differed in the study years. In 2013-2015, the highest yield was obtained from the tolerant variety Perruche. The root yields of this varierty and var. Charly were significantly higher than the average yield of the less yielding conventional variety denoted as Conventional 2 (Table 2). In 2013, better yields were obtained both from the tolerant var. Perruche and another tolerant var. Sława KWS than from the other conventional variety. In 2014, the root yield from every tolerant variety was significantly higher than the yields from both conventional varieties.

In two out of three study years, a significant dependence of the sugar content on specific beet varieties was established. However, it was not a repeated dependence, hence the polarisation in all the varieties, both BCN-tolerant and conventional ones, was similar for the years 2013-2015 (Table 3). In 2014, most sugar was contained in the roots of the conventional variety

Table 2

Yield of sugar beet roots (Mg ha^{-1})

Variety	Year			
	2013	2014	2015	average 2013-2015
Charly	75.2	72.0	80.1	75.8
Perruche	82.9	72.9	73.7	76.5
Sława KWS	81.3	71.3	69.7	74.1
Conventional 1*	75.7	61.4	76.4	71.2
Conventional 2*	69.6	57.1	73.6	66.8
$LSD_{p = 0,05}$	10.7	8.2	5.1	8.7

* see chapter Materials and Methods

Table 3

Polarisation of sugar beet roots (%)

Variety	Year			
	2013	2014	2015	average 2013-2015
Charly	16.8	17.6	18.1	17.5
Perruche	16.8	17.2	17.6	17.2
Sława KWS	17.3	18.0	17.7	17.7
Conventional 1*	17.1	18.3	17.7	17.7
Conventional 2*	17.2	17.4	18.4	17.6
$LSD_{p = 0,05}$	ns**	0.9	0.7	ns

* see chapter Materials and Methods ** ns – not significant

Conventional 1, and subsequently in the varieties Sława KWS, Charly, Conventional 2, while the variety Perruche contained significantly less sugar. In 2015, the largest polarisation was also demonstrated in the roots of a conventional variety, namely var. Conventional 2, while var. Perruche achieved the lowest polarisation level.

In the study period, the influence of the sugar beet varieties on the content of molasses-forming components in root mush was inconsistent (Table 4). In 2013, the BCN-tolerant varieties Perruche and Sława KWS contained significantly more potassium than one of the conventional varieties, which had the lowest content of this element. In 2015, however, the potassium content in the roots of the tolerant variety Charly was lower than in both conventional varieties. The α-amino nitrogen content in the BCN-tolerant varieties was slightly or significantly higher than in the conventional varieties, but only in the first two study years. In the third year, the trend was reverse, although the differences were insignificant. No repetitive relationship between the degree of tolerance of a given variety to BCN tolerant or conventional varieties, and the sodium content in root mush was determined, although the trait was significantly diversified by the variety factor in every

Table 4

Molasses-forming components in roots of sugar beet (mmol 1000 g^{-1})

Variety	Year			
	2013	2014	2015	average 2013-2015
Potassium				
Charly	41.2	34.3	36.6	37.4
Perruche	43.4	36.1	39.4	39.6
Sława KWS	43.8	36.4	37.9	39.4
Conventional 1*	42.0	37.4	40.1	39.8
Conventional 2*	37.4	35.0	40.3	37.6
$LSD_{p = 0,05}$	4.1	ns**	2.6	ns
α-amino nitrogen				
Charly	13.4	10.8	11.1	11.8
Perruche	15.2	8.5	10.0	11.2
Sława KWS	15.4	8.4	11.2	11.7
Conventional 1*	12.0	8.3	11.6	10.6
Conventional 2*	10.8	6.1	12.2	9.7
$LSD_{p = 0,05}$	2.6	0.3	ns	ns
Sodium				
Charly	10.7	8.1	6.0	8.3
Perruche	12.3	6.0	4.6	7.6
Sława KWS	12.5	4.8	6.4	7,9
Conventional 1*	12.7	6.5	5.4	8.2
Conventional 2*	10.4	4.1	4.4	6.3
$LSD_{p = 0,05}$	1.2	1.4	0.7	1.9

* see chapter Materials and Methods ** ns – not significant

year and in the three-year period on average. The variety Charly contained less sodium in 2013 than the other tolerant varieties and Conventional 1, while in 2014 it contained the most sodium of all the varieties.

The significant influence of a variety on the root yield and the many characteristics of the internal quality of sugar beet diversified the technological sugar yield (Table 5). In 2013 and 2015, the sugar yield of at least one BCN-tolerant variety, i.e. Sława KWS and Charly, respectively, was significantly higher than the yield obtained from a conventional variety, which performed worse in this respect. In 2014, the technological sugar yield from each tolerant variety exceeded the yield from the conventional variety Conventional 2.

Table 5

Technological sugar yield of sugar beet roots (Mg ha^{-1})

Variety	Year			
	2013	2014	2015	average 2013-2015
Charly	11.0	11.3	13.0	11.8
Perruche	12.0	11.2	11.6	11.6
Sława KWS	12.2	11.6	9.9	11.2
Conventional 1*	11.2	10.1	12.0	11.1
Conventional 2*	10.5	9.0	12.1	10.5
$LSD_{p = 0,05}$	1.5	1.6	0.9	ns**

* see chapter Materials and methods ** ns – not significant

DISCUSSION

Research into sugar beet yielding suggests that the main factors determining the root and sugar yield are the habitat, soil and weather conditions in the growing period (Ostrowska et al. 2002, Rzekanowski et al. 2005), as well as agricultural practices, such as: fertilisation, sowing and harvest time, plant protection (Wyszyński et al. 2004, Zimny et al. 2005, Hoffmann et al. 2009). An important factor in the health of sugar beet is a crop rotation (Steinmann, Dobers 2013). Occurrence of diseases or pests depends on the sequence of crops (Parker, Howard 2001, Märländer et al. 2003, Kluth, Varrelmann 2010). Of no less importance is the production potential of individual varieties (Nenadić et al. 2003). It manifests itself to different degrees, depending among others on the habitat conditions and farming practices, including the pressure from diseases and pests (Hauer et al. 2015). According to these authors, the dry mass and sugar yields in beet varieties that were different in terms of BCN resistance levels would decrease, but to different degrees, depending on the egg and larval count of the nematode in the soil. The yields from tolerant and resistant varieties were higher than from conventional sugar beet variety. In our experiment there was also strong diversification in root yields in soils infested with BCN eggs and larvae between tolerant and conventional varieties in individual years. In each year, as well as on average for the study period, at least one tolerant variety would bring better yields than one or both conventional varieties. Nevertheless, no simple dependence between better yields from tolerant varieties than from conventional ones and the number of eggs and larvae in the soil was discovered, as the largest difference was apparent in 2014, when there was the least infestation before the sowing of beet, i.e. 657 of eggs and larvae per 100 g soil.

In infected fields, the influence of a selected variety on the technological sugar yield was similar as in the case of root yield. On average, in the three years of field experiment, the sugar yield from each tolerant variety was higher than the average yield from conventional varieties, even though the differences were not statistically significant. Nonetheless, in every year, the sugar yield from at least one tolerant variety was significantly higher than from a conventional variety producing poorer yield. These results suggest the need to grow tolerant varieties of sugar beet in Poland, in high BCN-pressure conditions, as they favour higher sugar yields. This conclusion is further confirmed by the results of research conducted in other countries (Heijbroek et al. 2002, Westphal 2013). The choice of a variety ought to be preceded by good understanding of its biological potential as well as the habitat and farming practices because the yields from tolerant varieties are usually smaller than from conventional ones in infection-free conditions (Nowakowski, Szymczak-Nowak 2007). Under such conditions, the authors did not ascertain any influence of a variety on the technological quality of roots, including the content of molasses-forming components. The research cited in this paper suggests that cultivation of tolerant varieties is justified in conditions of a high BCN egg and larva count, i.e. 800 - 1000 per 100 g soil. These results correspond to a large extent with our findings, as in the presence of *ca* 1000 BCN eggs and larvae in soil for most years, the differentiation in the sugar content was significant, as was the differentiation in potassium, sodium and α-amino nitrogen levels in roots, even though it was not always in favour of tolerant varieties.

CONCLUSIONS

1. Under the conditions of infestation with *Heterodera schachtii* eggs and larvae, BCN tolerant varieties give higher root and technological sugar yields than conventional varieties, but only if appropriately chosen.

2. Root and sugar yields, as well as the internal technological quality characteristics of individual tolerant varieties of sugar beet, were strongly diversified over the study period, and not always superior to those from conventional varieties.

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