Scientia Horticulturae 230 (2018) 126–133

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Different types of organic pop-up fertilizers in carrot cultivation: Effects on the concentrations of polyacetylenes and sugars

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ARTICLE INFO

Keywords:
Falcarinol
Falcarindiol
Falcarindiol-3-acetate
Sucrose
Glucose
Fructose
Quality
Fertilizer
Organic
Polyacetylenes

ABSTRACT

The effects on the concentration of falcarinol-type of polyacetylenes and sugars at harvest and after storage of carrots after application of different types (powder, digestate, two micro-granular) of organic pop-up fertilizer, where the fertilizer was placed in small amounts together with the seeds, were studied. Both groups of investigated compounds reflect important sensory attributes of the carrots, while polyacetylenes are considered as potentially health-promoting compounds. Results showed that the type of pop-up organic fertilizer as well as the dose can affect the concentrations of polyacetylenes and sugars. The dose of nitrogen applied did not seem to alone affect the concentration of polyacetylenes in carrots, while low amounts of applied phosphorus could be related to higher amounts of falcarindiol. The liquid digestate resulted in the highest concentrations of polyacetylenes in two of the treatments, even though the applied doses of digestate contained among the lowest amounts of nutrients. Storage resulted in both increases and decreases of total polyacetylenes, falcarindiol and falcarinol, while falcarindiol-3-acetate generally increased during storage. The sugars showed less variation due to the type or dose of fertilizer applied, as compared with the polyacetylenes.

1. Introduction

Quality aspects of products have become increasingly important for consumers, as well as for the wholesaler companies who play an important role for the supply to the market. For organic produce the quality aspects can have even higher importance for many consumers (Bonti-Ankomah and Yiridoe, 2006; Mondelaers et al., 2009). It is therefore of great importance that the chosen types of organic fertilizers or application methods will not lead to lower quality, including sensory traits. In carrots the typical flavours include both elements of sweet and bitter taste, though the latter should not be too prominent (Haglund et al., 1998; Talcott et al., 2001). When organically and conventionally cultivated carrots were compared regarding sensory attributes, year, variety and growing system had effects in both systems, and while conventionally cultivated scored higher for carrot taste, there was no difference found in sweetness between the growing systems (Haglund, 1998).

The sugars present in carrots contributing to the sweetness are sucrose, glucose and fructose (Kjellenberg et al., 2012). Bitterness in carrots is of more complex origin, but some polyacetylenes of falcarinol-type, as well as 6-methoxymellein, and other phenolic compounds have been suggested to contribute to the bitter taste (Talcott et al., 2001; Christensen and Brandt, 2006; Kjellenberg et al., 2010). Bitter taste has recently been connected with modulation of carbohydrate metabolism in an animal model (Palatini Jackson et al., 2017). In addition, some of the polyacetylenes of falcarinol-type have also been suggested to have human heath promoting properties (Christensen and Brandt, 2006), which could be an important aspect for many consumers of organic produce. The polyacetylenes of falcarinol-type have been suggested to have anticancer, antifungal, antibacterial, anti-inflammatory, and serotogenic effects (Dawid et al., 2015; Kobaek-Larsen et al., 2017). In carrots, the main falcarinol-type polyacetylenes are falcarindiol, (*Z*)-heptadeca-1,9-diene-4,6-diyne-3,8-diol; falcarinol, (*Z*)-heptadeca-1,9-diene-4,6-diyn-3-ol; and falcarindiol-3-acetate, (*Z*)-3-acetoxyheptadeca-1,9-diene-4,6-diyn-8-ol (Minto and Blacklock, 2008).

Organic production of vegetables may include many different types of organic fertilizers, including green manure, composted animal manure, vermicompost, dried and pelleted manure, agricultural waste, or other organic source such as ash (Gaskell and Smith, 2007; Evanylo et al., 2008; Kumar et al., 2014). The vast range of the differences in their composition and structure, as well as their water content, makes the release of nutrients after application in the soil different among the various types of fertilizer. The rate of the dispersal of the nutrients from the various solid fertilizers is different, due to the composition of

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https://doi.org/10.1016/j.scienta.2017.10.010
Received 21 April 2017; Received in revised form 31 August 2017; Accepted 10 October 2017
Available online 27 November 2017
0304-4238/

nutrients and their solubility, as well as the size of the particles. Horticultural crops, both conventionally and organically cultivated, are often inefficient in using the applied nutrients, resulting in leakage of nutrients to the environment as well as unnecessary high costs for the growers (Follett and Hatfield, 2001). There is therefore a need to develop fertilizer strategies that will result in more precise management of nutrient applications, leading to reductions of costs, a more efficient use of the finite nutrient phosphorus, and minimizing the impact on the environment, but at the same time result in products with good quality attributes.

Starter, or pop-up fertilizer, has been introduced for a number of vegetable crops, including onion, cabbage, lettuce, green bean and carrot (Costigan, 1984; Stone, 1998, 2000; Stone et al., 1999). The placement of a small amount of fertilizer near the seed is suggested to meet the demands of the early growth and to supply the new root system with sufficient available nutrients until the root system develops (Stone et al., 1999; Stone, 2000). Alley et al. (2010) define that "starter" fertilizers are placed near but not with the seed, while pop-up fertilizers are placed with the seed at seeding. Due to the relatively small size of their root system, the developing plants must maintain high nutrient influx to sustain maximum growth rate (Woodhouse et al., 1978). This can be achieved with a sufficiently high nutrient concentration in the close vicinity of the growing root system, which gain the growth of the plant and thereby can affect the yield. Previous investigations, with a similar experimental set-up as the present investigation, showed that the carrot yield could be increased by 5000 kg per hectare when microgranular pop-up fertilizer (Eco-Fos 4–10-0) was applied in the amounts of 30–60 kg per hectare, while Digestate as pop-up fertilizer (13-2-4 per 10 m^3), applied in the amount of 400 L per hectare, resulted in higher yield, though only close to significantly different ($P = 0.06$) (Svensson et al., 2016). A recent review of effects of fertilizers placement, including 40 field studies, concluded that fertilizer placement lead to overall 3.7% higher yield and 11.9% higher nutrient content in above-ground parts than fertilizer broadcast (Nkebiwe et al., 2016).

The purpose of this investigation was to study the effects of different types of pop-up fertilizer, where the fertilizer is placed in small amounts together with the seeds, in organic cultivation of carrots with respect to the concentration of polyacetylenes and sugars at harvest, reflecting important sensory attributes of the carrots as well as potentially health-promoting compounds. In addition, the concentration of polyacetylenes and sugars were analysed after storage of the carrots.

2. Materials and methods

2.1. Plant materials, cultivation conditions, and fertilizer treatments

The study was performed during two years in organically managed farmland. First year the investigation was placed at Kvidinge, in the Southern part of Sweden (N 56° 8.045′, E 13° 3.078′) where the soil was of light type; sandy soil with clay content 2% and organic content 2.5%. Due to high presence of weeds, the second year trials was performed at another farm, at Åraslöv in the Southern part of Sweden (N 56° 5.896′, E 13° 58.269′) where the soil was also of light type; sandy soil with clay content 6% and organic content 4.5%. The carrot cultivar 'Bolero F1′ (Vilmorin, France) was used in all treatments.

The experiment performed in first year was a pre-experiment, to establish methods and pop-up fertilizer types and doses. Before treatments, the field was fertilized with 700 kg ha^{-1} with pellet fertilizer (Biofer 10-3-1; Lantmännen Lantbruk, Sweden) through broadcast application. Thereafter, two different types of organic pop-up fertilizers were studied: powder fertilizer (here abbreviated POF) (Biofer 7–9-0; Lantmännen Lantbruk, Sweden), and liquid manure digestate (Biodigestate; Hagavik, Sweden), each applied in three different doses. The field trial was organized as a randomized block design study, with three repetitions (Table 1).

Table 1
Experimental set-up in the pre-experiment (first year) and the experiment (second year) as regarding the total amount, and amounts of nutrients in the organic pop-up fertilizers.

Pre-experiment	Year 1			
Treatments	Tot	N	P	K
	kg ha^{-1}			
POF I	76	5.0	7.0	0.0
POF II	210	15.0	19.0	0.0
POF III	383	27.0	34.0	0.0
Digestate I	180	0.7	0.1	0.3
Digestate II	360	1.4	0.2	0.6
Digestate III	720	2.8	0.4	1.1
Experiment	Year 2			
POF 1	38	2.7	3.4	0.0
POF 2	70	4.9	6.3	0.0
POF 3	134	9.4	12.1	0.0
Digestate 1	384	0.5	0.1	0.2
Digestate 2	576	0.8	0.1	0.2
Digestate 3	943	1.2	0.2	0.4
MG-P 1	29	1.2	2.9	0.0
MG-P 2	60	2.4	6.0	0.0
MG-P 3	123	4.9	12.3	0.0
MG-K 1	27	1.9	0.8	2.2
MG-K 2	50	3.5	1.5	4.0
MG-K 3	102	7.1	3.1	8.2

Abbreviations: Tot, Total amounts of fertilizer; POF, powder fertilizer; Digestate, liquid manure digestate; MG-P, microgranular fertilizer; MG-K, microgranular fertilizer.

Due to uneven and sometimes low germination rates, the second year's field trials were performed with some changes in doses of the fertilizers. In addition, two microgranular fertilizer types were used to decrease the risk of getting occasionally too locally concentrated nutrients as could be the result of pellet (of larger size) fertilizer, leading to fewer surviving plants, and also to optimize the rate of the nutrients dispersal into the soil. As in the first year, before treatments the field was fertilized, but this year with 40 kg N ha^{-1} to get the equivalent basic fertilization (Vinass, liquid; Lantmännen Lantbruk, Sweden). Four different types of organic pop-up fertilizers were used for the experiment in the second year: powder fertilizer (here abbreviated POF) (Biofer 7–9-0; Lantmännen Lantbruk, Sweden), liquid digestate (Biodigestate; Hagavik, Sweden), microgranular fertilizer (here abbreviated MG-K) (Eco-Mix 4; DCM, Belgium), and microgranular fertilizer (here abbreviated MG-P) (ECO-FOS; DCM, Belgium) (Table 1). The field trial was organized as a randomized block design study, with three repetitions.

2.2. Sampling and storage

The harvest of the carrots was performed on 17th of August the first year (pre-experiment) and 15th of September the second year (experiment). Sampling of the different treatments were carried out as the following: for each of the harvests, a total of 50–70 carrots were sampled into three replicate samples, evenly collected from the three blocks in the field. The carrot samples were brought in cold storage boxes to the laboratory within 24 h. Approximately 60 g carrot for each fresh sample was frozen and kept at −80 °C until further analysis.

In addition, the second year samples were stored at approximately 1 °C and 97% relative humidity. The carrot samples were kept separated in perforated plastic bags. The storage period was terminated simultaneously for all samples on March 8th (second year experiment). After storage, samples were cut and approximately 60 g of each sample was immediately frozen and kept at −80 °C until further analysis.