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Research paper

The influence of high tunnel on yield and berry quality in three floricane raspberry cultivars

Pauliina Palonen*, Anni Pinomaa, Tero Tommila

Department of Agricultural Sciences, University of Helsinki, PO Box 27, FI-00014, Finland

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A B S T R A C T

Growing raspberries in polyethylene tunnels is becoming more and more common. We wanted to examine the effect of high tunnel growing conditions on yield and berry quality in three floricane raspberry cultivars, 'Glen Ample', 'Glen Dee', and 'Maurin Makea', under Northern high-latitude conditions. Compared to the open field, fruit yield per cane was doubled in the tunnel. Fruit bioactive properties, including phenolic compounds and antioxidant activity, were not affected by the tunnel growing conditions. Of the cultivars investigated, 'Glen Dee' fruit had the lowest concentration of total phenolics. In the open field, the total phenolics content in 'Glen Ample' berries was 48% higher than 'Glen Dee'. Berries grown in the open field had higher contents of soluble solids (°Brix) and higher titratable acidity than those grown in the tunnel. Additionally, 'Glen Ample' and 'Maurin Makea' berries were sweeter than 'Glen Dee' berries. In conclusion, raspberry production in polyethylene tunnels may provide major benefits through increased fruit yield. While fruit bioactive properties were not affected, sensory taste may be different, however, as berry sweetness and acidity were decreased in the high tunnel.

1. Introduction

Raspberry (*Rubus idaeus*) production in the world has nearly doubled over the past 20 years. Growing public awareness of the putative health benefits of berries and greater interest in healthy diets has increased the demand of the fruit. Raspberries are commonly sold in the fresh market, and long shelf life is an important quality parameter. Because of the superior fruit quality and shelf life when produced in a protected environment, more and more raspberries are grown in polyethylene tunnels. In some countries, in fact, this is a requirement set by the supermarkets. Polyethylene tunnels have also been reported to increase yields and extend the season (Hanson et al., 2011; Fernandez and Perkins-Veazie, 2013; Xu et al., 2014).

Many environmental parameters in the tunnel are different from the open field, including light intensity and quality, temperature, humidity, wind, as well as pest and disease pressures. In high tunnels, long cane plants are commonly used and grown in substrate. Little information, however, is available on the influence of these altered growing conditions on internal berry quality including taste, and nutritional and health-related compounds, especially in Northern high-latitude conditions.

The perceived sweetness in raspberry fruit comes from sugars, 40–50% being fructose, 30–40% glucose, and 10–20% sucrose (Wang et al., 2009). Acidity is caused by the high concentration of organic acids, citric acid being the most important. Usually warm and dry weather increases sugar content and decreases acidity in raspberry fruit (Jennings, 1988; Malowicki et al., 2008). However, lower sugar content was observed in the primocane-type raspberry 'Polka' fruit when grown in high tunnels compared to an open field environment (Król-Dyrek and Siwek, 2015). This study indicates parameters other than the temperature difference between the tunnel and open field influenced this quality trait.

Rubus berries are a rich source of antioxidants and other bioactive compounds. The most important antioxidants in raspberry fruit are phenolic compounds and ascorbic acid (vitamin C) (Beekwilder et al., 2005). Among the ten raspberry genotypes studied by Mazur et al. (2014a), the main phenolic compounds were ellagitannins (57%) and anthocyanins (42%). The contents of total phenolics, flavonoids, and anthocyanins may be used to describe the antioxidant activity and thus potential health benefits of raspberry fruit (Wang and Lin, 2000; Liu et al., 2002; Anttonen and Karjalainen, 2005). Antioxidant activity is strongly correlated with the total phenolic concentration in raspberries (Deighton et al., 2000; Connor et al., 2005).

* Corresponding author.
E-mail address: pauliina.palonen@helsinki.fi (P. Palonen).

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Temperature has contrasting effects on bioactive compounds in raspberry fruit (Remberg et al., 2010). Lower temperatures increase berry size through increased moisture content, therefore decreasing concentrations of bioactive compounds when expressed on a fresh weight basis (dilution effect). Vitamin C was an exception, which increased even on a fresh weight basis at low temperatures. However, since large berry size is an important quality parameter for commercial production, Remberg et al. (2010) recommended relatively low temperatures, 12–18 °C, during the ripening of raspberry fruit.

Remberg et al. (2010) also suggested that fluctuations in temperature may enhance the accumulation of bioactive compounds in raspberry fruit, especially when compared to constant temperatures. Interestingly, long day conditions during fruit growth have also been shown to increase the concentrations of vitamin C, total phenolics, organic acids, and antioxidant capacity, while reducing the sugar content in raspberry fruit (Mazur et al., 2014b). In addition to photoperiod, light spectral composition may also affect berry quality; in our previous study, ellagic acid in raspberry fruit was increased under the film absorbing far red light, while the sugar:acid ratio was slightly reduced (Palonen et al., 2011).

The aim of our present study was to examine how high tunnel growing conditions affect the yield and berry quality, including sugar content, acidity, and the contents of total phenolics, as well as the antioxidant capacity, in three floricane raspberry cultivars under Northern conditions.

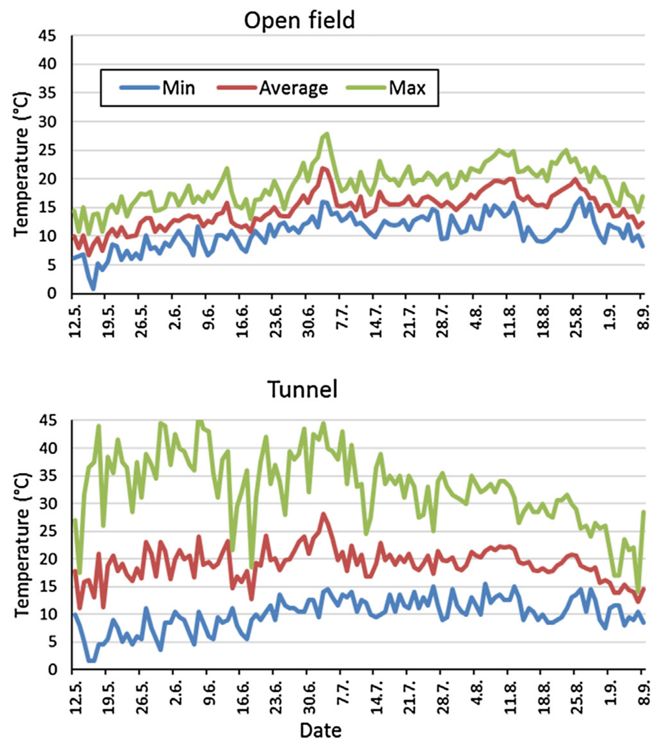

Fig. 1. Daily average, minimum and maximum temperatures in the open field and high tunnel during the growing season 2015.

2. Material and methods

2.1. Plant material and experimental design

The experiment was conducted at the University of Helsinki research field in Viikki (60°13′N; 25°1′E) during growing season 2015 using floricane raspberry cultivars ‘Glen Ample’, ‘Glen Dee’, and ‘Maurin Makea’. The experiment was set up as an identical RCBD in a polyethylene tunnel and an adjacent open field. In each environment (tunnel versus field), plants were grown in three rows (blocks). In the tunnel environment, each row had five plants each of the three different cultivars, while in the open field, each row had six plants each of the three different cultivars. This experiment was part of a larger variety trial which included six different raspberry genotypes.

‘Glen Ample’ and ‘Glen Dee’ are releases by the James Hutton Institute, Scotland. ‘Maurin Makea’ was discovered as an open-pollinated seedling in a raspberry breeding population at the Natural Resources Institute, Finland and released in 1996. It is known for its excellent winter hardiness and good fruit flavor.

2.2. Growing conditions

The experiment was established in 2014 in sandy soil on a gentle South-facing slope. In the open field, the raised raspberry beds were covered with black woven polypropylene fabric (MyPex®). White clover (*Trifolium repens*, cv. Grassland Huia) at the rate of 10 000 seeds/m^2 was sown between the rows. The polyethylene tunnel (8 m × 35 m, 4 m high) was oriented South-to-North and covered with clear polyethylene (Folitec UV M 42, Folitec, Westerburg, Germany). In the tunnel, the plants were grown in 10-L pots filled with peat (OPM 630 W, Kekkilä Oy, Vantaa, Finland). The tunnel floor was covered with white woven polypropylene fabric (MyPex®). The three rows were spaced 2.40 m apart in the tunnel and 2.60 m apart in the open field. Plant spacing within a row was 40 cm in the tunnel and 50 cm in the open field.

Tunnel plastic was removed for the winter on 30 October 2014 and replaced on 27 April 2015. The tunnel was ventilated mainly through the tunnel doors at either end. Tunnel plants were fertigated through drip irrigation three times a day with a 0.01% compound fertiliser, Taimi-Superex (NPK 19–4.4–20.2 plus microelements) (Kekkilä Oy, Vantaa, Finland), from 16 May through 5 June, and with a mixture of Taimi-Superex and Turve-Superex (NPK 12–4.7–27.1 plus microelements) (0.08%) from 6 June through 19 August. Plants in the open field were fertigated through trickle irrigation system using the same fertilisers six times during the growing season. One to two floricanes per plant were grown in the tunnel and one to three in the open field. New primocanes were allowed to grow freely during the experiment.

A bumblebee (*Bombus terrestris*) hive (Minipol, Koppert Biological Systems, Romulus, MI, USA) was placed in the tunnel to ensure pollination. No chemical control of pests or diseases was used in the experiment. In the tunnel, biological pest control included *Amblyseius cucumeris* to control thrips, *Phytoseiulus persimilis* to control spider mites, and BerryProtect tubes containing different species (*Aphidius ervi*, *A. matricariae*, *A.colemani*, *Ephedrus cerasicola*, *Praon volucre*, *Aphelinus abdominalis*) were used to control aphids (Biotus Oy, Forssa, Finland).

Temperature data in the open field are from the Finnish Meteorological Institute (Fig. 1). Tunnel temperatures were measured in 30-min intervals throughout the experiment. Light spectral composition in the open field and the tunnel was recorded on 15 September 2015 (Fig. 2).

2.3. Harvesting and sample preparation

Raspberry fruits were harvested three times a week and were weighed and counted to determine total yield and the number of berries per cane. For chemical analyses of fruit quality, 150–200 g of berries per block were sampled and immediately frozen at −20 °C and held at −20 °C until analyses. To measure soluble solids (SS) and titratable acidity (TA), samples were taken four times during the harvest season, and three times for analyses of total