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Effects of production system and transplanting time on yield, quality and antioxidant content of organic winter squash (*Cucurbita moschata* Duch.)

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ABSTRACT

Research was carried out on butternut squash cultivar "Waltham F_1", following the organic agriculture practice, in order to evaluate the effects of two production systems (open field and greenhouse) and four transplanting times (16 April, 30 April, 14 May, 28 May in the open field; 2 April, 16 April, 30 April, 14 May in the greenhouse) on growth, productivity and fruit quality indicators at harvest and during an eight months storage of fruits. Yield, number and mean weight of fruits showed a better performance in greenhouse than in open field crops. The highest yields were recorded with the second and the third transplanting time. Greenhouse crops produced fruits with higher values of dry weight, sucrose, total proteins and ascorbate, whereas the open field cultivation produced fruits with better values of glucose, fructose, total acidity, ash, colour and carotenoids content. Most quality indicators increased from the first to the fourth transplanting; starch, total proteins and ascorbate did not vary. The open field crops produced fruits with higher content of calcium, potassium, copper and iron, but lower nitrates compared with the greenhouse cultivation. The fruit mineral content decreased from the earliest to the latest transplanting time, with the only exception of calcium, which increased. During the eight months storage a complex evolution pattern was recorded: dry matter and starch content in the fruits decreased; glucose and fructose increased; soluble solids, sucrose, acidity, total proteins, ash and colour showed an initial increase followed by a later decrease; the mineral composition did not change with time.

The greenhouse system proved to be more effective than the open field management in terms of yield and, to a certain extent, of fruit quality. The intermediate transplanting performed in the second half of April in greenhouse, and in the first half of May in the open field, gave the nearest match in yield and fruit quality.

1. Introduction

Italy is the second highest producer of pumpkins, squash and gourds (FAO aggregation) in Europe, and the production of these fruits has been steadily increasing over the last decade, to a total of 520,000 t in the year 2012 (FAOSTAT, 2014). Unfortunately, the low storage lifetime of squashes harvested in the summer does not fit with the year-round consumer demand which extends into the spring of the following year (Candon et al., 2005). In fact, during the spring period the Italian market is supplied with South American winter squashes.

The relatively small size and weight of butternut squash (*Cucurbita moschata* Duch.) make it easy to manage during the harvest, handling, packaging and marketing process. In this respect, consumers tend to prefer fruits of smaller dimensions compared with larger types of squash, e.g. most *Cucurbita maxima* cultivars, which are often sold in slices due to their large size (Habibunisa et al., 2001).

Squashes are suitable for numerous culinary uses, either as a vegetable or as an ingredient in food preparations like pies, soups (Pinho et al., 2011) and they are also popular in various systems of traditional medicine as antidiabetic, antihypertensive, anticancer, immunomodulatory, antibacterial, hypocholesterolemic, intestinal antiparasitic, antiinflammation and antalgic (Fu et al., 2006).

Winter squash is mostly grown in the field, but greenhouse environmental conditions allow for an enhancement of crop productivity in mild climate areas characterized by rainy early spring

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season (Chen and Jiang, 1998; Roberts and Anderson, 1994). Moreover, protected cultivation is reportedly suitable to organic horticulture, which is more susceptible to the environmental unbalances caused by a less intensive management (Maynard, 1994; Roe et al., 1997). Lastly, since the higher market prices of the organic vegetables usually result in a higher income for farmers (Diouf, 2007; Bulluck et al., 2002), greenhouse cultivation of butternut squash may be regarded as a cost effective alternative to traditional open field farming.

Compared with direct seeding, starting a squash crop from transplants was shown to stimulate early fruit set and to produce higher total yield. However, the choice of transplanting time affects both cycle length and the productivity of squash crops. Notably, Rulevich et al. (2003) found that the initiation of *C. moschata* fruit set using transplants on mulched soil was advanced by nine days compared to direct-seeding. Moreover, in Nigeria early spring planting of *Cucurbita pepo* crops resulted in higher antioxidant activity as associated to higher crop cycle mean temperature (Oloyede et al., 2014).

Butternut squash is highly appreciated for its nutritional quality and sensory attributes; among the latter flesh colour is considered to be an important quality trait for consumer acceptance of the product (Barrett, 1988; Harvey and Grant, 1992). The flesh colour of ripe squash fruits can vary considerably from greenish yellow to dark orange (Paris, 1994) and intense orange flesh is an especially attractive quality in winter squash (Murphy et al., 1966). Although this trait is not easily measurable as part of a sensory analysis, the intensity of flesh colour is positively correlated with total carotenoid content, as winter squash owes its pulp colour to these compounds (Hidaka et al., 1987). The carotenoid composition of *C. moschata* fruits includes α-carotene, β-carotene, lutein, violaxanthin, while the linear carotenoids such as phytoene and lycopene are absent or present only in trace amounts as reported by Nakkanong et al. (2012). Squash may be regarded as a major source of carotenoids in the human diet: carotenoids serve as vitamin A precursors (Cunningham and Gantt, 1998) therefore contributing to eye disease prevention (Bai et al., 2011; Manzi et al., 2002).

It was reported that some of the fruit quality attributes also affect the shelf-life of buttercup squash (*C. maxima*) (Harvey et al., 1997). Notably, rot appearance is attributable to storage conditions (temperature and relative humidity), but also to the amount of dry matter and to the ratio between starch and sugars in the mesocarp (Hurst et al., 1995). In this respect, at harvest starch content is relatively high and sugars amount is low, but during post-harvest storage the conversion of starch to sugar occurs (Irving et al., 1997), resulting in improved flavour and sweetness (Harvey and Grant, 1992; Harvey et al., 1997).

The aim of this research was the evaluation of production system and transplanting time effects on growth, yield and quality of butternut squash grown in southern Italy.

2. Materials and methods

2.1. Plant material and growth conditions

Butternut squash (*C. moschata* Duch. var. Waltham F1) was grown according to the organic farming practices in Capua (province of Caserta, Southern Italy, 41°10′N, 14°17′E, 25 m a.s.l.), in a Mediterranean or Csa climate according to the Köppen classification scheme (Peel et al., 2007). The field trials were repeated in the years 2011 and 2012, on a clay-loam soil (Table 1); the air temperature data (Table 2) were continuously recorded using a Salmoiraghi (Salmoiraghi S.p.A., Milano, Italy) chart recorder model 750/B, placed under a shade at 40 cm above the soil level.

Table 1
Soil analysis.

Coarse sand	18.9%
Fine sand	27.6%
Silt	30.0%
Clay	23.5%
Organic matter (Walkley and Black method)	1.4%
Total nitrogen (N)—Kjeldahl method	0.1%
Available phosphate (P_2O_5)—Olsen method	42.0 ppm
Available potassium (K_2O)—ammonium acetate method	640.0 ppm
pH	7.4
Electrical conductivity at 25 °C	0.44 mS cm^{-1}

Analysis of ≤2 mm soil fraction. Results per 100 g of air dried soil sample.

The organic farming practice complied with EC Regulation 834/2007. Squash crops were preceded by cabbage and each year the fertilization supplied the crops with 120 kg ha^{-1} of N, 45 kg ha^{-1} of P_2O_5 and 265 kg ha^{-1} of K_2O (Tesi, 2010). Half of the fertilizers dose was given just before transplanting and the remaining 50% on dressing by fertigations at two week intervals. The first 50% amount of fertilizers was supplied as Bioilsa 6-5-13 and 7-0-21, while the remaining dose was given by fertigation using the Agritalia 8.5 N hydrolyzed animal epithelium. Plant protection from fungal diseases and insects was achieved by adopting the following procedures: Trichoderma suspensions for the prevention of root and collar rot, before transplanting; copper for downy mildew control, until early fructification; sulphur + propolis for the control of powdery mildew, from early fructification till late harvest time; azadirachtin against aphids, all over crop cycles. Drip irrigation was activated when the soil available water capacity (AWC) decreased to 80%, and it was suspended ten days before the beginning of harvest. In both years 2011 and 2012 two production systems (open field or greenhouse) and four transplanting times (16 April, 30 April, 14 May, 28 May in the open field; 2 April, 16 April, 30 April, 14 May in the greenhouse) were compared. The choice of the transplanting times was based on the usual squash transplanting calendar in the research area: mid April in the greenhouse and end of April in the field. The experimental treatments were randomized in a split-plot design, assigning production systems to the main plots and transplanting times to the sub-plots. Each treatment had a 28.1 m^2 (7.2 × 3.9 m) surface area, including 25 plants. The whole design was replicated three times.

Squash plants were grown on raised beds mulched with a 15 μm biodegradable film; at the planned times, plantlets were arranged in double rows, 0.5 m apart with 3 m between each double row. Plant spacing was of 0.75 m along the row, corresponding to 0.89 plants m^{-2}.

For the protected environment treatments, the crops were grown under three greenhouses each of them made of two spans 10 m wide, 20 m long and 4.5 m high; the structure was covered by thermal polyethylene.

Within each plot, ripe fruits were harvested at weekly intervals from 13 July to 10 August in 2011 and from 18 July to 8 August in 2012.

2.2. General analytical methods

Ripe, undamaged, regularly shaped and heavier than 600 g fruits were classified as "marketable". At each harvest, the weight and number of marketable fruits in each plot was recorded and the mean weight was assessed on random samples of 15 fruits per plot. The weight of fruits unsuitable for the market was also recorded in order to monitor total biomass production for each treatment. Cumulative plant biomass was calculated as the sum of the above-ground plant biomass at the end of the experiment plus the total fruit production from the beginning of the harvest period. Dry weight was assessed after dehydration of the fresh samples in an