Influence of cold storage on growth, productivity and root reserves of 'Kwanza' raspberry

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Abstract

The long-cane raspberry production system under tunnels allows fruit production throughout the year. However, the effect of plant origin and the duration of the artificial chilling period on plant productivity are not yet fully understood. The objective of this study was to evaluate the influence of cold storage duration in the production and development of 'Kwanza' raspberry in Odemira, Portugal (37°35'05"N; 8°40'36"W). Plants of Portuguese and Dutch origin were stored at 1°C for 11 and 15 weeks (short-term), later referred as treatments "STPt" and "STHol", respectively, or for 42 and 46 weeks at -1°C (long-term), later referred as treatments "LTPt" and "LTHol", respectively. These plants were grown in pots with coconut fiber substrate with varying long-cane density per pot, but with the same density m^{-1} at planting. Short-term plants from Portugal and Holland produced 3919 and 4409 g of commercial quality fruit m^{-1}, respectively and the production of long-term plants from Portugal and Holland was 744 and 806 g of fruit m^{-1}, respectively. Short-term plants were planted later (February) than long-term plants (November) and benefited from longer photoperiod and higher temperatures than long-term stored plants. This increased availability of light and temperature had a pivotal role to achieve not only higher yield, but also higher fruit quality since fruits from plants of short-term storage were larger and less misshapen. Overall, plants that stayed in the cold for a shorter period were more vigorous, less susceptible to diseases, and had a greater number of fruiting laterals. Moreover, starch root percentage was different ($P<0.05$) between treatments. STPt and STHol had 3 and 5 mg of starch 100 mg^{-1} of root dry weight, respectively whereas STPt and STHol had 0.7 and 0.8 mg of starch 100 mg^{-1} of root dry weight, respectively. These data demonstrate that long duration storage leads to a greater consumption of root carbohydrate storage resulting in lower productivity. Strategies to increase energy storage in the root should be developed and implemented. Currently, farmers need to evaluate whether out-of-season production using long-term stored plants is economically viable despite lower productivity.

Keywords: long-cane, long-term storage, short-term storage, off-season production, *Rubus idaeus*

INTRODUCTION

In Portugal, protected cultivation is the system that prevails, since it is not dependent on climatic variations, it uses water and agricultural inputs more efficiently and it allows producing out of season in certain areas of the country. The production of raspberries out-of-season became possible with the use and development of production technologies both for early and late harvest periods. Late production is achieved with primocane-fruiting cultivars (Oliveira et al., 1998) and early production with long-canes (Oliveira et al., 2002). Long-canes are raspberry plants stored in cold chambers during a short- or a long-term after flower bud differentiation occurs in the nursery. Plants are allowed to grow more than 200 cm and are then pruned at 160-170 cm. Topping aims to eliminate the buds at the top of the plant that have a weak productive potential. After tip cutting, the whole plant is stored in the cold chamber and used in the second year for production (Sønsteby et al., 2009). Two of the main aspects to take into account in the production of long-canes are the timing of floral induction

and the success of the breaking of dormancy. It is necessary to avoid partial floral induction and an incomplete break of the dormancy (Funt and Hall, 2013). Firstly, it is essential that floral induction begins when the plant is at the peak of its potential fruiting, avoiding unnecessary production breaks and plant material of poor quality (Sønsteby and Heide, 2008). Secondly, the production of a long cane quality lies in the success of the breaking of dormancy. The success of bud break relates directly to the hours of cold storage. If the buds do not receive the number of cold hours necessary for a cultivar, they will remain dormant (partially or completely), triggering later a deficit on the photosynthetic capacity of the plant due to smaller leaf area and poor fruit set.

It is necessary to manage efficiently temperature and time of cold storage in order to prevent damage to the buds, dehydration and nutrition deficiency. Even though the plant is in dormancy, it is still metabolically active and consume nutrients stored mostly in the roots. Sønsteby and Heide (2014) in 'Glen Ample' and 'Asker' cultivars concluded that chilling for 20 weeks at near-freezing temperatures is necessary for the complete release of bud dormancy and the promotion of flowering along the entire length of the raspberry cane, which are pre-requisites for high fruit yields (Heide and Sønsteby, 2011; Sønsteby et al., 2013). In 'Glen Ample' and 'Asker' cultivars, Sønsteby and Heide (2014) observed that flowering was significantly enhanced when the storage period was extended from 7 to 14 weeks, while no further increase in flowering took place when the period was further extended to 21 weeks, possibly due to the depletion of storage reserves in the canes during extended chilling. Oliveira et al. (2016) studied carbohydrate reserves in two summer fruiting cultivars and observed that starch concentration in the roots declined in cold storage in 'Glen Ample' but not in 'Tulameen' after 2136 chilling hours. However, to produce during winter (out-of-season), longer periods of cold storage are necessary to allow planting of long-canes in October. As far as we know, there are no published studies regarding long-term storage on raspberry physiology and production. In Portugal, long-cane production is based on long-canes imported from Holland. Thus, it is important for Portuguese growers to know if agro-climatic conditions in Portugal are also suitable for long-cane planting material.

The objective of this study was to evaluate the impact caused by plant cold storage in production and development considering plants produced in Holland and Portugal submitted to a short and long-term cold storage and planted in spring at Odemira, Portugal.

MATERIALS AND METHODS

'Kwanza' is a late primocane-fruiting cultivar. The fruit is a reddish, conical shaped and with an average weight of 7 g. 'Kwanza' long-canes with Portuguese and Dutch origin were stored at 1°C for 11 and 15 weeks, STPt and STHol, respectively, and for 42 and 46 weeks at -1°C LTPt and LTHol, respectively. The trial was located at Odemira, (37°35'05"N; 8°40'36"W) in four polyethylene tunnels, each tunnel had a length of 70 m by 6.6 m wide with rows of 2.2 m apart. Plants were grown in 7-L pots with coconut fiber substrate with the density of 3 canes m^{-1}. The plants grew vertically through a trellis system with wooden posts 1.8 m high, and three wires arranged up to 0.4, 0.8 and 1.2 m. Regarding the origin of plant material, in this trial both Portuguese and Dutch plants grown under polyethylene tunnels and already had a primocane crop.

Planting date for plants subject to a long period of storage LTPt and LTHol was November 20, 2017 for production in March, for the short-term treatment STPT and STHOL February 14 and January 30, 2018, respectively, to obtain a production in conventional season (May/June). Before planting, three canes from each treatment were randomly collected in order to evaluate root starch reserves. Roots were separated according to their diameter<2 mm or ≥2 mm. The <2 mm roots were dried to 40°C for starch content analysis. The starch content was determined according to amyloglucosidase/α-amylase method (Megazyme kit) and readings were at 510 nm using a spectrophotometer Shimadzu UV-Visible. Starch content was expressed as mg of starch 100 mg^{-1} of root dry weight.

Biometric data as height, top and base cane diameter, node number, number of fruiting laterals, length, and diameter of the fruiting zone were recorded from four canes per treatment. Fruits were collected weekly from 35 m of row (plot size) and production m^{-1} was

calculated.

At the end of harvest, physiological plant conditions was recorded based on a 4-step scale (Figure 1), where 0 corresponds to a dead plant and 3 to a healthy plant and 1 and 2 to intermediary stages. The main phenotypic criteria were discoloration or yellowing of leaves and leaf shed.

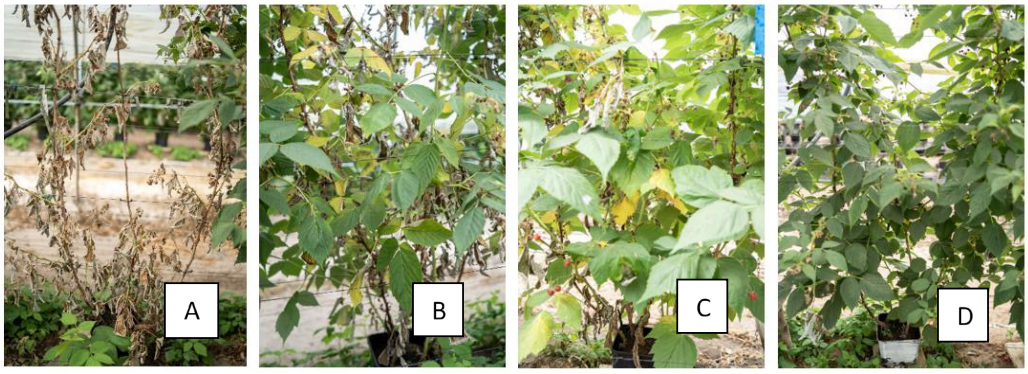

Figure 1. Scale to evaluate physiological plant condition at the end of harvest: A – 0, dead plant, B – 1, C – 2 and D – healthy plant.

Data analysis

Data were analyzed by one-way ANOVA, and the means compared by Tukey test (α=0.05), was performed using Statistix 9 (Analytical Software, Tallahassee, Florida).

RESULTS AND DISCUSSION

The percentage of starch was residual in the roots of long-term plants from Portugal and Holland (0.7 and 0.8 mg 100 mg^{-1} root dry weight) (Figure 2) since the storage of these plants for more than 40 weeks in the cold chamber at -1°C caused the depletion of the root reserves and weakening of the nutritional state. Accordingly, short-term plants from Portugal and Holland had more reserves (3 and 5 mg of starch 100 mg^{-1} root dry weight), because they were stored for a shorter period of time.

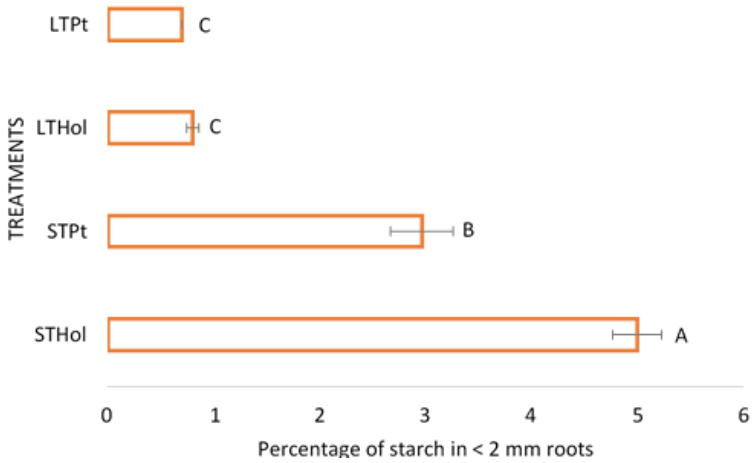

Figure 2. Percentage of starch in the <2 mm root dry weight of the plants subjected to the following treatments: LTPt, long-term Portugal; LTHol, long-term Holland; STPt, short-term Portugal; STHol, short-term The Netherlands. Letters correspond to significant differences (Tukey α=0.05). Error bars represent the standard error of the means.

The percentage of bud break was not significantly different between all treatments, LTPt (long-term Portugal) LTHol (long-term The Netherlands), STPt (short-term Portugal), STHol (short-term The Netherlands) was 78, 70, 74 and 72%, respectively. Canes of the long storage period were smaller and had less node number comparing with canes of the short-term storage, (particularly the canes from Holland) because of the first year fruit production (Table 1). The storage period had a large influence on the laterals fruiting zone length, diameter and number of fruit nodes (Table 1). LTPt and LTHol plants are similar to each other, as well as the STPt and STHol plants. Plants treated with a short length of time in storage have a higher average length and greater number of fruiting nodes (Table 1). The higher temperature and light availability inherent to the production peak during May/June justifies the difference between the production of long and short-term duration treatments. Short-term plants had longer laterals, greater number of fruiting nodes and consequently an increase in the productive potential of plants.

Table 1. Cane length, node number and lateral fruiting zone length, diameter and fruiting nodes for the following treatments: LTPt (long-term Portugal), LTHol (long-term The Netherlands), STPt (short-term Portugal), STHol (short-term The Netherlands).

Treatments	Cane		Laterals		
	Length (cm)	Node (No)	Fruiting zone length (cm)	Fruiting zone diameter (cm)	Fruiting nodes (No)
LTPt	119.1B	31.3A	25.8B	4.3B	8.3B
LTHol	80.2C	22.3B	26.3B	4.5B	7.5B
STPt	156.1A	33.3A	38.4A	5.0AB	11.0A
STHol	127.3B	30.3A	42.5A	5.8A	10.5A
Mean	120.7	29.3	33.2	4.9	9.3
SEM	3.15	0.83	1.54	0.23	0.31
PROB F	<0.001	<0.001	<0.001	0.003	<0.001

Long storage treated plants showed a weaker health status, abundance of yellow dried leaves, brown laterals, and lower leaf density (Figure 3). Only 30 and 44% of the plants of the LTPt and LTHol, respectively, were healthy, whereas 81 and 79% of the plants of the STPt and STHol, respectively had a healthy score. Clearly, the higher the storage time of the plants in the cold chamber, the more reserves are consumed. This jeopardizes the nutritional status, which will strongly influence the cycle productivity. Moreover, plants from the short-term treatments developed under better lighting conditions and temperature.

Regarding fruit production (Figure 4), weekly production peaks of STHol and STPt treatments was 4 times greater than the one measured for LTHol and LTPt plants. STPt and STHol plants produced 3919 and 4409 g of commercial quality fruit m^{-1}, respectively, and the production of long-term plants and LTPt and LTHol was 744 and 806 g of fruit m^{-1}, respectively. Studies carried out in Norway (Sønsteby and Heide, 2014) support these results, where it was proven that time range ideal for storing long-canes in the cold in order to ensure a successful bud break and consequently a high production is roughly 14 weeks.

CONCLUSIONS

Short-term plants from Portugal and The Netherlands produced high yields with an average 3.9 and 4.4 kg of commercial quality fruit m^{-1}, respectively, in contrast to the low production of long-term plants from Portugal and The Netherlands which was 0.7 and 0.8 kg of fruit m^{-1}, respectively. An important result concerning fruit production is the similarity between the production plants of short-term from The Netherlands and Portugal, which allows us to conclude that it is possible to produce long canes with quality in the southwest Alentejo similar to plant material imported from The Netherlands. Long-term storage resulted in poor root starch and very low production. Consequently, plant manipulations that allow carbohydrate increase in the plant should be applied to support bud break, flowering and fruiting. To attain this objective, trials with first year fruit removal, delayed pruning before

cold storage, or other practices that maximizes reserves in the root systems should be done. Evaluation of cultivars that may be eventually more adapted to this system is also needed. This will eventually allow out-of-season long-cane production in the southern European countries with long-term storage plants. With regard to the value of the commercial production, we can conclude that despite the higher price of the out-of-season production, early and late spring production generates higher revenue. The producer has to analyze the costs of production and operation and decide whether it is economically viable to use long canes subjected to a long storage.

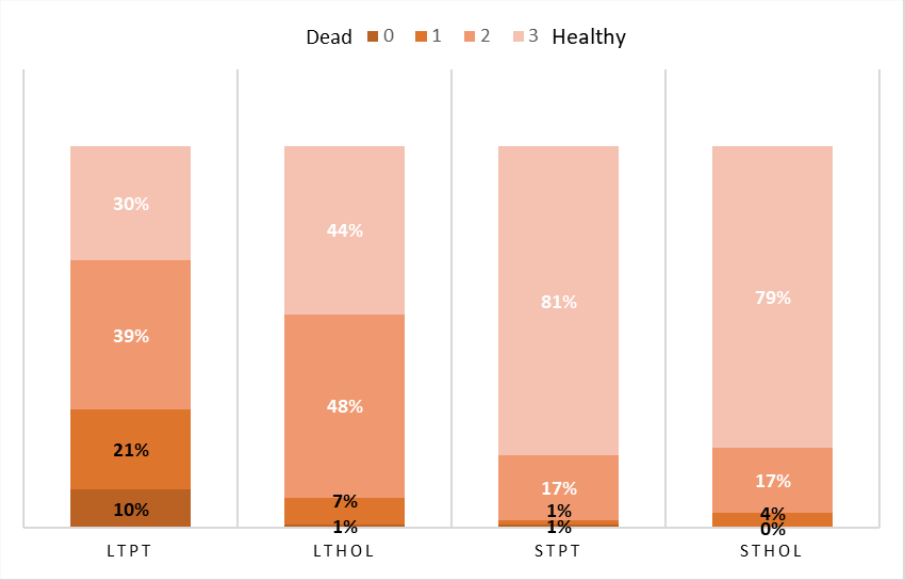

Figure 3. Percentage of plants with different physiological condition, according to the scale 0 to 3 in the following treatments: LTPt (long-term Portugal) LTHol (long-term The Netherlands), STPt (short-term Portugal), STHol (short-term The Netherlands).

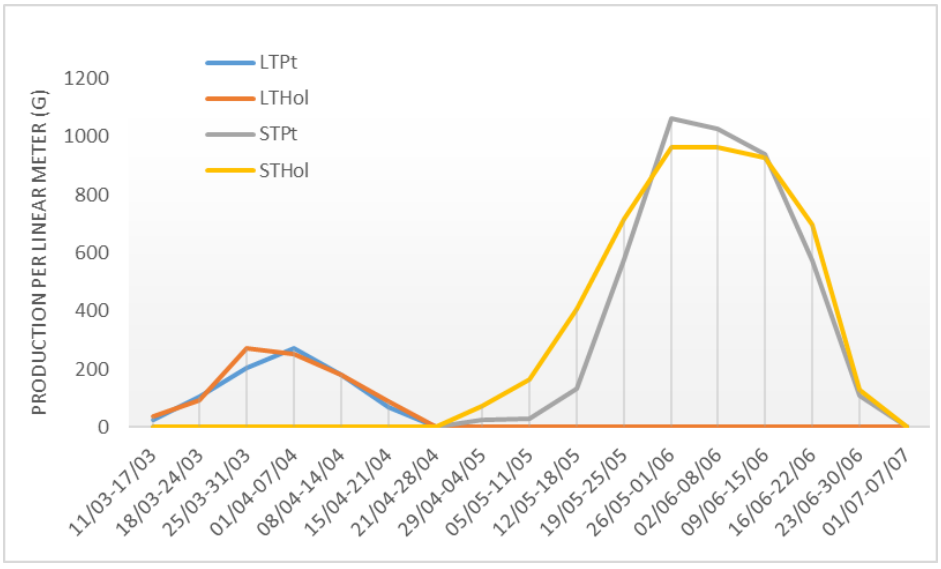

Figure 4. Weekly production m^{-1} (g) from March 11 to July 7 of the plants subjected to the following treatments: LTPt (long-term Portugal), LTHol (long-term The Netherlands), STPt (short-term Portugal), STHol (short-term The Netherlands).

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