Environmentally Friendly and Safe Technologies for Quality of Fruits and Vegetables

UNIVERSIDADE DO ALGARVE | 2010

14. CONSEQUENCES OF IRON DEFICIENCY ON FRUIT QUALITY IN CITRUS AND STRAWBERRY

Maribela Pestana[1], Amarilis de Varennes[2], Maria Graça Miguel[3], Pedro José Correia[1]*
[1] Universidade do Algarve. ICAAM. FCT-DCBB, Ed 8. Campus de Gambelas. 8005-137 Faro. Portugal
[2] Biosystems Engineering Center, Technical University of Lisbon (TULisbon), Tapada da Ajuda, 1349-017 Lisboa. Portugal
[3] Centro de Biotecnologia Vegetal, IBB, Universidade do Algarve, FCT-DQF. Ed 8, Campus de Gambelas, 8005-139 Faro. Portugal
*E-mail: fpestana@ualg.pt

Abstract

Iron deficiency (iron chlorosis) is an important nutritional disorder in several plants, including fruit trees and strawberry. Iron chlorosis does not result from a small level of iron in soils but rather from impaired acquisition and use of the metal by plants. Calcium carbonate, present in great amounts in calcareous soils, and the resulting large levels of bicarbonate ions, are the main causes of iron deficiency. Countries in southern Europe, such as Portugal, Spain, Italy and Greece, have large areas of calcareous soils with established orchards, where iron chlorosis is a major factor that limits yield and profit for the farmer. Iron chlorosis affects several metabolic processes and leads to nutrient imbalances in sensitive plants. Decreased yield and poor quality of fruit resulting from the iron deficiency justify the development of methods to diagnose and correct this disorder. No single approach has been found to solve iron chlorosis satisfactorily, making it one of the most complex nutritional deficiencies known. In this chapter we describe some aspects of the effects of iron availability on quality of strawberry and citrus fruit.
Keywords: Iron deficiency, fruit quality, orange, strawberry, tangerine

Introduction

Iron deficiency leads to a decrease in the concentration of photosynthetic pigments in leaves, usually referred to as iron chlorosis. The symptoms occur primarily in young leaves and became apparent as an interveinal chlorosis with the appearance of a fine reticulation (Abadía 1992).

Iron chlorosis is a major limiting factor in fruit trees established on calcareous soils in Mediterranean areas, due to limitations on iron absorption, long distance transport and/or utilization by plants. Iron chlorosis affects several metabolic processes, leads to nutrient imbalances in plants (Sanz *et al.* 1995; Belkhodja *et al*. 1998; Pestana *et al.* 2004, 2005), and is responsible for significant decreases in yield, fruit size and quality (Álvarez-Fernández *et al.* 2006). Iron chlorosis can also lead to a delay in fruit ripening in orange and peach (Sanz *et al.* 1997; Pestana 2000; Pestana *et al.* 2001a, 2002). In *Citrus* spp., (El-Kassas 1984) reported a negative effect of iron chlorosis on gross yield and fruit quality, resulting in smaller fruit that were more acidic and contained less ascorbic acid. In peach, changes on chemical composition were reported, affecting organoleptic and nutritional properties, although the external aspect of the fruits remained unaltered (Álvarez-Fernández *et al.* 2003).

In a review, (Tagliavini *et al.* 2000) summarized the economical impact of iron chlorosis in kiwi, peach and pear orchards established on calcareous soils in Italy, Spain and Greece and concluded that yield losses were directly related to the intensity of iron chlorosis, and that a significant proportion of peaches and kiwifruit were unsuitable for the market. However, (Sanz *et al.* 1997) found that iron chlorosis only affected peach quality when visual symptoms were obvious, corresponding to a severe deficiency.

Strawberries are also affected by iron chlorosis, and they are a more convenient test plant, as they grow faster and occupy a smaller area than trees. They can also be grown in hydroponic systems so that the nutritional status can be manipulated more easily.

In this chapter we review some aspects of the effects of iron availability on quality of strawberry and citrus fruit.

What Are the Effects of Iron Chlorosisi Citrus Fruit Quality?

In a citrus orchard established on a calcareous soil, foliar treatments with iron (+Fe) increased both fruit quality and size in 'Encore' tangerine trees and 'Valencia Late' orange trees (Table 1).

Table 1 - The effect of iron chlorosis (-Fe) on yield of tangerines and oranges (Pestana *et al.* 1999, 2002). (+Fe) - Trees sprayed with Fe.

	Fresh weight	Diameter	Juice content	Maturation
	g fruit^{-1}	mm	ml	index
Tangerine 'Encore'				
-Fe	66 b	55 b	33 b	4.5 b
+Fe	107 a	65 a	51 a	6.7 a
Variation	*-38 %*	*-15%*	*-35%*	*-32%*
Orange 'Valencia Late'				
-Fe	121 b	62 b	59 b	9.1 b
+Fe	157 a	68 a	80 a	10.9 a
Variation	*-23 %*	*-9 %*	*-26%*	*-17%*

Maturation Index is calculated by the ratio between total soluble solids and titrable acidity. For each species, means in a column followed by the same letter are not significantly different at 5% (Duncan test).

Non-sprayed trees had smaller fruits (a decrease between 9 and 15%), less fresh weight (a decrease between 23 and 38%) and less total juice content (a decrease between 26 and 35%) compared to treated trees. No differences were found for total soluble solids, but the maturation index was smaller in fruits from chlorotic trees (Table 1). The application of Fe to orange trees thus enhanced fruit quality and advanced the ripening process, as in citrus the acidity (mainly citric acid) declines and the sugar concentration (expressed as total soluble solids) increases (Spiegel-Roy & Goldschmidt 1996). It conclusion, addition of iron resulted in fruits with a greater diameter, representing a gain of more than 35% in gross income to the farmer (Pestana *et al*. 2001a).

Which Are the Residual Effects of Iron Pools in Orange Trees?

Iron chlorosis is a complex process in fruit trees, as the development of this nutritional imbalance in one year may affect the reproductive cycle in the following years. Furthermore, iron chlorosis is also associated with other nutritional imbalances such as: P, Mg, K and Zn deficiencies (Pestana *et al*. 2001b, 2002, 2004, 2005). Together, these elements negatively affect fruits characteristics and cause a delay in fruit ripening. Accordingly, a prolonged period of chlorosis is supposed to induce a depletion of carbohydrate and Fe reserves, and consequently affect fruit production (Álvarez-Fernández *et al.* 2006).

In another field experiment, orange trees established on a calcareous soil were sprayed with (+Fe) or without iron (-Fe) during one growing season (Year 1). One year later (Year 2), the same trees were studied, but no iron was applied in both treatments. Fruits were collected at the end of the foliar treatments (Year 1) and again one year later (Year 2) to assess the residual effects of iron sprays on quality parameters. In the first harvest season (Year 1), the fruits of treated trees were larger (greater diameter), heavier (greater fresh mass) and matured earlier (maturation index) than those of chlorotic trees (Table 2).

Table 2. Fruit quality of oranges collected in two consecutive years (Year 1 and Year 2) in the same orchard. (+ Fe) - Trees sprayed with iron only in Year 1; (-Fe) – Untreated trees (Pestana *et al.* 2002).

		Fresh weight	Diameter	Juice content	Maturation
	Fruit harvest	g fruit^{-1}	mm	ml	index
- Fe	Year 1	184 b	72 a	89 b	9 a
	Year 2	143 c	65 b	67 c	6 b
	Variation	*-22 %*	*-10 %*	*-25 %*	*-37 %*
+ Fe	Year 1	206 a	76 a	98 a	9 a
	Year 2	193 a	74 a	95 a	10 a
	Variation	*-6 %*	*-5 %*	*-3 %*	*6 %*

Means in a column followed by the same letter are not significantly different at the 95% probability level (Duncan test).

One year later (Year 2), the fruits of treated trees still had greater diameters, and more juice and fresh weight than those of untreated trees. Although the positive impact of iron sprays in Year 2 was smaller than in Year 1, it is clear that fruit size and quality in Year 2 were dependent on the nutritional status of the tree in the previous year. In conclusion, foliar applications with Fe made in Year 1 had a positive effect on fruit quality one year later.

Does Iron Chlorosis Affects Internal Quality of Strawberries Fruits?

Strawberry (*Fragaria ananassa* Duch.) quality can be defined by texture, taste (soluble sugars and organic acids) and colour (anthocyanin content) of the fruit at harvest (Kafkas *et al*. 2007). Although the main constituents of strawberries during maturation are well known, very few studies have concentrated on the impact of nutritional disorders on these parameters. In spite of a similar external appearance, fruits grown in the absence of Fe had changes in internal quality parameters associated with a delay in fruit ripening, namely smaller sugar and anthocyanin contents (Table 3).

Iron deficiency did not significantly affect the relative proportions of each type of anthocyanin (Pestana *et al.* 2010). However, chlorotic fruits had smaller total anthocyanins content, comparatively to fruits of green plants (Table 3).

It is curious to note, however, that parameters related to health-promoting compounds can be enhanced in chlorotic plants. Strawberry fruits are an excellent source of ascorbic acid, and its concentration was greatest in fruits collected from chlorotic plants (an increase of 28%).

Table 3. Total content of sugars, ascorbic acid and anthocyanins of juice of fruits from strawberry plants grown with (+Fe) and without iron (-Fe) (Pestana *et al.* 2010).

	Total	Total	Ascorbic	Antioxidant activity		
	sugars	anthocyanins	acid	DPPH•	ORAC	TEAC
	mg g^{-1} FW	µg g^{-1} FW	mg 100 g^{-1} FW	IC50	µM Trolox ml^{-1} juice	IC50
-Fe	11 b	431 b	37 b	260 b	27 b	272 b
+Fe	14 a	651 a	29 a	359 a	48 a	341 a
Variation	*-21 %*	*-34 %*	*28 %*	*-28 %*	*-44 %*	*-20 %*

For each column, means with the same letter are not significantly different at $P \geq 0.05$ (Duncan test). FW–fresh weight; DPPH●- antioxidant activity using the free radical scavenging activity; ORAC - efficiency of antioxidants to restrain the decline of the fluorescence induced by a peroxyl generator, 2,2´-Azobis(2-aminopropane) dihydrochlorideTrolox equivalent antioxidant capacity; TEAC - suppression of the absorbance of radical cations of 2,2´-azinobis (3-ethylbenzothiazoline 6-sulfonate) (ABTS●+) by antioxidants.

Fruits from non-chlorotic plants had more capacity to scavenge peroxyl radicals, while fruits from chlorotic plants had more capacity to scavenge DPPH• and ABTS•+ radicals (reflected as smaller values) than green plants. The greater antioxidant activity measured by these two methods followed the increase observed in ascorbic acid concentrations (Pestana *et al.* 2010).

The delay observed in fruit ripening due to Fe deficiency was probably related to the different biomass allocation in chlorotic plants (Saavedra *et al.* 2009). Strawberry plants with symptoms of iron chlorosis produce fruits with similar weight but with less intense colour and poor organoleptic characteristics (Pestana *et al.* 2008).

Conclusions & Outlook

Undoubtedly, there has been a major improvement in the understanding of lime-induced iron chlorosis over the last 20 years. Nevertheless, several aspects remain unclear, especially those related to fruit trees grown under field conditions. Our results have indicated that iron chlorosis affects compounds related to flavour and healthfulness. Citrus and strawberries are classified as non-climateric fruits, so the nutritional imbalance induced by Fe deficiency may affect not only the harvest date but also fruit storage and commercialization. Further studies should focus on iron management to increase strawberry quality even if this leads to a reduction in berry size and yield. The use of an integrated management system to correct iron chlorosis should consider economic, ecological and social aspects. Orchard management techniques are sustainable only if they represent an advantage for fruit growers, and the studies on iron chlorosis should include the effects on fruit quality and yield. Iron chlorosis causes fruit quality losses in citrus orchards that may be prolonged for at least another year. The impact of controlling iron chlorosis prior to fruit formation on fruit yield and quality also deserves further investigation.

Acknowledgements

This study was funded by the national Project from the FCT (PTDC/AGR-ALI/66065/2006).

References

Abadía J. 1992. Leaf response to Fe deficiency: A review. *J Plant Nut* 15:1699-713

Álvarez-Fernández A, Abadía J, Abadía A. 2006. Iron deficiency, fruit yield and fruit quality, pp:437-48. In: *Iron nutrition in plants and rizospheric microorganisms. Developments in plant and soil sciences*, Barton LL, Abadía J (eds), Springer, Dordrecht, The Netherlands

Álvarez-Fernández A, Grasa R, Abadía A, Sanz M, Abadía J. 2003. Evaluación agronómica de nuevos quelatos de hierro. *Phytoma* 145:30-6

Belkhodja R, Morales F, Sanz M, Abadía A, Abadía J. 1998. Iron deficiency in peach trees: effects on leaf chlorophyll and nutrient concentrations in flowers and leaves. *Plant & Soil* 203:257-68

El-Kassas SE. 1984. Effect of iron nutrition on the growth, yield, fruit quality, and leaf composition of ceded balady lime trees grown on sandy calcareous soils. *J Plant Nut* 7:301-11

Kafkas E, Kosar M, Paydas S, Kafkas S, Baser KHC. 2007. Quality characteristics of strawberry genotypes at different maturation stages. *Food Chem* 100:1229-36

Pestana M. 2000. Caracterização fisiológica e nutritiva da clorose férrica em citrinos. Avaliação dos mecanismos de resistência aos efeitos do HCO3--, Universidade do Algarve, Faro, Portugal

Pestana M, Beja P, Correia PJ, de Varennes A, Faria EA. 2005. Relationships between floral nutrients and fruit quality in orange trees grown in a calcareous soil. *Tree Physiol* 24:761-7

Pestana M, Correia PJ, de Varennes A, Abadía J, Faria EA. 2001a. Effectiveness of different foliar applications to control iron chlorosis in orange trees grown on a calcareous soil. *J Plant Nut* 24:613-22

Pestana M, Correia PJ, de Varennes A, Abadía J, Faria EA. 2001b. The use of floral analysis to diagnose the nutritional status of oranges trees. *J Plant Nut* 24:1913-23

Pestana M, Correia PJ, Miguel MG, de Varennes A, Abadía J, Faria EA. 2002. Foliar treatments as a strategy to control iron chlorosis in orange trees. *Acta Hortic* 594:223-8

Pestana M, de Varennes A, Goss MJ, Abadía J, Faria EA. 2004. Floral analysis as a tool to diagnose iron chlorosis in orange trees. *Plant & Soil* 259:287-95

Pestana M, Gama F, Saavedra T, Correia PJ, Dandlen S, Miguel MG. 2010. Evaluation of Fe deficiency on strawberry fruit quality. *Acta Hortic* 868:423-8

Pestana M, Gama F, Saavedra T, Dandlen S, Miguel MG. 2008. The effects of Fe deficiency on organic acids, sugars and anthocyanins in strawberry fruits, pp:673-80. In: *Proc. XII Cong Ibérico sobre a Nutrição Mineral das Plantas,* Granada, Spain

Pestana M, Gonçalves DA, de Varennes A, Faria EA. 1999. The recovery of citrus from iron chlorosis using different foliar applications. Effects on fruit quality, pp:95-8. In: *Improved crop quality by nutrient management,* Anaç D, Martin-Prével (eds), Kluwer Academic Publishers, Dordrecht

Saavedra T, Gama F, Correia PJ, Pestana M. 2009. Deficiência de ferro em plantas de morangueiro: efeitos na partição da biomassa e na produção, pp:251-6. In: *Proc V Cong Ibérico de Ciências Hortícolas,* Logroño, Spain

Sanz JV, Montañés L, Monge E. 1995. Application of chlorophyll fluorescence to study iron and manganese deficiencies in peach tree. *Acta Hortic* 383:201-9

Sanz M, Pascual J, Machín J. 1997. Prognosis and correction of iron chlorosis in peach trees: Influence on fruit quality. *J Plant Nut* 20:1567-72

Spiegel-Roy P, Goldschmidt EE. 1996. *Biology of Citrus.* Cambridge University Press, Cambridge, UK

Tagliavini M, Abadía J, Rombolà AD, Abadía A, Tsipouridis C, Marangoni B. 2000. Agronomic means for the control of iron chlorosis in deciduous fruit trees. *J Plant Nut* 23:2007-22