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EFFECTS OF ZINC FOLIAR NUTRITION ON 'GALA' APPLE (*MALUS DOMESTICA* BORKH) FRUIT QUALITY

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Abstract

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To improve fruit color features research has focused on the use of foliar nutrition with zinc. There is a lack of know about apples. The aim of this trial was to evaluate the effects of foliar zinc treatment on the qualitative characteristics of 'Gala' apple. Apple trees Cv 'Gala' were submitted to a foliar spray application of Zn in the form of aqueous solution of 0.2% and 0.4% zinc sulfate ($ZnSO_4$) for three times. Fruit was harvested at commercial ripening and physicochemical parameters, yield, crop load, yield efficiency and zinc leaf content were measured. Results revealed that yield, crop load, fruit weight, cover color index and cover color percentage of the observed trees was influenced by zinc foliar spray treatment in each harvest date. The foliar fertilization using zinc influenced yield and several fruit quality traits. Since the ZN1 and ZN2 treatments do not differ significantly in the effect, the choice may lie in the adoption of the first treatment as it yields more economic and sustainable outcomes.

Key words: foliar fertilization, microelements, skin color

Introduction

Apple (*Malus domestica* Borkh) is the second production among the major fruit crops worldwide, after Musa, and it is produced in more than 90 countries (FAOSTAT, 2013). The European market of fresh apple is the largest one in the world, in 2013 there were produced more than 15 000 000 tons of apples; Turkey, Poland and Italy are the main producing countries, more particularly, according to recent official data, Italian apple production is about 2216.963 tons (FAOSTAT, 2013). Among the early ripening varieties 'Gala' varietal group is produced by the main exporting countries, i.e. U.S.A., Chile, New Zealand, and in Europe. In the European Union, 'Gala' accounted for 10% of total apple production in 2012 and, in Italy, it is the second cultivar (277 000 tons), after Golden delicious (Wapa, 2012) and both cultivars cover more than 60% of yield. In Italy, apple is mainly cultivated in the hill areas around the Po river (northern Italy), and in the mountainous inland areas of Sicily (southern Italy) (Lo Bianco and Farina, 2012; Farina and Mossad, 2011).

'Gala' is a diploid variety with early fruit maturation that comes from the cross of 'Kidd's Orange' x 'Golden Delicious' by J.H. Kidd in 1939 (Sansavini et al., 1986). In the last decade, in Italy, a large number of new genotypes, basing on limb mutations from the original cultivar, have been obtained by several apple-breeding programs and developed by the fruit industry (Iglesias and Echeverria, 2009; Sansavini et al., 2005). A suitable color development at harvest is often a serious problem for most of these new clones, and, in the southern European countries hot dry summers do not favor fruit color development (Iglesias and Alegre, 2006). Moreover, some reversions of color have been observed as a result of a lack of stability and reported by White and Johnstone (1991) and White et al. (1994). Nowadays, even with adequate size, intensity and quality of red color of fruits are two important factors and commercial standards used by the

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European Union (EU) to evaluate quality of fruit (Reg. CE No. 1238/2005) (DOUE, 2005) thus a reduction (Iglesias and Alegre, 2006) of intensity and quality of color is generally associated with a low consumer acceptance (Baugheret al., 1990; Crassweller and Hollender, 1989). Therefore, intense red color and uniformity of pattern is very important for this variety.

The cyanidin-3-galactoside (Sun and Francis, 1967) is the most important pigment responsible for the red color of apple and it belongs to the family of red pigments called anthocyanins.

According to previous literature light (Lancaster, 1992; Arakawa, 1991; Saure, 1990; Tan, 1980; Downset al., 1965), temperature (Faragher, 1993; Blankenship, 1987) and cultivar (Iglesias et al., 1999; Curry, 1997; Iglesias, 1996; Warrington et al., 1990; Arakawa, 1988; Dickinson and White, 1986) are the main elements that influence red color. In southern Europe, under typical climatic conditions, there are many techniques that can be used to attain a certain degree of red color. Apples are harvested progressively, in several picks, in order to obtain fruit with optimum color and high market value (Marsh et al., 1996). A delayed harvest influences negatively quality of fruit (firmness, storability) and increases the incidence of fruit cracking in 'Gala' apples (Iglesias et al., 2008).

Moreover, to improve color features (hue and distribution), recent research has focused on the use of foliar nutrition, with micro and macro elements, more particularly, many researches have been carried out on the use of foliar nutrition using N, P, K (Fallahi et al., 1984) and Ca, some other studies focused on the application of zinc (Sokri et al., 2015; Ojeda-Barrios et al., 2014; de Angelis et al., 2011; Khayyat et al., 2007; Boaretto et al., 2002), which is a cofactor of over 300 enzymes and proteins and it was used on cell division, nucleic acid metabolism, and protein synthesis (Marschner, 1986). The biological importance of zinc in plant growth was found at the beginning of the 20th century when zinc deficiency symptoms were observed on corn (Mazé, 1915), on peach (*Prunus persica* Batsch) (Chandler et al., 1931) and pecan (*Carya illinoensis)* (Alben et al., 1932). Zinc deficiency reduces plant growth, pollen viability, flowering, number of fruits and seed production (Nadergoli et al., 2011; Kaya et al., 2005; Sharma et al., 1990). Indeed, zinc is an important microelement involved in many catalytic reactions. It has a reduced mobility within the plant and in soil and thus, it is absorbed with difficulty by the roots. The portion of Zn taken up by the trees using the foliar treatment was greater than the amount absorbed through the soil application (Amiri et al., 2008; Ferguson and Watkins, 1989). Zn is quite mobile and it is able to distribute itself in all the woody parts of plants including roots, and more than 50% in new shoots. Hipps and Davies (2001) observed a positive effect in apple trees with a reduction of blooming and fruit set without negative influence on fruit firmness or peel color. In citrus, grapes (Swietlik, 2002), pomegranate (Hasaniet al., 2012), olive (Ramezani et al., 2010), walnut (Keshawarz, 2011), zinc foliar spray has a positive effect on fruit production. This effect can be considered useful for apple varieties, particularly for 'Gala', in those climatic areas where it is difficult to reach the optimal size and color.

The aim of this research is to evaluate the effects of foliar zinc treatment on the qualitative characteristics of 'Gala' apple fruits cultivated in mountainous areas where it is not easy to reach the best of standards color. Moreover, another objective is to point out the best zinc nutritional supply for 'Gala' apple fruit, in order to avoid plant toxicity and economic waste of plant nutrients and hand-labor.

Materials and Methods

Sixty 12-years old uniform trees of apple 'Gala' clone 'Galaxy', grafted on M9 rootstock, planted in 4 x 1.5 m row and trained to central leader, and cultivated in the inland areas of Sicily (37° 49' N; 13° 53' E, 805 m a.s.l.) were used for this study. Trees were selected and divided by three groups of 20 trees. The soil was a clay loam (53% (by volume) sand, 18% silt and 29 % clay) with pH 7.3 and 18 g/kg active carbonates. At field capacity, soil water content was around 0.26 m^3/m^3 and soil water potential around –17 kPa. The first two groups were treated with a foliar spray application of Zn in the form of aqueous solution of 0.2% (ZN1) and 0.4% (ZN2) zinc sulfate ($ZnSO_4$), whereas a group of 20 trees was sprayed with tap water (CTR). The plants were sprayed at the rate of 10 L $tree^{-1}$ drop-offby using a hand-sprayer immediately after sunset. The Zn solution was sprayed on trees 30 days after fruit set stage (30 June), when the fruit started to change skin color (15 July) and 20 days before the first harvest (1st August) by using hand held sprayer, until the complete wetting of leaves, having sprayed more than once, as zinc is not easily absorbed and transported by leaves (Swietlik, 2002; Hipps and Davies, 2001).

Fruit were harvested at commercial ripening stage on 18, 22 and 25 August according to their maturity level, using a Starch Pattern Index (SPI), 1-10 point scale as maturity indicator (from 1 for full starch, so immature, to than 10 for low starch, over mature) (Iglesias et al., 2008). A sample of 10 fruits per tree was submitted to the analyses. Biometrical (transversal diameter, height/diameter ratio, weight) and chemical-physical characteristics (total soluble solid, titratable acidity) were observed. Fruit weight (FW) was determined by digital scale (Gibertini, Italy); transversal diameter (TD) by a digital caliper TR53307 (Turoni, Forlì, Italy); flesh firmness (FF) by a digital penetrometer TR5325 (Turoni, Forlì, Italy); total soluble solid (TSS) by digital refractometer Atago Palette PR-32 (Atago Co., Ltd, Tokyo, Japan), titratable acidity (TA) expressed in g L^{-1} of malic acid and pH using a CrisonS compact tritator (Crison Instruments, SA, Barcelona, Spain).FAS procedure based on digital images were used to determine percentage and intensity of color (Francaviglia et al., 2013). Each fruit was photographed with a digital camera and digital images were used to determine percentage and intensity of peel red color. Specifically, we used an algorithm that converts images from RGB to CIE L*a*b* format, extracts the fruit from the image (removing the image background), and quantifies color characteristics as the weighed distance of each pixel in the image from a reference sample (best colored area interactively chosen from a well colored fruit) (Sortino et al., 2015). The output is an index ranging from 0 to 1 (identical to reference sample).

For those fruits with red cover color, a green-red threshold algorithm was used to obtain a separation of the total fruit area (number of pixels) into two sub-regions, cover color (closer to red) and ground color (closer to green). The pixel ratio was used to quantify cover color as a percentage of the total fruit area.

The output is an index for the cover color (CCI) ranging from 0 (not red) to 1 (red). Percentage of cover color (CCP) was calculated dividing the number of pixels of the red region by the number of pixels of the entire fruit area.

Yield per tree was measured by weighing and counting the total number of fruit per tree, at each harvest time, trunk circumference was measured at ~15 cm above the graft union. Yield efficiency and crop load were expressed as kilogram or number of fruit per trunk cross-sectional area (TCSA) or leaf area.

A sample of 20 leaves per tree were picked before the first treatment and at the last harvest date from the four canopy cardinal points on one-year-old branches, in order to analyze content of the zinc in leaves content before and after foliar Zn application.

Collected data concerning yield fruit quality and growth were compared by two-way analysis of variance (with picking as main factors) using SYSTAT procedures (Systat Software Inc.; Richmond, CA, USA).

Results and Discussions

Results revealed that yield and fruit quality of the observed trees were influenced by zinc foliar spray treatment in each harvest date (Table 1). More particularly ZN1 treatment improved quantity and quality of yield. The highest yield per tree was obtained in ZN1, whereas ZN2 did not differ significantly from the CTR fruit (Table 1). Yield improvement was caused by an increase of fruit size, rather than to the number of fruits, nevertheless, crop load was higher for ZN1 than for CTR and ZN2. Moreover, the highest yield efficiency was observed in ZN1 treatment, followed by the ZN2 and the CTR.

Regarding the influence of zinc on fruit quality, there were observed interactions among treatments and harvest times. About fruit CCI and CCP, as expected, results showed an increase from the first to the third harvest time. In fact, ZN1 and ZN2 trees significantly differ from CTR trees (Table 2) both in the first and in the second harvest: ZN1 affected CCI during the first harvest, whereas ZN2 did not differ significantly from CTR. During the second harvest both treatments influenced CCI, whereas during the third harvest, treated fruits did not differ from CTR fruits. This treatment shows a better peel color (intensity, extension and cover) which is considered a primary trait of selection for consumers (Ivascu, 2002) and therefore an appreciated parameter by the GDO (Sansavini et al., 2009). This CCP increase in ZN1 could be due to a progressive absorption of zinc.

Zinc treatment affected FW, in fact ZN1 fruit reached the best size in each harvest time. Moreover, there are no differences between ZN1, ZN2 and CTR trees for TSS and TA, and starch index (data not shown) in each harvest date. No variations of FF were obtained from the first to the last harvest, and compatible values for trade where obtained even in ZN1 and ZN2 fruits. Moreover, zinc treatment did not have a negative effect on calcium metabolism (Martin et al., 1976; Yogaratnam and Johnson, 1982), which, is notoriously linked with flesh consistency (Hipps and Davies, 2001). A good organoleptic balance with a TSS of 13 °brix and 5 gL^{-1} of TA (Table 3) was observed in all treatments (Sansavini et al., 2009).

Zinc treatment influenced the increase of fruit weight contrarily to other studies wherein bio-stimulants with zinc,

Table 1

Yield, No of fruit per tree, Yield efficiency and crop load of the observed trees sprayed with 0.2% (ZN1), 0.4% (ZN2) zinc sulphate ($ZnSO_4$) and tap water (CTR). The values marked with different letters in the same column indicate significantly differences ($p \leq 0.05$)

Treatments	Yield (kg/tree)				No.of fruitsper tree				Yield efficiency (kg/cm^2 TCSA)				Crop load (no.fruit/cm^2TCSA)			
CTR	13.59	±	2.12	b	41.26	±	4.09	a	0.59	±	0.01	c	1.79	±	0.14	b
ZN1	16.10	±	3.85	a	39.36	±	4.97	a	0.74	±	0.02	a	1.92	±	0.12	a
ZN2	13.19	±	2.89	b	34.41	±	4.04	b	0.62	±	0.03	b	1.77	±	0.21	b

Table 2

Cover color index and cover color percentage of the observed trees sprayed with 0.2% (ZN1), 0.4% (ZN2) zinc sulfate ($ZnSO_4$) and tap water (CTR). The values marked with different letters in the same column indicate significantly differences ($p \leq 0.05$)

Harvest	Treatments	Cover Color index				Cover Color Percentage			
	CTR	0.890	±	0.01	d	43.93	±	18.61	e
I	ZN1	0.903	±	0.01	c	64.54	±	14.99	dc
	ZN2	0.892	±	0.01	d	50.79	±	20.50	de
	CTR	0.916	±	0.01	c	70.59	±	15.54	bc
II	ZN1	0.933	±	0.01	b	90.85	±	3.91	a
	ZN2	0.931	±	0.01	b	88.33	±	5.00	ab
	CTR	0.950	±	0.01	a	90.42	±	7.47	a
III	ZN1	0.964	±	0.01	a	94.24	±	4.21	a
	ZN2	0.956	±	0.00	a	93.00	±	3.16	a

Table 3

Pomological traits and chemical-physical parameters of Gala fruits (Mean ± SD). Fresh weight, Firmness, Total soluble solids content and Tritatable Acidity. The values marked with different letters in the same column indicate significantly differences ($p \leq 0.05$)

Harvest	Treatments	Fresh Weight (g)				Firmness (kg cm^{-2})				Total soluble solids (brix°)				Tritatable Acidity (g L^{-1})			
	CTR	120.89	±	16.28	e	7.10	±	2.19	ns	13.75	±	0.12	ns	4.15	±	0.28	ns
I	ZN1	143.97	±	20.31	bc	7.56	±	1.89	ns	13.50	±	0.17	ns	4.27	±	0.44	ns
	ZN2	135.38	±	20.67	cd	7.82	±	1.96	ns	13.49	±	0.13	ns	4.31	±	0.38	ns
	CTR	135.31	±	20.03	cd	7.62	±	2.37	ns	13.00	±	0.14	ns	4.87	±	0.34	ns
II	ZN1	153.47	±	18.88	ab	7.39	±	1.82	ns	13.35	±	0.12	ns	4.48	±	0.3	ns
	ZN2	135.97	±	17.94	cd	7.39	±	1.86	ns	13.60	±	0.16	ns	4.34	±	0.28	ns
	CTR	130.31	±	20.27	de	7.83	±	1.98	ns	13.06	±	0.17	ns	4.50	±	0.29	ns
III	ZN1	156.47	±	21.78	a	7.23	±	1.78	ns	13.55	±	0.16	ns	4.20	±	0.24	ns
	ZN2	138.02	±	19.45	cd	7.48	±	2.20	ns	13.74	±	0.14	ns	4.34	±	0.38	ns

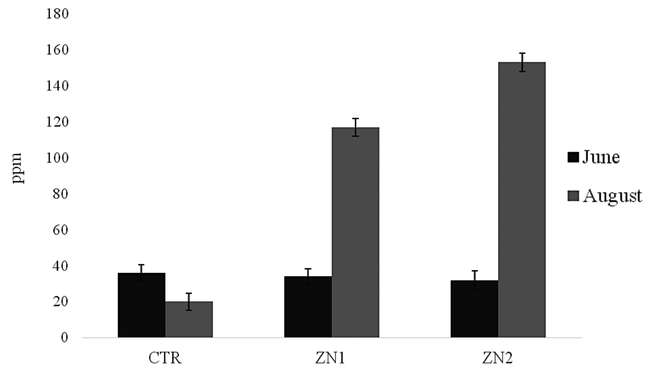

Fig. 1. Zinc Content in Leaves. Before treatments (on June) and after treatment (on August). T1: 12g of zinc fertilizer; T2: 24g of zinc fertilizer; CTR: only water

nitrogen, potassium and phosphorus were used (Fabbroni et al., 2007). Fruit firmness reached in all treatments a value that assures handling on a good post-harvest conservation and shelf life (Abbott, 1999).

Foliar diagnostic analyses showed that leaves accumulated zinc after the three treatments ZN1 and ZN2, but in the CTR trees, where it decreased because fruits used all the quantity (Figure 1). Finally, there was a significant difference of ZN leaf concentrations among all the treatments: the highest value was observed in the foliar ZN2 treatment.

Conclusions

The foliar fertilization using Zinc increased fruit weight, cover color index and cover color percentage. This effect was influenced by the harvest date; it is increased from the first to the last one. Moreover ZN1 treatment influenced positively yield, yield efficiency and crop load.

Despite the effects of the ZN1 and ZN2 treatments do not differ significantly, the choice may be to adopt of the first treatment as it provides more economic and sustainable outcomes. Overall, the use of zinc foliar treatment in a mountainous environment for ‘Gala’ Cv may be a better choice to increase fruit quality. This better color quality may contribute to enhance 'Gala' Cv commercialization at higher market prices and then higher income for the farmer.

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