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Boron in combination with calcium reduces sunburn in apple fruit

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ABSTRACT

Sunburn damage on apple fruit has been reported widely [1]. Sunburn incidence is expected to increase in future, specifically in the Western Cape in South Africa, with very clear climate change predictions [2]. Sunburn thus has significant financial implications on profitability for the South African export dominated apple industry, as sunburnt fruit is not accepted in the main export markets. In the United Kingdom, no visible sunburn on apples is allowed, whereas only fruit with class 1 sunburn (Sunburn classification guide [3]) is accepted in Europe. To reduce sunburn, which can be 40% for some cultivars, an affordable and sustainable alternative is needed. Researchers [4] reported that Manni-Plex® calcium (Ca) and boron (B), applied in combination as pre-harvest foliar applications, reduced sunburn significantly for 'Golden Delicious' (GD) apples. This research was continued to investigate the efficacy of the Ca/B combination as alternative formulations on GD. The biggest reduction in sunburn incidence was found in sunburn class 1. Results indicated that more formulations will be suitable to reduce sunburn on GD significantly compared to the control than the initial sorbitol formulation. The Spraybor (5 g)/Calsol combination applied as six weekly foliar applications from 28 days after full bloom (DAFB) was the most efficient combination to reduce sunburn on GD in 2015/16.

1. Introduction

Sunburn is categorised as a physiological disorder in reaction on direct or indirect high flux densities of solar radiation [1]. It can also be induced indirectly by an increase in radiant heat [5,1,6]. This is a worldwide phenomenon on apple fruit, but differs in intensity between cultivars and growing regions.

In the Western Cape region of South Africa, apple production is one of the main agricultural activities with a very important contribution towards revenue. Approximately 50 % of all production is exported [7, 8]. Sunburn damage to fruit is predicted to increase due to clear predictions of increased temperatures and a decrease in precipitation by the IPCC [2]. The impact of sunburn incidence on fruit is significant, as losses due to sunburn of up to 50 % of fruit of exportable quality has been reported [9]. Thus amelioration for sunburn reduction will become a necessity for a sustainable income.

Present amelioration strategies to reduce sunburn incidence in apple orchards include physical shading of fruit and cooling of fruit. Physical shading include pruning strategies [1], the selection of root stocks and shade net structures [10-12]. Direct cooling of fruit has been achieved by overhead irrigation [12,13-15] during susceptible periods of fruit to sunburn damage. The latest development was the application of protective films [6,12,16,17]. However, all of the above strategies have limitations, whether financial or logistics and therefore room for alternative, sustainable solution exists.

Research with foliar applications of calcium and boron to reduce bitter pit lead to an unusual outcome on sunburn in apples. [4] reported that Manni-Plex® (Ca)/ Manni-Plex® (B), applied in combination as pre-harvest foliar applications, reduced sunburn significantly in 'Golden Delicious' (GD) apples. Although B has been reported to have antioxidant characteristics [18], it has never been implicated in sunburn mitigation in apples. This research was continued during 2014/15 and 2015/16 to investigate the efficacy of the Ca/B combination with alternative formulations and less applications on three apple cultivars. In this paper, only the trial on GD during 2015/16 will be discussed.

2. Materials and methods

2.1. Site selection and treatment application

The initial trial [4] was performed on a commercial farm (Queen Anne; 34°2'41.10" S 19°12'53.20" E) in the Elgin-Vyeboom-Villiersdorp area, Western Cape,

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South Africa during 2011/12-2012/13. The extension of the research was carried out on a different farm (Applethwaite; 34°12’08.0” S 18°59’16.5” E) in the same area, during 2015/16. As the first trial was described in [4], a summary of treatments are given in Table 1 and details of only the second trial in 2015/16 will be described in full.

A randomised block design with seven treatments replicated eight times on single trees were applied to full bearing GD trees on M793 with a history of severe sunburn damage. Various combinations of foliar Ca & B described in Table 2 were applied from 28 DAFB on a weekly basis for six weeks.

2.2. Parameters quantified related to fruit quality

Mineral analyses (Ca, nitrogen (N) and B) of the peel (2015/16) of six fruit of similar size per tree, were conducted by a commercial laboratory Bemlab Pty Ltd, Strand, two weeks after the last foliar application (Table 3).

On the commercial harvest date, 26th of February 2016, approximately 17 kg of fruit was harvested randomly, per tree, from the most exposed side of the row (Western side) to include the highest possible sunburn incidence. A sample of 10 fruit of similar size was picked at shoulder height, at random, from each tree

Table 1. Foliar applications of Ca and Ca/B combinations applied 21 DAFB for eight weeks during 2011/12 and 2012/13 adapted from Lötze and Hoffman [4]

Product B	Product Ca	Composition for B-formulation	Composition for Ca formulation
Control no B	Control no Ca	0	0
None	10 ml Manni-Plex Ca	0	100g/kg Ca 80 g/kg N
6 ml Manni-Plex B	10 ml Manni-Plex Ca	33 g/kg B, 50 g/kg N	100g/kg Ca 80 g/kg N
None	67 ml Calflo™		180 g/kg Ca, 140 g/kg N 10 mg/kg B, Si 10 mg/kg, Mo 10 mg/kg
None	Afri-CAL®19 ($CaCl_2$)		138 g/kg Ca

Table 2. Foliar combinations of Ca/B applied weekly from 21 DAFB for eight weeks on GD during 2015/16. Amounts calculated for 10L water.

Products B	Products Ca	Active Ingredients Composition of B product	Active Ingredients Composition for Ca product
Control no B	Control no Ca	0	0
6 ml Manni-Plex B	10 ml Manni-Plex Cal-Zn	33 g/kg B, 50 g/kg N	60 g/kg Ca, 60 g/kg N, 30 g/kg Zn
6 ml Manni-Plex B	68 g Calsol	33 g/kg B, 50 g/kg N	190 g/kg Ca, 155 g/kg N
5g Spraybor (Na2B4O7·10H2O)	68 g Calsol	165 g/kg B	190 g/kg Ca, 155 g/kg N
7.5 g Spraybor	68 g Calsol	165 g/kg B	190 g/kg Ca, 155 g/kg N
10 g Spraybor	68 g Calsol	165 g/kg B	190 g/kg Ca, 155 g/kg N
9ml ‘No-burn’	60 g Calcimax	Not declared	78,5 g/kg Ca, 5 g/kg B

for fruit quality analyses at the laboratory of the Department of Horticultural Science, Stellenbosch University. Standard methods were used to determine the starch break down, fruit firmness, total soluble solids, back ground colour and fruit size. Detailed results are presented in [3].

Approximately 100 fruit was used for a visual classification of sunburn incidence on individual fruit basis, using an adapted sunburn classification guide for GD [3] (Table 4) from [19] (Fig 1).

Statistical analyses were performed with SAS 9.3 (SAS Institute, Inc, Cary, North Carolina, USA) using a two-way ANOVA. Significant differences were allocated for P < 0.05.

3. Results and discussion

No significant differences were recorded between treatments for N concentration in the peel in spite of the addition of nitrate to the fruit in the Ca/B combination treatments.

Table 3. Mineral analyses results for apple peel 80 DAFB after the last application to GD in 2015/16.

Treatment	**N**	**Ca**	**B**
	mg.100 g FW^{-1}		
Control	89 ^{ns}	10.57 ba	7.42 bc
Manni-Plex B & Manni-Plex Cal-Zn	84	8.65 b	5.60 c
Manni-Plex B & Calsol	85	12.38 ba	7.78 bac
5 g Spraybor & Calsol	90	12.73 ba	9.17 bac
7.5 g Spraybor & Calsol	94	16.88 a	11.8 a
10 g Spraybor & Calsol	99	12.60 ba	11.6 ba
No-burn alt. Calcimax	90	11.84 ba	9.34 bac
P	0.481	0.037	<0.0001

Table 4. Sunburn incidence of GD fruit at harvest 2015/16.

Treatment	Total Sunburn (%)	Class 0 (%)	Class 1 (%)	Class 2 (%)	Class 3 (%)	Class 4 (%)	Class 5 (%)	Class 6 (%)
Control	35.8^{ns}	64.2^{b}	16.4^{a}	10.6^{a}	5.1^{ns}	2.3^{ns}	0.75^{ns}	0.6^{ns}
Manni-Plex B & Manni-Plex Cal-Zn	33.0	67.0^{b}	17.4^{a}	6.9^{ba}	4.2	2.4	1.57	0.6
Manni-Plex B & Calsol	23.9	76.1^{ba}	10.2^{ba}	5.7^{ba}	4.6	2.6	0.46	0.3
5 g Spraybor & Calsol	12.5	87.5^{a}	5.65^{b}	3.3^{b}	1.8	0.8	0.23	0.7
7.5 g Spraybor & Calsol	27.3	72.7^{ba}	11.4^{ba}	8.7^{ba}	4.4	2.4	0.23	0.2
10 g Spraybor & Calsol	19.7	80.3^{ba}	10.7^{ba}	4.5^{ba}	2.6	1.2	0.32	0.5
No-burn alt. Calcimax	29.9	70.1^{ba}	14.2^{ba}	8.2^{ba}	4.7	1.4	1.16	0.2
P	0.1753	0.0089	0.0164	0.0642	0.1893	0.3412	0.1413	0.8207

Figure 1. Sunburn classification for GD adapted by Daiber [3]

At this phenolocial stage (80 DAFB), the foliar application of additional Ca compared to the control with none, did not reflect a significant increase in Ca peel concentration which was unexpected. The Ca concentration differed significantly between two treatments – Manni-Plex Cal-Zn/ Manni-Plex B and Spraybor (7.5 g)/Calsol, but these did not differ significantly from the rest of the treatments. The lowest Ca concentration was associated with the Manni-Plex Cal-Zn/ Manni-Plex B which was unexpected, as it was also lower than the control (not sign.), and may be due to the addition of the Zn to the original formulation used in 2011-2013 (Manni-Plex Ca).

Significant differences in the B concentration in the peel were found between the control and Spraybor (7.5 g)/ Calsol treatment, with the latter showing significant higher B levels in the peel which confirms the effect of applying additional B to the fruit. The B concentration was also significantly higher in the Spraybor (7.5 g)/ Calsol and Spraybor (10 g)/ Calsol treatments compared to the Manni-Plex Cal-Zn/ Manni-Plex B, confirming the higher initial B concentration of Spraybor in these combinations.

With regards to sunburn incidence, total sunburn percentage was significantly reduced in the Spraybor (5 g)/ Calsol treatment (12.5 %) compared to the control (35.8 %) and Manni-Plex Cal-Zn/ Manni-Plex B treatments (33.0 %) that did not differ from one another. This contrasted previous results with the sorbitol formulation [4] and indicated the suitability of alternative Ca/B formulations for the reduction of sunburn in GD. When sunburn incidence in the different sunburn categories were considered, the Spraybor (5 g)/ Calsol combination was the only treatment with a significantly lower percentage sunburn in class 1 and class 2 than the control. Treatments had no effect on higher sunburn classes 3 to 5. The Manni-Plex Cal-Zn/ Manni-Plex B treatment showed the same high class 1 sunburn incidence (17.4 %) than the control (16.4 %), again indicating contrasting results of [4], which may be due to the addition of Zn.

Fruit quality was not compromised by any of the treatments [3], except for a slight advancement in maturity with the Spraybor (10 g)/Calsol treatment and was not related to the reduction in sunburn.

4. Conclusions

Previous findings of a significant reductions sunburn incidence in GD [4] were confirmed. However, it was a different formulation of the Ca/B combination that resulted in the highest reduction in total sunburn as well as percentage fruit in classes 1 and 2. The Spraybor (5 g)/Calsol treatment consistently reduced sunburn significantly compared the control and Manni-Plex Cal-Zn/Manni-Plex B treatment in total sunburn as well as class 1. It also resulted in a significantly lower percentage of sunburn fruit in class 2. This tendency persisted towards classes 3 to 5 (non-sign.). Thus, it is possible to reduce sunburn significantly with a different foliar application (Spraybor (5 g)/Calsol) with six weekly applications from 28 DAFB.

Treatment combinations containing calcium nitrate as Ca source showed significant higher B concentrations in fruit peel, but at present, the elevated B levels only cannot be correlated to the reduction of sunburn in these treatments. The actual concentration of B in the fruit peel did not fully explain the positive results with sunburn mitigation. There was no clear relationship between the reduction in sunburn incidence and the Ca or B concentration in the peel at 80 DAFB, indicting another mode of action for the reduction of sunburn.

From previous reports [3; 4], the significant reduction cannot be ascribed to a direct effect of the B or Ca supplementation only. An application of Manni-Plex® Ca or Manni-Plex B only did not reduce sunburn, thus it has to be a combination of these two elements which was confirmed by result from 2015/16. Data from 2015/16 also indicated that fewer applications (6) applied slightly later (28 DAFB) was efficient in reducing sunburn on GD.

In future, the unusual role of B in combination with Ca as pre-harvest foliar application to reduce sunburn has to be validated on more cultivars and fruit kinds. The most beneficial combination, time of application and number of applications required for the optimum results can be refined. The Ca and/or B concentration in the peel and/or fruit alone did not explain the mode of action of the reduction in sunburn and points towards a different approach than a physical alteration of the peel which was initially put forward.

An alternative mode of action may be changes in the biochemical composition of the peel after the foliar application of Ca and B. Boron has been reported to influence the metabolism of phenolic compounds and anti-oxidant activities [18; 20] in tobacco. Similarly, the role of B is known to abate sugar transport in plants [21; 22] and may play a role in polyphenol synthesis [23] which will be upregulated if additional B is applied. In addition the anti-oxidative properties of Ca as well as the recent study [24] that indicated the role of Ca in signalling in the chloroplast need to be considered in this respect. The role of regulation of chlorophyll, anthocyanins and quercetin glycoside concentrations in the peel with the foliar application of the Ca and B combination that is known to play a role in sunburn development [25;26] can be another explanation for the observed reduction of sunburn. In the next phase of this project, various analyses for anti-oxidant -, phenolic - and pigment concentrations in these apple peels have commenced, will discuss these topics in detail and will be used to propose a mode of action.

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