RESEARCH TOWARDS REDUCING ORCHARD COLD DAMAGE OF 'HASS' AVOCADO FRUIT

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ABSTRACT

As freezing temperatures did not occur in 2024, the efficacy of late season foliar sprays towards increased cold-hardiness could not be verified. However, the leaf nutrient analysis and differences in leaf Total Soluble Solids (TSS) gave valuable information. The aim in 2022 and 2024 to increase the TSS by applying 5 salicylic acid foliar sprays earlier in the year, compared to 3 foliar sprays in 2021, was successful in 2022. This confirms the ability of salicylic acid to increase TSS and that more sprays will increase TSS. However, the Alexin sprays in 2021 were associated with a leaf TSS of 15.5 °Brix 2021 and in 2024 the Alexin was associated with a leaf TSS of 13.8 and 14.4 °Brix content. Although the 2001 leaf N was lower at 2.4% compared to 2.5% in 2024, the TSS was not higher in the Haenertsburg 'Hass' orchard, although at a similar fruit maturity of 64% moisture (36% dry matter content). This might be due to the higher elevation and colder weather in Haenertsburg. This indicates the TSS at the start of the trial in 2021 was already higher. Furthermore, it suggests that Alexin sprays need to start a month earlier (April) in Haenertsburg to ensure that higher TSS values are attained at the time freeze temperatures arrive. The aim in 2024 was to apply 2 soil application of Rappid K (which contains 2 macro nutrients, P and K), and 2 soil applications of Microflex Super (which contains micronutrients B, Fe, Mo, Mn, Mg, and Zn), as well as 5 foliar applications of Microflex Super, successfully increased the cold-hardiness of 'Hass' avocado. The addition of these nutrients as soil and foliar applications led to increased leaf TSS with a value of 13.8 °Brix when compared to the untreated control (UTC) that showed 12.2 °Brix. Furthermore, the addition of these nutrients as soil and foliar applications, in combination with the 5 salicylic acid foliar applications, increased the TSS to 14.40 °Brix, when compared to 5 foliar salicylic acid applications alone, that showed a TSS of 13.8 °Brix. This result confirms literature that indicates that increased P leads to increased leaf TSS. As was found in 2022, the foliar application of Rappid K was unsuccessful in increasing the leaf K and P content. This confirms the difficulty these nutrients have in penetrating the avocado waxy leaf skin.

Soil and foliar applications of Microflex Super led to effective increases in leaf Mg, Fe, Zn, B, and Mo. The leaf Mn content, however, showed a lot of variation between treatment plots with no proof of increase evident. Six foliar applications of Foral BMo that contains sea weed extract and additional B, Zn, KO_2, and Mo effectively increased leaf TSS to 13.70 °Brix and leaf B, Zn, and Mo content. As with Rappid K, applications of Foral BMo did not increase leaf K content, even though the product contains KO_2. Six foliar applications of Eckosil when applied alone and in combination with Foral BMo, led to increased leaf TSS (13.78 °Brix and 13.90 °Brix, respectively) when compared to the UTC that showed 12.2 °Brix, as well as increased leaf Si content (211.6 mg/kg and 218 mg/kg, respectively) when compared to the UTC (148.6 mg/kg). Six foliar applications of low biuret urea showed an increase in TSS with a value of 13.9 °Brix, when compared to the 12.20 °Brix of the UTC. Nutrition management is an important tool to provide frost/freeze protection. Unhealthy and low nitrogen trees are more susceptible to frost damage, and good fertilization improves tree health. This suggests that all factors that influence fruit TSS and maturity rates need to be managed throughout the season to raise the TSS from early in the season to the maximum and then to add salicylic acid sprays or other treatments 1.5-2 months prior to the expected freezing temperature to increase cold-hardiness further. Therefore orchards should be managed from early in the season to try to obtain fruit with a faster maturation rate when periods of possible freezing temperatures are reached. It is recommended that nutrition management of orchards prone to freeze damage should focus on increasing the N to 2.5-2.6% (higher than the norm of 2.2-2.4%). K and P are also important in increasing cold-hardiness, and should be increased to the higher margin of their respective norms. Secondary macronutrients Ca and Mg, as well as micronutrients Fe, Mn, Zn, Cu, B, and Mo that play an important role in optimum cold-hardiness, should all be within the leaf nutrient norm, near the high margin of their

respective leaf nutrient norms, as any deficiencies will reduce the level of cold-hardiness. Si plays an important role as it promotes movement of most other nutrients from the soil into the roots. Soil treatments in small amounts throughout the season can make a big difference in the leaf nutritional composition. In short, these orchards should be managed from early in the season with the goal in mind that fruit with a faster maturation rate are produced when periods of possible freezing temperatures are reached. Cosmocell is busy with final registration trials in South Africa on a wetter/penetrator namely Inex-A that is effectively used on avocado in Australia, which showed promise in 2023 and was used in all foliar applications in 2024.

INTRODUCTION

In some years, severe cold temperatures have been recorded in various South African avocado growing regions. As a result of these temperatures, considerable losses were recorded in the 2007 season in Tzaneen on most cultivars due to freeze damage rendering fruit unmarketable. Products applied as foliar sprays have been effective in reducing freeze damage in other commodities. The need existed to test the efficacy of these products on avocado. The main objective at the start of the project was to determine the efficacy of the combined foliar application of two AECI products (Alexin and Rappid K) in an attempt to increase the cold-hardiness of 'Hass' avocado fruit. AECI indicated that where producers applied these two products to annual crops, reduced freeze damage was noted in field. Alexin contains salicylic acid known to improve freezing tolerance of several commodities. In 2021, the avocado fruit from trees treated with Alexin + Rappid K exhibited no internal pulp orchard cold damage, indicating their possible use in improving cold-hardiness. On account of the positive results obtained in 2021, the objectives for the 2022 and 2023/24 seasons were identified and other treatments were included to compare differences in efficacy.

Nutrition management is important in preventing frost/freeze damage to fruit. Unhealthy and low nitrogen trees are more susceptible to frost damage and fertilization improves tree health. Also, trees that are not properly fertilized tend to lose their leaves earlier in the autumn and bloom earlier in spring, which increases susceptibility to frost damage. However, the relationship between specific nutrients and increased resistance to frost damage is obscure, and the literature contains many contradictions and partial interpretations.

In general, nitrogen (N) and phosphorus (P) fertilization before a frost spell encourages growth and increases susceptibility to frost damage. To enhance the hardening of plants, applications of N fertilizer in late summer or early autumn should be avoided. P is important for cell division and therefore is important for recovery of tissue after freezing, hence optimum soil P is important. Kruger *et al*. (2008) showed that low N orchards were more prone to develop orchard cold damage, so the time of application is crucial to maintain optimum N levels. 'Fuerte' fruit with a low N content and suboptimal iron (Fe) levels were more prone to develop black cold damage. On the other hand, fruit from high N trees with high Fe content developed no black cold damage (Lemmer *et al*., 2005). In this regard, most studies indicated that the addition of N results in significant increases in the availabilities of micronutrients such as copper (Cu), manganese (Mn), and iron in soils (Malhi *et al*., 1998; Tian *et al*., 2015; Tian *et al*., 2016; Wang *et al*., 2017). Field experience suggests that elevated levels of trace minerals, particularly Mn and B, but also zinc (Zn), Cu, Fe, and molybdenum (Mo) can reduce the effects of freezing temperatures significantly within days or hours of application (Wang *et al*., 2017). The application of Mo could be useful in situations where enhanced frost resistance is required with wheat (Al-Issawi *et al*., 2013).

Potassium has a favourable effect on water regulation and photosynthesis, drought tolerance, improved winter hardiness, and protein synthesis in plants (Snyder and De Melo-Abreu, 2005). Silicon (Si) and potassium (K) helped in synthesis of more sugars in citrus fruit and thus increased Total Soluble Solids (TSS). An increase in TSS is associated with a decrease in acidity. K helps with sugar translocation and is used as an osmosis agent in opening and closing stomata, an important mechanism involved with water uptake and usage. More nutrient water uptake resulted in increased juice content in citrus (Alva *et al*., 2006). Apart from the aforementioned roles, K reportedly reduces frost damage in tuberous crops such as potato. It is possible that the effect of K in frost tolerance is related to an increase in phospholipids, membrane permeability, and an improvement in biophysical and biochemical properties of cells. Potassium builds strong cell walls which can increase the plant's tolerance to frost (Kant and Kafkafi, 2002). Furthermore, it is suggested that K regulates the osmotic and water potential of the cell sap and reduces the electrolyte leakage caused by freezing temperatures and provides protection against oxidative damage caused by frost (Kampf, 2020). Although the mechanism is not clear, K accumulation may lead to an increase in cell solute concentration (by increasing TSS) (Sakai and Larcher, 1987). Membrane damage is mainly due to the dehydration that occurs during the freeze-thaw cycle. Freezing-induced destabilisation of the plasma membrane involves different types of lesions. Increases in TSS improve the impact of dehydration associated with freezing (Tomashow, 1999). The accumulation of sucrose, other simple sugars, and osmolytes that typically occurs with cold acclimation also seems to contribute to the stabilisation of membranes and may play a key role in protecting proteins from freezing and dehydration (Steponkus, 1984). Physiologically, compatible solutes should have no adverse metabolic effects even at very high concentrations. They are thought to stabilise sensitive cellular components under stress conditions and also act as bulk osmo-protectants.

Resistance to frost damage increases when plants accumulate photosynthates in their sensitive tissues (Proebsting, 1978). Consequently, good plant nutrition and sanitary status favours acclimatisation and resistance to freezing (Abagdonas *et al*., 1978). New growth tends to have fewer solutes than older plant parts that have hardened. Since solutes in the water contribute to lowering the freezing point, any management activity that encourages growth decreases solute content and increases sensitivity to freezing. This shows the importance of increasing plant TSS to increase cold tolerance, preferably prior to expected cold periods.

Scientific studies have shown that regular application of seaweed extract (kelp) can increase frost resistance. Seaweed extract applied at 10-day periods throughout the frost danger period can give 2-3 °C extra frost tolerance for pome and stone fruit. The first application should be made at least 36 hours before an expected frost. They contain a number of plant growth regulators of which 2 (cytokinin and betaines) increase cell wall turgidity. Seaweed extract also contains sugars such as mannitol and potassium - both of which will lower the freezing point of the cell fluid and explain part of the observed effect. Extensive work by scientists in the UK seems to indicate that there is something in the seaweed extract that triggers a gene responsible for "hardening of" the plants (Young, 2012).

Phosphorus (P) is known to improve acclimatisation of plants but also intensifies growth, and new growth is more sensitive to freezing. However, P is also important for cell division and therefore is important for recovery of tissues after freezing. Many varieties of crop types with greater frost tolerance have higher P absorption from cold soils, resulting in acclimatisation (Bagdonas *et al*., 1978).

Cold stress can be offset with Si. Si is also an important micronutrient that can protect plants from freeze damage by modification of the cell wall and prevention of membrane damage. South African scientists working with bananas have shown that silicon protected plants from cold damage (Kidane, 2008). Calcium (Ca), boron (B), and Si are synergists and together represent proactive cell wall and membrane strengthening that will protect a plant during any stress condition. Plant cells undergo dehydration during freezing stress due to the presence of ice in extracellular spaces (Levit, 1980). When plants have high levels of pectin, the pectin will reduce or eliminate the free water in the interstitial space. This pectin layer is built by Ca, Si, and B. With the right form of silica, a noticeable difference in leaf thickness and cell hardness can usually be noticed inside a week of a foliar application.

OBJECTIVES

- To determine the efficacy of the foliar application of two AECI products (Alexin and Rappid K) with and without the foliar and soil application of two macronutrients (P and K) and several micronutrients (B, Fe, Mo, Mn, Mg, and Zn, Microflex Super) to increase the cold-hardiness of 'Hass' avocado fruit.
- To determine if the inclusion of a Si product (Ecko-sil, DuxAgri product), known to increase cold-hardiness, assists in increasing the cold-hardiness of 'Hass' avocado fruit.
- To determine if the inclusion of seaweed (Foral BMo, DuxAgri product), also known to increase cold-hardiness, assists in increasing the cold-hardiness of 'Hass' avocado fruit.
- To determine the efficacy of additional foliar and soil applications of a product, Microflex Super, which contains a combination of micronutrients B, Fe, Mo, Mn, Mg, and Zn to increase cold-hardiness of 'Hass' avocado fruit.
- To determine if the inclusion of two macronutrients (K and P), reported to TSS, can increase the cold-hardiness of 'Hass' avocado fruit.

MATERIALS AND METHODS

Based on the most important findings of 2021, 2022, and 2023; the research protocols for the 2024 season were identified.

Important findings of 2021

- Alexin effectively increased the TSS of avocado fruit. This most likely illustrates the ability of salicylic acid to increase the TSS in avocado fruit.
- Fruit were harvested after a significant cold event of -1.5 °C and the untreated Count 20 fruit with no visible skin damage, exhibited the highest incidence of internal cold damage (41.8%).
- Alexin (PANAF 5 used as adjuvant) treated Count 20 fruit with no visible orchard cold damage, exhibited no internal pulp orchard cold damage. The positive results warranted further research in 2022.
- The -1.5 °C cold event unfortunately occurred quite late in 2021 and the fruit maturity also advanced quickly during this season.
  - o The fruit with a maturity of 36% dry matter content (DM) was more tolerant against internal pulp orchard damage and the severity of the disorder would likely have been worse if the fruit maturity was 30% DM.
  - o Hypothetically, later fruit sets that are less mature are more prone to develop orchard cold damage.

Important findings of 2022

- The efficacy of Alexin (contains salicylic acid) in increasing TSS of fruit was confirmed in the second year of the study.
- B, Fe, and Si applied as foliar sprays were effectively absorbed into the skin and pulp of 'Hass' avocado fruit.
  - o However, these micronutrients did not increase TSS. As freezing temperatures did not occur in 2022, the efficacy of late season foliar sprays of these nutrients could not be confirmed and so the research needed to be repeated in 2023/24.
- Ca, P, and K did not penetrate the skin and pulp of 'Hass' avocado fruit when applied as foliar sprays.
  - o Tronic, a good penetrator that dissolves the

waxy layers, unfortunately contributed to significant leaf drop and is not an option to be used in avocado orchards.
- o Further research is needed to identify an effective wetter/penetrator to assist in better absorption of these nutrients. Cosmocel is in the process of registering a wetter/penetrator (Inex-A) in South Africa that is used on avocados in Australia. This product was included in the 2023 trials.

To optimise the content of N, P, K, B, Ca, Fe, and Si in the leaves and fruit, soil applications were applied if these nutrients were not within the optimum leaf nutrient norms in 2023. It was therefore important to verify the leaf nutrient status of the identified experimental orchard at the beginning of the trials. N and P are important in ensuring that the TSS of leaves and fruit are high before freeze temperatures are reached. In the case of N, the literature indicated that high N orchards are more tolerant to freeze damage. Increasing the levels of these nutrients with foliar applications, when levels are low or deficient, is difficult.

Important findings of 2023

SAAGA indicated that the trial should be done in Haenertsburg where freeze temperatures are more likely to occur. While sourcing an appropriate orchard, most producers indicated that either sprays of Si or urea were applied as protection. Jannie Lombard indicated that one of their 'Hass' orchards is prone to orchard cold damage. Since no products were applied in this orchard to prevent cold damage, this orchard was deemed suitable for this research. Samples were taken in May 2023 to analyse the leaf nutrient content. The analysis results indicated: N = 2.0%, P = 0.07%, K = 0.39%, B = 20 mg/kg, Ca = 1.2 mg/kg, Fe = 145 mg/kg. The norms for N, P, K, and B were low, and Mn too high, and so it was decided to test the impact of foliar applications in increasing cold-hardiness in 2024 with a new high nitrogen orchard identified. It was anticipated that TSS in this orchard would have increased to a more acceptable level to enhance its

Treatment protocol of 2024

Table 1: Different foliar and soil treatments applied in an attempt to increase the cold-hardiness of 'Hass' avocado fruit in the Haenertsburg area during 2024 are shown

No.	Products and application rates	Adjuvant; Dosages	Timing	Start	End
T1	Untreated control	-	-	-	-
T2[6]	Soil and foliar nutrient treatments only:				
	+ foliar spray: Microflex Super[1] (32 g/100 L)	Inex (50 ml/100 L)	5X 21 days apart	W2 May	W4 Jul
	+ Soil application: Microflex Super (31 kg/ha)	-	2X 8 weeks apart	W2 May	W1 Jul
	+ Soil application: Rappid K[2] (7 L/ha)	-			
T3[6]	Alexin[3] (2 L/ha) + Rappid K (7.5 L/ha)	Inex (50 ml/100 L)	5X 21 days apart	W2 May	W4 Jul
	+ foliar spray: Microflex Super (32 g/100 L)		5X 21 days apart	W2 May	W4 Jul
	+ Soil application: Microflex Super (31 kg/ha)	-	2X 8 weeks apart	W2 May	W1 Jul
	+ Soil application: Rappid K (7 L/ha)	-			W1 Jul
T4[6]	Foliar spray: Alexin (2 L/ha) + Rappid K (7.5 L/ha)	Inex (50 ml/100 L)	5X 21 days apart	W2 May	W4 Jul
T5[6]	Foliar spray: Foral BMo[4] (200 - 300 mL/100 L) alone	Inex (50 ml/100 L)	5X 21 days apart	W2 May	W4 Jul.
T6[6]	Foliar spray: Foral BMo (200 - 300 mL/100 L)	Inex (50 ml/100 L)	5X 21 days apart	W2 May	W4 Jul
	+ foliar spray: Eckosil[4] (50 -130 L/100 L)				
T7[6]	Foliar spray: Eckosil (50 -130 L/100 L) alone	Inex (50 ml/100 L)	5x 21 days apart	W2 May	W4 Jul
T8[6]	Foliar spray: Low biuret urea[5] (2%/ha)	Inex (50 ml/100 L)	5X 21 days apart	W2 May.	W4 Jul.

1. **Microflex Super** contains micronutrients (**B, Mn, Mo, Fe, Zn, Cu, and Mg**) that are linked to cold-hardiness according to literature.
2. **Rappid K** contains P and K that both increase **leaf and fruit TSS** and therefore increase cold-hardiness. Plants can protect themselves against this by storing K and sugar in cells. Both lower the freezing point of the cell sap and act as a natural antifreeze. Soil application of Rappid K to attempt to increase the TSS still needs to be tested.
3. **Alexin and Rappid K** showed promise in the first year of Tzaneen orchard cold project in reducing orchard cold damage. Alexin contains salicylic acid that was effective against freeze damage in several commodities.
4. **Foral BMo** contains **seaweed extract** and **Mo, B, and Zn** that, according to literature, increases cold-hardiness. A few producers in Haenertsburg use a combination of **Foral BMo and Eckosil** (contains Si) to give protection against freeze damage.
5. A few producers in Haenertsburg use **low biuret urea** to give protection against freeze damage.
6. **Naturafend** has been shown to increase cold-hardiness in avocados in Israel. It is, however, currently registered as a fungicide on avocados in South Africa. It contains L-Phenylalanine (an amino acid) that increases inherent cold-hardiness.
7. **KungFu 538 SC** (2.0 L/ha to control INA bacteria that form the nucleus around which ice crystals develop) was applied on W2 May 2024.

inherent capability to resist freeze damage.

Trial foliar applications of Si with Eckosil (an orthosilicate that is applied at a rate of 500 -1 000 ml/100 L from DuxAgri) and EcoKsil (a potassium silicate applied at a rate of 250 ml/100 L from AECI) as well as low biuret urea (used by some Haenertsburg producers to prevent orchard cold damage; applied at a rate of 2 000 g/100 L). The lowest recorded temperatures were between 23-27 July 2023 at 0 °C and 0.5 °C. Thirteen days after these cold days, no cold damaged fruit drop from treated trees was observed and samples of Count 20 fruit did not show any internal orchard cold damage in the untreated control treatment. The trial ended in mid-August 2023 as the lowest temperatures in the weather forecast were between 7 and 10 °C. Samples of fruit and leaves were sent to be analysed to verify the efficacy of nutrient absorption. The inclusion of Inex-A (a penetrator of Cosmocel) as adjuvant resulted in increased absorption of Si (products Eckosil and EcoKsil) and N (low biuret urea) into avocado leaves. It was decided to include Eckosil in the 2024 research trial as it has a neutral pH compared to EcoKsil (pH 12). The lower pH of Eckosil provides easier mixing without compatibility issues with other products in combined foliar treatments.

Foliar applications to increase cold-hardiness 2024

Different foliar and soil treatments were applied in an attempt to increase the cold-hardiness of a high nitrogen 'Hass' orchard in the Haenertsburg area during 2024 (Table 1).

Evaluation

Foliar and soil applications, in an attempt to increase the cold-hardiness of avocado fruit, were applied commencing from the 2nd week of May 2024. A total of 5 foliar applications were done in this trial. The soil applications comprising different macro- and micronutrients, were applied twice (2nd week of May and 1st week of July, Table 1). Unfortunately, the lowest temperatures recorded during July 2024 were 1 °C and 0 °C. Thirteen days after these two cold days, no cold damaged fruit drop was observed and samples of Count 20 fruit did not show any internal orchard cold damage in the untreated control treatment. The trial ended in mid-August 2024 as the lowest forecasted temperatures were between 5 °C and 9 °C. Forty leaves (5th leaf of non-fruit bearing branches) were sampled from each treatment on 28 August 2024, 3 weeks after the last foliar application, and sent for mineral analyses to verify the efficacy of the products in increasing macro- and micronutrient levels in the trees. Unfortunately, the picking team of the producer picked the fruit of the marked trial site a week before fruit samples were due to be sampled and hence fruit mineral analysis could not be done.

DISCUSSION

The selected orchard had a leaf N of 2.4% in May 2021 and 2.2% in 2022. TSS increases at a higher rate in high nitrogen orchards, which partly explains the lower start and end TSS values obtained in avocado fruit in 2022 compared to 2021. Therefore it was important to identify a high nitrogen orchard for trials in 2024. Nutrition management is an important tool to provide frost/freeze protection. Unhealthy and low nitrogen trees are more susceptible to frost damage and fertilization improves tree health. Trees that are not properly fertilized tend to lose their leaves earlier in autumn and bloom earlier in spring, which increases susceptibility to frost damage. From the literature study conducted, important nutrients that assist plants to inherently be more cold hardy are the macronutrients K and P, secondary macronutrients Ca and Mg, and micronutrients Fe, Mn, Zn, Cu, B, Mo, and Si (see introduction for detail). In 2024 a healthy high nitrogen orchard in Haenertsburg was identified and leaf samples were taken of the 8 treatment plots to ensure these nutrients were within the nutritional norms of SAAGA, and that the treatment trees within these plots had comparable leaf nutritional compositions.

1. The TSS and leaf mineral composition at the start of the trial (samples taken on 12 May 2024) (Table 2)

1.1 Leaf TSS

The leaves (the 5th leaf of non-bearing branches) sampled at the start of the trial of the high nitrogen trees of the different treatment sites, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] exhibited similar TSS values of 8.10 °Brix, 8.40 °Brix, 8.40 °Brix, 8.10 °Brix, 8.20 °Brix, 8.20 °Brix, and 8.30 °Brix, respectively.

1.2 Leaf macronutrient content, N, P, and K, and secondary macronutrients Ca and Mg, at the beginning of the trial:

- The leaf nutrient analysis of the high N trees of the different treatment plots [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf N content of 2.57%, 2.54%, 2.52%, 2.55%, 2.53%, 2.56%, 2.6%, and 2.60%, respectively, that were higher than the 2.2 - 2.4% SAAGA norm.
- The leaf nutrient analysis of the high N trees of the different treatment plots [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf P content of 0.11%, 0.11%, 0.12%, 0.11%, 0.12%, 0.11%, 0.12%, and 0.12%, respectively (average = 0.12%), that were at the lower margin of the 0.12 - 0.2% SAAGA norm.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf K content of 0.96%, 0.99%, 0.93%, 0.95%, 0.97%, 0.99%, 0.97%, and 0.91%, respectively (average = 0.96%), that were within the 0.75 - 1.15% SAAGA norm.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf Ca content of 1.10%, 1.11%, 1.12%, 1.10%, 1.12%, 1.10%, 1.11%, and

RESULTS

Table 2: TSS and mineral composition of leaf samples (40 leaves of the 5th leaf of non-bearing branches) that were taken at the start of trial on 12 May 2024 from, a 'Hass' orchard prone to orchard cold damage in Haenertsburg. The SAAGA norms for each mineral at the time of writing, are noted below the heading for each mineral

		TSS	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo	Si
12 May Leaf sap TSS (˚Brix) and mineral composition (% or mg/kg)														
	Treatments	(°Brix)	2.2 - 2.4 (%)	0.12 - 0.2 (%)	0.75 - 1.15 (%)	1.2 - 2.0 (%)	0.5 - 0.6 (%)	75 - 150 (mg/kg)	75 - 250 (mg/kg)	30 - 100 (mg/kg)	5 - 15 (mg/kg)	50-80 (mg/kg)	- (mg/kg)	- mg/kg
T1	**UTC**	**8.10**	**2.57**	**0.11**	**0.96**	**1.10**	**0.53**	**138**	**118.0**	**34**	**8**	**31**	**1.55**	**153.4**
T2	**Nutrients**	**8.40**	**2.54**	**0.11**	**0.99**	**1.11**	**0.56**	**131**	**103.0**	**34**	**9**	**32**	**1.52**	**155.3**
T3	**Alexin + Rappid K + nutrients**	**8.40**	**2.52**	**0.12**	**0.93**	**1.12**	**0.52**	**132**	**109.9**	**35**	**8**	**30**	**1.49**	**153.0**
T4	**Alexin + Rappid K alone**	**8.10**	**2.55**	**0.11**	**0.95**	**1.10**	**0.51**	**130**	**99.3**	**34**	**8**	**31**	**1.54**	**150.7**
T5	**Foral BMo alone**	**8.40**	**2.53**	**0.12**	**0.97**	**1.12**	**0.51**	**132**	**111.0**	**36**	**8**	**33**	**1.48**	**157.8**
T6	**Eckosil alone**	**8.20**	**2.56**	**0.11**	**0.99**	**1.10**	**0.50**	**135**	**101.0**	**36**	**9**	**30**	**1.49**	**160.3**
T7	**Eckosil + Foral BMo**	**8.20**	**2.60**	**0.12**	**0.97**	**1.11**	**0.51**	**133**	**100.0**	**34**	**9**	**31**	**1.55**	**159.7**
T8	**Low biuret urea alone**	**8.30**	**2.60**	**0.12**	**0.91**	**1.10**	**0.51**	**130**	**101.4**	**33**	**8**	**30**	**1.54**	**150.3**
	Average:	8.26	2.56	0.12	0.96	1.11	0.52	133	105.5	35	8	31	1.52	155.1
% difference to the UTC														
T1	**UTC**	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	**Nutrients**	3.7	-1.2	0.0	3.1	0.9	5.7	-5.1	-12.7	0.0	12.5	3.2	-1.9	1.2
T3	**Alexin + Rappid K + nutrients**	3.7	-1.9	9.1	-3.1	1.8	-1.9	-4.3	-6.9	2.9	0.0	-3.2	-3.9	-0.3
T4	**Alexin + Rappid K alone**	0.0	-0.8	0.0	-1.0	0.0	-3.8	-5.8	-15.8	0.0	0.0	0.0	-0.6	-1.8
T5	**Foral BMo alone**	3.7	-1.6	9.1	1.0	1.8	-3.8	-4.3	-5.9	5.9	0.0	6.5	-4.5	2.9
T6	**Eckosil alone**	1.2	-0.4	0.0	3.1	0.0	-5.7	-2.2	-14.4	5.9	12.5	-3.2	-3.9	4.5
T7	**Eckosil + Foral BMo**	1.2	1.2	9.1	1.0	0.9	-3.8	-3.6	-15.3	0.0	12.5	0.0	0.0	4.1
T8	**Low biuret urea alone**	2.5	1.2	9.1	-5.2	0.0	-3.8	-5.8	-14.1	-2.9	0.0	-3.2	-0.6	-2.1

1.10%, respectively (average = 1.11%), that were within but at the lower margin of the SAAGA norm of 1.2 - 2%.

- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar Mg content of 0.53%, 0.56%, 0.52%, 0.51%, 0.51%, 0.50%, 0.51%, and 0.51%, respectively (average = 0.52%), that were within the 0.5 - 0.6% SAAGA norm.

1.3 Leaf micronutrient content: Fe, Mn, Zn, Cu, B, Mo, and Si at the beginning of the trial:

- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf Fe contents of 138 mg/kg, 131 mg/kg, 132 mg/kg, 130 mg/kg, 132 mg/kg, 135 mg/kg, 133 mg/kg, and 130 mg/kg, respectively (average = 133 mg/kg), that were within the 75 - 150 mg/kg SAAGA norm.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed leaf Mn contents of 118 mg/kg, 103 mg/kg, 109 mg/kg, 99.3 mg/kg, 111 mg/kg, 101 mg/kg, 100.0 mg/kg, and 101.4 mg/kg, respectively (average = 105.5 mg/kg), that were within the 75 - 150 mg/kg SAAGA norm, but with more variation between treatment plots.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf Zn contents of 34 mg/kg, 34 mg/kg, 35 mg/kg, 34 mg/kg, 36 mg/kg, 36 mg/kg, 34 mg/kg, and 33 mg/kg, respectively (average = 35 mg/kg), that were within, but closer to the lower margin, of the 30 - 100 mg/kg SAAGA norm.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf Cu contents of 8 mg/kg, 9 mg/kg, 8 mg/kg, 8 mg/kg, 8 mg/kg, 9 mg/kg, 9 mg/kg, and 8 mg/kg, respectively (average = 8 mg/kg), that were within, but closer to the lower margin of the 5 - 15 mg/kg SAAGA norm.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf B contents of 31 mg/kg, 32 mg/kg, 30 mg/kg, 31 mg/kg, 33 mg/kg, 30 mg/kg, 31 mg/kg, and 30 mg/kg, respectively (average = 31 mg/kg), that were lower than the 50-80 mg/kg SAAGA norm.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf Mo contents of 1.55 mg/kg, 1.52 mg/kg, 1.49 mg/kg, 1.54 mg/kg, 1.48 mg/kg, 1.49 mg/kg, 1.55 mg/kg, and 1.54 mg/kg, respectively (average = 1.52 mg/kg). There is, at the time of writing, no SAAGA norm for Mo.
- The leaf nutrient analysis of the high N trees of the different treatment plots, [T1], [T2], [T3], [T4], [T5], [T6], [T7], and [T8] showed similar leaf Si contents of 153.4 mg/kg, 155.3 mg/kg, 153.0 mg/kg, 150.7 mg/kg, 157.8 mg/kg, 160.3 mg/kg, 159.7 mg/kg, and 150.25 mg/kg, respectively (average = 155.1 mg/kg). There is, at the time of writing, no SAAGA norm for Si.

2. Leaf TSS and nutritional composition at the end of the trial (28 August 2024, Table 3)

2.1 Treatments towards increased cold-hardiness

2.1.1 Foliar applications of Alexin + Rappid K

Fruit harvested after a significant cold event of -1.5 °C in the 2021 season at Count 20 had no visible skin damage, and exhibited the highest incidence of internal cold damage at 41.8%. In 2021 the three foliar applications of Alexin + Rappid K increased leaf and fruit TSS. Count 20 fruit with no visible orchard cold damage from this treatment, exhibited no internal pulp orchard cold damage. However, in 2022 P and K did not penetrate the skin and pulp of 'Hass' avocado fruit when applied as foliar sprays (Rappid K). This illustrates the difficulty these macronutrients have in penetrating avocado leaf and fruit skins. K as well as P are important to increase cold-hardiness and preharvest soil applications must therefore be in place to ensure optimum levels in leaves and fruit of trees in orchards exposed to freezing temperatures.

Therefore, it was decided to include Alexin + Rappid K foliar applications with (T3) and without (T4) Rappid K soil applications as treatments, in an attempt to obtain increased effectiveness of mineral uptake. Additionally, foliar and soil applications of Microflex Super, that contains micronutrients (B, Mn, Mo, Fe, Zn, Cu, and Mg) linked to cold-hardiness according to the literature, were included with T3 and left out with T2.

The following results were obtained (Table 3):

- Five foliar applications of Alexin + Rappid K [T4] resulted in 13.1% higher leaf TSS (13.8 °Brix) compared to the untreated control (UTC) [T1].
  - o This confirms the efficacy of the salicylic acid in Alexin to increase TSS as stated in literature.
  - o The foliar application of Rappid K did not increase the leaf P and K content [T4] as similar values were obtained to the untreated control [T1].
- Five foliar applications of Alexin + Rappid K, in combination with two soil applications of Rappid K (contains K and P) and five foliar applications of Microflex Super (contains B, Mn, Mo, Fe, Zn, Cu, and Mg, [T3]), resulted in:
  - o The highest TSS value of 14.4 °Brix (a percentage increase of 18.03) compared to all other treatments. The UTC [T1] had a leaf TSS of only 12.20 °Brix. Higher leaf K and salicylic acid treatments are known to increase TSS, provided there is a synergistic effect to obtain the highest TSS. Combined Rappid K soil applications and Alexin foliar applications increased the K con-

Table 3: TSS and mineral composition of leaf samples (40 leaves of the 5th leaf of non-bearing branches) that were taken on 28 August 2024 (3 weeks after the last foliar application) from a high nitrogen 'Hass' orchard prone to orchard cold damage in Haenertsburg, to determine the efficacy of different treatments of soil and foliar applications towards improving cold-hardiness. The SAAGA norm for each mineral is noted below the heading for each mineral

28 August Leaf sap TSS (°Brix) and nutritional composition (% or mg/kg)														
Treatments		TSS (°Brix)	N 2.2 - 2.4 (%)	P 0.12 - 0.2 (%)	K 0.75 - 1.15 (%)	Ca 1.2 - 2.0 (%)	Mg 0.5 - 0.6 (%)	Fe 75 - 150 (mg/kg)	Mn 75 - 250 (mg/kg)	Zn 30 - 100 (mg/kg)	Cu 5 - 15 (mg/kg)	B 50-80 (mg/kg)	Mo - (mg/kg)	Si - mg/kg
T1	**UTC**	12.20	2.5	0.12	0.94	1.12	0.50	124	122.2	34	9	31	1.52	148.6
T2	**Nutrients**	**13.80**	2.52	**0.14**	**1.15**	1.11	**0.55**	**148**	125.3	**40**	**12**	**38**	**2.45**	152.4
T3	**Alexin + Rappid K + nutrients**	**14.40**	2.53	**0.15**	**1.14**	1.12	**0.56**	**145**	128.2	**41**	**12**	**37**	**2.26**	139.0
T4	**Alexin + Rappid K alone**	**13.80**	2.52	0.11	0.90	1.10	0.5	128	96.1	35	11	32	1.56	151.0
T5	**Foral BMo alone**	**13.70**	2.56	0.12	0.93	1.11	**0.56**	131	108.8	**38**	**11**	**35**	**1.98**	155.6
T6	**Eckosil alone**	**13.78**	2.53	0.12	0.91	1.12	0.51	121	112.8	35	**12**	31	1.45	**211.6**
T7	**Eckosil + Foral BMo**	**13.90**	2.56	0.12	0.9	1.12	**0.55**	126	95.2	**39**	**11**	**34**	**2.24**	**218.6**
T8	**Low biuret urea alone**	**13.90**	**2.77**	0.11	0.91	1.11	0.5	124	122.1	35	**12**	**30**	1.55	153.0
% /INCREASE														
T1	**UTC**	-	-	-	-	-	-	-	-	-	-	-	-	-
T2	**Nutrients**	**13.11**	0.80	**16.67**	**22.34**	-0.89	**10.00**	**19.35**	2.50	**17.65**	**33.33**	**22.58**	**61.18**	2.52
T3	**Alexin + Rappid K + nutrients**	**18.03**	1.20	**25.00**	**21.28**	0.00	**12.00**	**16.94**	4.91	**20.59**	**33.33**	**19.35**	**48.68**	-6.45
T4	**Alexin + Rappid K alone**	**13.11**	0.80	-8.33	-4.26	-1.79	0.00	3.23	-21.36	2.94	**22.22**	3.23	2.63	1.60
T5	**Foral BMo alone**	**12.30**	2.40	0.00	-1.06	-0.89	**12.00**	5.65	-10.97	**11.76**	**22.22**	**12.90**	**30.26**	4.69
T6	**Eckosil alone**	**12.95**	1.20	0.00	-3.19	0.00	2.00	-2.42	-7.69	2.94	**33.33**	0.00	-4.61	**42.36**
T7	**Eckosil + Foral BMo**	**13.93**	2.40	0.00	-4.26	0.00	**10.00**	1.61	-22.09	**14.71**	**22.22**	**9.68**	**47.37**	**47.11**
T8	**Low biuret urea alone**	**13.93**	**10.80**	-8.33	-3.19	-0.89	0.00	0.00	-0.08	2.94	**33.33**	-3.23	1.97	2.92

tent and salicylic acid, resulting in higher TSS.

2.1.2 2 soil applications of Rappid K (contains P and K) in an attempt to increase TSS

- Changes in the leaf K and P content as a result of the two soil applications of Rappid K ([T2] and [T3]) were as follows:
  - o These two treatments [T2] and [T3] marginally increased leaf P content to 0.14% and 0.15%, respectively (increases of 16.67% and 25%, respectively) compared to the UTC [T1] with a value of 0.12%.
  - o These soil treatments [T2] and [T3] increased leaf K content to values of 1.15% and 1.14%, respectively (increases of 22.34% and 21.38%, respectively) compared to the untreated control [T1] with a value of 0.94%.

2.1.3 2 soil applications and 6 foliar applications of Microflex Super (contains B, Fe, Mo, Mn, Mg, and Zn) in an attempt to increase the content of these micronutrients.

- Changes in the leaf mineral content after 2 soil applications and 6 3-weekly foliar applications of Microflex Super (T2 and T3):
  - o Increased leaf Mg content to values of 0.55% [T2] and 0.56% [T3] compared to the UTC [T1] which had a lower value of 0.50% (increases of 10% and 12%, respectively).
  - o Increased leaf Fe content with values of 148 mg/kg [T2] and 145 mg/kg [T3], compared to the UTC with a lower value of 124 mg/kg (percentage increases of 19.35 and 16.94, respectively).
  - o Showed a lot of variation in leaf Mn content between different treatment plots with values 125.2 mg/kg [T2] and 128.2 mg/kg [T3] that were slightly higher than the UTC [T1] (122.2 mg/kg).
  - o Showed an increase in leaf Zn content with values of 40 mg/kg [T2] and 41 mg/kg [T3], compared to the UTC [T1] (34 mg/kg) (percentage increases of 17.65 and 20.59, respectively).
  - o Showed an increase in leaf Cu content with values between 11 mg/kg and 12 mg/kg for all treatments ([T2], [T3], [T4], [T5], [T6], [T7], and [T8]) compared to the UTC (9 mg/kg). All these treatments received one foliar spray of KungFu 538 SC (2.0 L/ha to control INA bacteria that form the nucleus around which ice crystals develop) during W2 May 2024.
  - o Showed an increase in leaf B content with values 38 mg/kg [T2] and 37 mg/kg [T3], compared to the UTC (21 mg/kg) (percentage increases of 22.58 and 19.35, respectively).
  - o Showed an increase in leaf Mo content with values 2.45 mg/kg [T2] and 2.26 mg/kg [T3], compared to the UTC [1.52 mg/kg] (percentage increases of 61.18 and 48.68, respectively).

2.1.4 Foliar application of Foral BMo and Eckosil (DuxAgri products).

Foral BMo is a highly concentrated seaweed extract from *Ascophyllum nodosum* from the cold waters of the Northern Seas of Europe. It is characterised by an excellent bioactivity and nourishing action, and is particularly suited to promote all physiological processes related to the yield quality and quantity, stimulates cell multiplication, activates growth processes, regulates the transport of nutrients, and promotes the accumulation of sugars. It contains over 60 micronutrients, plant natural hormones (auxins, gibberellins, cytokinin), vitamins, enzymes, peptides, free amino acids, carbohydrates, and phytochromatic substances, with high efficiency of the biostimulant components which can be used quickly by plants after a foliar or root application.

Si has long been known to increase freeze resistance. By its own nature Eckosil (a DuxAgri product that contains Si and SiO_2) can absorb surface moisture from plants; increasing a plant's resistance to various abiotic stress such as high and low temperatures, drought, wind, and high concentrations of harmful salts. In order to prevent freezing inside the plant, the water in the intercellular space needs to be reduced. When plants have high levels of pectin, the pectin will reduce or eliminate the free water in the intercellular space. This pectin layer is built by calcium, silica, and boron. By applying the right form of silica, a noticeable difference in leaf thickness and cell hardness can usually be noticed within a week. Several studies have shown that Si ameliorates the stress effects on photosynthesis by protecting photosynthetic machinery and its function, leading to increased photosynthesis and carbohydrate levels, which in turn leads to increased TSS levels (Ullua *et al*., 2021).

In Haenertsburg some producers use foliar sprays with a combination of Foral BMo and Eckosil from May onwards on a three-weekly basis. It was decided to include treatments of these products each on its own (T5 and T6) and a combination of Foral BMo and Eckosil (T7).

- 5 foliar applications of Foral BMo [T5] (contains K, B, Mo, and Zn) resulted in (Table 3):
  - o Increased leaf TSS (13.7 °Brix) [T5] compared to the UTC (12.2 °Brix) [T1] (increase = 12.30%). The known increased photosynthetic output induced with seaweed extract treatments will increase the TSS in leaves. The positive results show effective absorption of this product in 'Hass' avocado leaves.
  - o Increased leaf B content (35 mg/kg) [T5] compared to the UTC (31 mg/kg) [T1] (increase = 12.9%). This is still lower that the lower margin of the norm (50 mg/kg).
  - o Increased leaf Mo (1.98 mg/kg) [T5], compared to the UTC (1.52 mg/kg) [T1] (increase = 30.26%).
  - o Increased leaf Zn (38 mg/kg) [T5], compared to the UTC (34 mg/kg) [T1] (increase = 11.74%).
  - o Increased leaf Mg (0.56 mg/kg) [T7], when compared to the UTC (0.50 mg/kg) [T1] (increase = 12%). Literature indicates that seaweed can lead to increased absorption and translocation of nutrients. It is unclear why only

Mg was affected by this treatment.
- o No increase in leaf K content [T7] compared to the UTC [T1]. This illustrates the difficulty this macronutrient has in penetrating an avocado leaf, also found with the Rappid K foliar treatment.

- 5 foliar applications of EcoKsil [T6] (contains Si and SiO_2) resulted in:
  - o Increased leaf TSS (13.78 °Brix) [T6] compared to the UTC (12.2 °Brix) [T1]. The known increased photosynthetic output and carbohydrate levels associated with foliar applications of silica, lead to increased TSS in leaves.
  - o Increased leaf Si (211.6 mg/kg) [T6], compared to the UTC (148.6 mg/kg) (percentage increase = 42.36). The positive results show effective absorption of this product containing Si into avocado leaves, as was also found in 2023.

- 5 foliar applications of the combination of EcoKsil (contains Si and SiO_2) and Foral BMo (contains K, B, Mo, and Zn) [T7] resulted in:
  - o Increased leaf TSS (13.90 °Brix) [T6] compared to the UTC (12.2 °Brix) [T1].
  - o Increased leaf Si content (218.6 mg/kg) [T7], compared to the UTC (148.6 mg/kg) (increase = 47.11%).
  - o Increased leaf B content (34 mg/kg) [T7], compared to the UTC (31 mg/kg) (increase = 9.68%). This is still lower than the B norm at the time of writing for avocado leaves (40-50 mg/kg).
  - o Increased leaf Mo (2.24 mg/kg) [T7], compared to the UTC (1.52 mg/kg) [T1] (increase = 47.37%).
  - o Increased leaf Zn (39 mg/kg) [T5], compared to the UTC (34 mg/kg) [T1] (increase = 14.71%).
  - o Increased leaf Mg (0.55 mg/kg) [T5], compared to the UTC (0.50 mg/kg) (increase = 10%).
  - o There was no increase in leaf K content [T5] compared to the UTC [T1]. This illustrates the difficulty this macronutrient has in penetrating avocado leaves, a characteristic shared with the Rappid K foliar treatment.

2.1.5 Foliar application of low biuret urea

Some producers in Haenertsburg use a foliar application of 1% low biuret urea as protection against orchard cold damage in orchards prone to freeze damage. This commercial practice was included as a treatment to test its efficacy compared to the other treatments in the current study. However, according to literature, potted avocado plants treated with 2% low biuret urea, gradually cooled, and exposed to -2 °C for 4 h, were significantly more hardy than control plants (Zilcah *et al*., 1996). It was decided to use the 2% dosage in the present trial.

Low biuret urea is a non-organic salty form of nitrogen used for protection against freezing temperatures in plant production and is associated with increased TSS. This method is similar to salting a road to keep it from freezing, by lowering the freezing point.

- 5 foliar applications of low biuret urea [T8] that contain a salty form of N, resulted in:
  - o An increased leaf TSS of 13.90 °Brix [T6] compared to the 12.2 °Brix in the UTC [T1].
  - o An increase in leaf N content, with a value of 2.77 [T8], compared to 34 mg/kg in the UTC [T1] (increase = 10.8%).

CONCLUSIONS

The aim in 2022 and 2024 to increase the TSS by applying five salicylic acid foliar sprays earlier in the year instead of three sprays, was successful. This confirms that application of salicylic acid can increase the TSS. However, the Alexin sprays in 2021 were associated with a leaf TSS of 15.5 °Brix and in 2024 with leaf TSS of 13.8 and 14.4 °Brix, at similar fruit maturity of 64% moisture content (36% DM). Although the 2021 leaf N was lower at 2.4% compared to 2.5%, the leaf TSS was higher compared to the Haenertsburg 'Hass' orchard. This might be due to the colder climate in Haenertsburg. This indicates that the TSS at the start of the trial in 2021 was already higher. Furthermore, it suggests that the Alexin sprays might need to start a month earlier in Haenertsburg than what was tested in this trial.

The aim in 2024 to apply two soil applications of Rappid K (which contains the 2 macronutrients P and K), two soil applications of Microflex Super (contains the micronutrients B, Fe, Mo, Mn, Mg, and Zn) and 5 foliar applications of Microflex Super, in an attempt to increase the cold-hardiness of 'Hass' avocados, was successful. The addition of these nutrients as soil and foliar applications led to increased leaf TSS with a value of 13.8 °Brix compared to the UTC (12.2 °Brix). Furthermore, the addition of these nutrients as soil and foliar applications, in combination with 5 salicylic acid foliar applications increased the TSS to 14.40 °Brix, compared to the five foliar salicylic acid applications alone (13.8 °Brix). As was found in 2022, the foliar application of Rappid K did not increase the leaf K and P content. This confirms the difficulty these nutrients have in penetrating the avocado waxy leaf skin.

Soil and foliar applications of Microflex Super led to effective increases in leaf Mg, Fe, Zn, B, and Mo. Mn, however, showed a lot of variation with proof of increase.

Five foliar applications of Foral BMo, that contains seaweed extract and additional B, Zn, KO_2, and Mo, effectively increased leaf TSS to 13.70 °Brix and leaf B, Zn, and Mo content. As with Rappid K, Foral BMo did not increase leaf K content, despite containing KO_2. Five foliar applications of Eckosil, both when applied alone and in combination with Foral BMo, led to increased leaf TSS (13.78 °Brix and 13.90 °Brix, respectively) compared to the UTC (12.2 °Brix), and increased leaf Si content (211.6 mg/kg and 218 mg/kg, respectively) compared to the UTC (148.6 mg/kg).

Five foliar applications of low biuret urea showed an increase in TSS with a value of 13.9 °Brix, compared to the 12.20 °Brix of the UTC.

Nutrition management is an important tool to provide frost/freeze protection. Unhealthy and low nitrogen trees are more susceptible to frost damage, and good fertilization improves tree health. This suggests that all factors that influence fruit TSS and maturity need to be managed throughout the season to raise the TSS from early in the season to the maximum and then to add salicylic acid sprays 1.5-2 months prior to the expected freeze temperatures to increase cold-hardiness further. It is recommended that nutrition management of orchards prone to freeze damage should focus on increasing the N to 2.5-2.6%, higher than the norm of 2.2-2.4%. K and P, which are also important for increasing cold-hardiness, should be increased to the higher margin of their respective norms. Secondary macronutrients Ca and Mg and micronutrients Fe, Mn, Zn, Cu, B, and Mo, which play an important role for a tree to obtain optimal cold-hardiness, should all be within the leaf nutrient norm and preferably near the upper margin of their respective leaf nutrient norms. Si plays an important role as it promotes movement of most other nutrients from the soil into the roots. Soil treatments in small amounts throughout the season can make a big difference in the leaf nutritional composition. In short, these orchards should be managed from early in the season with the goal to increase fruit maturation rate.

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