THE EFFECT OF COATINGS COMBINED WITH CONTROLLED ATMOSPHERE AND CONTROLLED ATMOSPHERE + 1-MCP TO RETAIN FRUIT FIRMNESS AND QUALITY DURING EXTENDED SEA FREIGHT EXPORTS

D Lemmer, HW Viljoen and D Viljoen

ExperiCo, Agri-Research Solutions
Idas Valley 7609, Stellenbosch SOUTH AFRICA

Corresponding authors: danie@experico.co.za • handre@experico.co.za • daniel@experico.co.za

ABSTRACT

The sea freight export voyage of exported South African 'Hass' fruit to export markets can take 6 to 10 weeks. In some cases, this long export period can even be further extended due to delays at the South African ports. SAAGA requested ExperiCo to verify the effect of coatings as an additional postharvest treatment with controlled atmosphere, towards improving shelf life and reducing loss in firmness when fruit are subjected to such extended storage periods. The aim of this study was to verify the effect of coatings as an additional postharvest treatment with controlled atmosphere or a combination of controlled atmosphere and SmartFresh™, towards improving shelf life and reducing loss in firmness when 'Hass' fruit are subjected to extended sea freight voyage periods (6-10 weeks). The seven different coatings applied on fruit stored at CA + 1-MCP obtained significantly higher days-to-ripen (DTR) values (14.8-12.9 days), compared to the CA + 1-MCP treatment without a coating (11.8 days), and storage under CA without coatings (9 days). This proves the efficacy of the CA + 1-MCP to lengthen the number of days to ripen, which is linked to improved shelf life. In an attempt to reduce the increased incidence of pathological disorders associated with extended storage, Thiabendazole (TBZ) was added to each of the seven coatings which led to significantly lower pathological disorders compared to coating treatments without TBZ. The two best coating treatments under storage at CA + 1-MCP with TBZ added in the coatings, were Nature-Cote™ and Vegan Wax which obtained the least colouring and showed the lowest loss of firmness. A third option would be CA + 1-MCP which resulted in no colouring after 4-7 weeks of storage and in 65% coloured fruit per carton after 10 weeks storage, with only low intensity of colouring present, and maintained firmness of all fruit. Pathological disorders proved to be the most limiting factor in maintaining optimum fruit quality during extended storage. A factor which plays a role towards obtaining acceptable fruit quality during extended storage, is the maturity which should be between 68-70% moisture content (MC, 30-32% dry matter content). This is required in order to limit the incidence of pathological disorders to acceptable levels and maintain quality after 2-3 months cold storage. Furthermore, timely optimised pre-harvest fungicide sprays should be in place as postharvest treatments have poor efficacy in controlling pathological disorders in orchards where fruit are already highly susceptible to developing such disorders.

INTRODUCTION

The sea freight export voyage of exported South African 'Hass' fruit to export markets can take 6 to 10 weeks. In some cases, this long export period can even be further extended due to delays at ports. SAAGA requested ExperiCo to verify the effect of coatings as an additional postharvest treatment with controlled atmosphere, towards improving shelf life and reducing loss in firmness during these extended storage periods.

The search for methods to delay both deterioration and fruit diseases is of great interest to all, both

producers and distributors of fresh fruits. Traditionally, edible coatings (ECs) have been used as a strategy to reduce the use of other types of chemical or synthetic substances that could have harmful effects on the health of consumers. Edible and wax coatings can help extend the shelf life of freshly cut fruits by several mechanisms: as a barrier to reduce moisture and solute migration, gas exchange, respiration, and oxidative reaction rates (Shami *et al*., 2019). For protection, biopolymers can reduce mechanical damage, light exposure, and the presence of contaminants. The great potential of edible coatings to be amended and act as carriers of antimicrobial compounds such, as essential oils, 'generally regarded as safe' (GRAS) compounds, and even microbial antagonists, can help to extend the shelf life of fruits and reduce the risk of a pathogen's establishment on their surfaces (such amended coatings are known as active coatings). Another interesting mechanism is related to biopolymers with antimicrobial activity such as chitosan. This biopolymer also has the capacity to act as an elicitor and activate enzyme production related to the mechanism of the fruit's defence, thereby reducing fruit spoilage (Gutiérrez-Martínez *et al*., 2014). In addition to the advantage that its application represents, edible coatings can be applied with different methods which range from immersion and aspersion to more sophisticated methods such as spreading/brushing (Ncama *et al*., 2018).

Modifying the composition of edible coatings or wax coatings with additional ingredients such as fungicides or potential "green" approach natural antimicrobial agents, antagonistic microorganisms, and film structure reinforcements may improve the quality of avocado fruit.

OBJECTIVE

To verify the effect of coatings as an additional postharvest treatment with controlled atmosphere or a combination of controlled atmosphere and SmartFresh™, towards maintaining quality and reducing the loss of firmness during extended sea freight voyage periods (6-10 weeks) of South African 'Hass' fruit to export markets.

DESIGN

In 2005, two long term storage trials were performed, one with 'Fuerte' (moisture content 68%, dry matter content/DM 32%) and the other with 'Hass' (moisture content 68%, DM 32%) (Lemmer *et al*., 2006). The fruit were treated with Prochloraz (250 mL/100 L) and waxed. After this, SmartFresh™ (1-MCP) was applied at the commercial dosage and at two higher rates. The fruit were then stored under controlled atmosphere (CA) conditions (6% CO_2 and 4% O_2) and under regular atmosphere. From the results it appeared realistic to store good quality 'Fuerte' avocado fruit for at least 2 months and 'Hass' 2-3 months, when combining SmartFresh™ and CA without any serious physiological and pathological disorders developing.

Taking these results into consideration, CA and 1-MCP (SmartFresh™) would be a good starting point to control quality problems with the potential; long export period to export markets. Although the fruit was waxed in the 2005 studies, the addition of different coatings to aid towards improved quality was not yet properly tested. The number of active coatings which already include fungicides is limited. However, fungicides can be added to the coating as was done by some packhouses in the past. Currently ICA Thiabendazole 500 SC is registered so as to be applied in coatings and can thus be included in the trial to give additional protection against the development of pathological disorders which are expected to increase during extended storage. The use of ZnO in coatings is quite prominent in recent literature as it inhibits fungal growth, increases the coating's strength, and provides better modified atmosphere properties.

DECCO and AgroFresh South Africa were approached as they have registered coatings for avocado fruit. Edible coatings mostly prevent moisture loss. They also have a modified atmosphere effect which is needed to change the respiration rate of the fruit to consequently inhibit premature ripening under periods of extended cold storage. DECCO indicated their wax coatings are the best option to optimally create a modified atmosphere. Currently they are busy with registration of two active edible coatings with two new fungicides. The EU market has a concern regarding the use of Avoshine carnauba wax which contains amines. DECCO indicated their carnauba wax coatings do not include amines and can be accepted in the EU.

Seven coatings available in South Africa were included in the trial:

❒ **Two DECCO products**

Vegan Longlife™

A quick dry shellac free, vegan-approved carnauba-based (E-903) coating for the use in citrus.

- Quick dry formulation
- Protects against moisture loss
- Long lasting shine
- Suitable for long storage periods
- Protection against chilling injury.

NaturCover Conservation Extra

A coating agent based on edible additives, generally allowed for postharvest treatment of pome fruit and other fruit.

- Slows down metabolic activity
- Reduces weight loss
- Has a natural antioxidant effect
- Allowed by the EU regulatory authorities.

❒ **Two AGROFRESH products**

Teycer™ Originals Prime 18

Improves fruit preservation, provides shine and protection, and reduces weight loss.

- Available in different concentrations
- It contains shellac and polyethylene
- It provides moisture and atmospheric protection.

VitaFresh™ Botanicals - Life 18

Organic postharvest edible coating for tropicals. VitaFresh™ Botanicals - Life Select helps enhance

freshness, resulting in better firmness, weight loss control and extending the fruit shelf life by 2-4 days. With versatile use, the application can be adapted to fit process and preferences, effective in preserving freshness before and after ripening. This solution offers uniform coverage, a light natural shine, reducing transpiration, and respiration. VitaFresh™ Botanicals - Life 18 maintains the natural appearance of fruits, increasing freshness, avoiding weight loss due to dehydration, and delaying the ageing of avocados, citrus, apples, papayas, and mangoes.

Extends shelf life in ready to eat and ready to buy stages:

- 50% waste reduction
- Better overall appearance
- Organically certified by CAAE in Europe.

❒ **Two JBT Corporation products**
(Cape Town, South Africa)

Nature-Cote™ Avocado

This edible coating maintains weight and enhances appearance while providing plant-based surface protection. It enhances the avocado's natural ability to lock in moisture and keep in freshness. This sustainable product is made from naturally-derived food ingredients making it an excellent choice for global use.

- Excellent in dehydration control

Table 1: Research protocol which included the 7 different coatings applied within 24 hours after harvest, stored under controlled atmosphere (CA, (6% CO_2:4% O_2), T1A, T2A, T3A, T4A, T5A, T6A, T7A, T8A) or as a combination of CA + 1-MCP (300 ppb, SmartFresh™ applied in the packhouse directly after the coating application, T1B, T2B, T3B, T4B, T5B, T6B, T7B, T8B). Two control treatments with no coating applied were stored under CA and CA + 1-MCP (T1A, T1B). Additional treatments where fungicides were applied in the coatings for the CA + 1-MCP storage treatment only, included two DECCO "green" fungicides (CEV and UPL-1, T2B1 and T2B2, respectively, that were only applied in the two DECCO coatings). TBZ was applied in all the coating products as a third additional treatment (T2B3, T3B3, T4B3, T5B3, T6B3, T7B3, T8B3)

With and without Coating		Storage	NO of Cartons	kg Fruit		Coating dosage		ml Fungicide into coating		
						L/Ton	(ml/kg)	yes/no	fungicide	1.4L/ton
no coating	NA	CA	12	48		NA	NA	NA	NA	NA
		Ca + 1-MCP	12	48						
DECCO	Vegan Longlife™	CA	12	48	96	1,4	134,4	no	-	-
		Ca + 1-MCP	12	48						
DECCO	Vegan Longlife™	Ca + 1-MCP	12	48		1,4	67,2	Yes	CEV	2,5
			12	48			67,2	Yes	UPL-1	1,21
DECCO	Vegan Longlife™	Ca + 1-MCP	12	48		1,4	67,2	Yes	TBZ	0,188
DECCO	NaturCover Avo.	CA	12	48	96	1,4	134,4	no	-	-
		Ca + 1-MCP	12	48						
DECCO	NaturCover Avo.	Ca + 1-MCP	12	48		1,4	67,2	Yes	CEV	2,5
			12	48			67,2	Yes	UPL-1	1,21
DECCO	NaturCover Avo	Ca + 1-MCP	12	48		1,4	67,2	Yes	TBZ	0,188
AgroFresh	Teycer™ Originals	CA	12	48	96	1,4	134,4	no	-	-
		Ca + 1-MCP	12	48						
AgroFresh	Teycer™ Originals	Ca + 1-MCP	12	48		1,4	67,2	Yes	TBZ	0,188
AgroFresh	VitaFresh™ Bot.	CA	12	48	96	1,4	134,4	no	-	-
		Ca + 1-MCP	12	48						
AgroFresh	VitaFresh™ Bot.	Ca + 1-MCP	12	48		1,4	67,2	Yes	TBZ	0,188
JBT	Nature-Cote™	CA	12	48	96	1,4	134,4	no	-	-
		Ca + 1-MCP	12	48						
JBT	Nature-Cote™	Ca + 1-MCP	12	48		1,4	67,2	Yes	TBZ	0,188
JBT	Vegan Wax	CA	12	48	96	1,4	134,4	no	-	-
		Ca + 1-MCP	12	48						
JBT	Vegan Wax	Ca + 1-MCP	12	48		1,4	67,2	Yes	TBZ	0,188
Apeel Sc.	Apeel	CA	12	48	96	1,4	144	no	-	-
		Ca + 1-MCP	12	48						
Apeel Sc.	Apeel	Ca + 1-MCP	12	48		1,5	72	Yes	TBZ	0,188

No coating applied **Coating alone** **Coating + green fungicide** **Coating + TBZ**

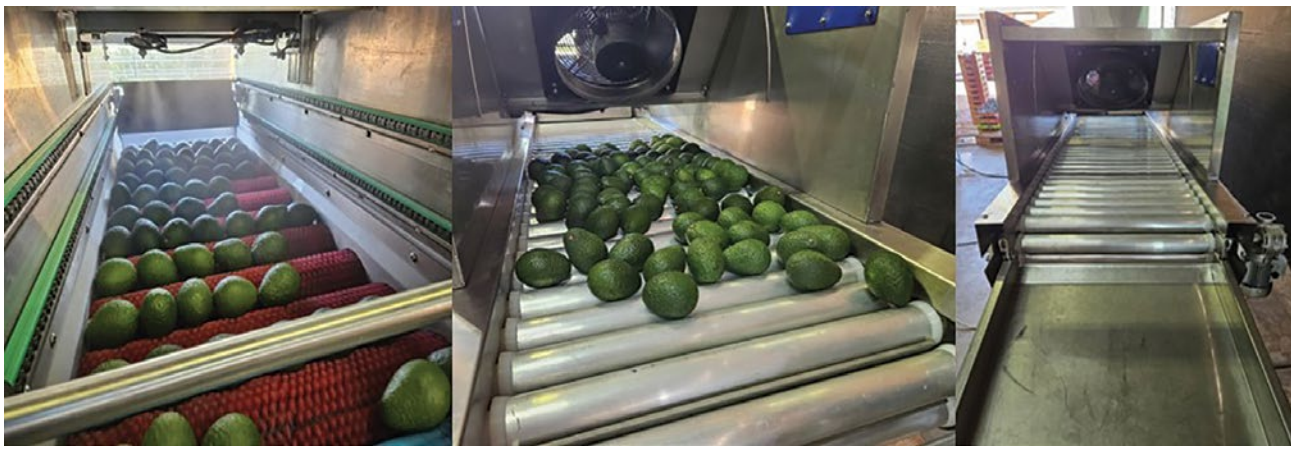

Figure 1: Coatings were applied with a custom-made coating machine designed for research purposes, transported from Stellenbosch (ExperiCo) to Limpopo to conduct the trial. This fully automated coating machine consists of a set of 13 rotating brushes (with speed setting) ensuring even distribution on the fruit surface, on the coating bed with 4 overhead atomizer spray nozzles within a stainless-steel cover to spray the coating/wax solutions on the passing fruit, which deliver evenly coated fruit onto a rotating roller belt with 2 overhead fans to dry the fruit before being packed in 4 kg cartons. Care was taken to load the brushes with the relevant coating solution before the fruit were introduced onto the coating bed to simulate optimum commercial practices.

- Does not interfere with natural ripening or preconditioning
- Reduces incidence of grey pulp
- Minimises shrinkage appearance.

Vegan Wax 196 (E-903)

- It is a quick-dry, vegan-approved carnauba-based (E-903) coating that includes shellac that is approved in the EU. Shellac is approved for use as a surface treatment for certain entire fruits, namely citrus, melons, apples, pears, peaches, pineapples, pomegranates, mangoes, avocados, and papayas and as a glazing agent on nuts [EU 1147/2012].

❒ **One APEEL SCIENCES product**

(Goleta, California)

Apeel is made of mono- and diglycerides, which are naturally-occurring in all fruits and vegetables. This plant-based coating keeps avocados at that perfect ripeness for 2-3 days longer.

- Apeel-Protected Avocados have a longer window of ripeness
- Avocados protected by Apeel keep moisture in and oxygen out, slowing down the respiration and associated oxidation, maintaining the perfect firmness and creaminess.

Treatment protocol

After discussions with DECCO, AgroFresh, JBT Corporation, and Apeel Sciences, seven coatings (described above) were identified to include in the project (Table 1):

- These 7 coatings were applied to fruit stored under controlled atmosphere only (CA: 6% CO_2, 4% O_2, T2A, T3A, T4A, T5A, T6A, T7A, T8A) and as a combination of CA + 1-MCP (300 ppb, SmartFresh™ applied in the packhouse directly after the coating application, T2B, T3B, T4B, T5B, T6B, T7B, T8B).
- Two control treatments with no coating applied were stored under CA and CA + 1-MCP (T1A and T1B respectively).

Modifying the composition of edible coatings or wax coatings with additional ingredients such as chemical fungicides or natural antimicrobial agents (the potential "green" approach) towards improving the quality of avocado:

- As additional treatments, two green fungicides (with no residue issues) were applied to the coatings for the CA + 1-MCP storage treatment only. These included two DECCO green fungicides (CEV and UPL-1, T2B1 and T2B2, respectively) that were only applied in the two DECCO coatings.
- A chemical fungicide, Thiabendazole 500 SC (TBZ), was applied in all the coating products as a 3rd additional treatment (T2B3, T3B3, T4B3, T5B3, T6B3, T7B3, T8B3).

Fruit storage, ripening and evaluation

After the coating and 1-MCP application, fruit were stored at 5.5 °C under CA for a duration of 70 days (total of 324 x 4 kg export cartons of 'Hass' fruit, see Table 1 for a breakdown of the different treatments). The storage temperature was lowered every four weeks in a 3-day step-down manner, from 5.5 °C to 4 °C and from 4 °C to 3 °C.

Fruit were removed from cold storage for evaluation after 4 weeks, 7 weeks, and 10 weeks of cold storage. Evaluation was done upon ripening (4 cartons per treatment) and included a full set of fruit quality parameters: number of days to ripen (DTR), % moisture loss, and physiological (grey pulp, chilling injury, lenticel damage, vascular browning) and pathological disorders (anthracnose and stem-end rot). Firmness evaluations (Sinclair firmness meter) were done upon removal from cold storage for the three evaluation periods. The TSS of two fruit per treatment carton was determined.

Site

The 'Hass' fruit (Export class 1, Count 20) were sourced from the Westfalia Estate Pack House on 9-10 July 2024. The fruit maturity progressed quickly

in the 2024 season and fruit sourced had 33% DM. Initially it was proposed to source fruit of 30% DM that would be able to handle the long shipping period better. The current cut-off maturity for export fruit is 36% DM. As the incidence of pathological disorders increases as fruit maturity progresses, it would be wise to implement a stricter cut-off point for export with a duration of longer than 4 weeks.

Statistical analysis

Statistical analysis was conducted on 4 carton replicates ('Hass', Count 20, 30% DM) per treatment. The data were subjected to one-way analysis of variance (ANOVA), using Statistica (statistical software).

RESULTS

- **Visual appearance upon evaluation after 4-, 7- and 10-weeks storage**

Figure 2: All the coatings applied hid or masked (95-100%) the white fungicide residue associated with TBZ.

The fruit of the 4-week storage regime were removed from cold storage to ripen and were evaluated on 8 August 2024. All coating treatments masked or totally hid the white residue on the fruit surface associated with postharvest application of TBZ in the packhouse. The packhouse currently applies the TBZ + Fludioxonil combination in the pack line for export. The combination of the two results in a reduction in the white residues on the fruit skin (Fig. 2).

Skins of 'Hass' avocados change colour in different stages from green to purple/black as fruit ripen. The stages include:

- Stage 1 - Green
- Stage 2 - Slight browning, mostly green
- Stage 3 - Green/brown
- Stage 4 - Brown
- Stage 5 - Purple
- Stage 6 - Black.

The fruit of the CA treatment (no coating and no 1-MCP applied) developed colour during storage indicating premature ripening (65% remained green and 35% in Stage 2 and 3 colouring - slightly brown and brown) (T1A, Fig. 3). Normally CA effectively controls premature colouring for up to 4 weeks of storage. The coating applications were done at room temperature and, to keep all treatments under the same conditions until the last application was completed, all 506 cartons of fruit were placed into cold storage at the end of the application. Thus there were no green 'Hass' fruit at 33% DM stored under CA for 4 weeks.

After 4 weeks CA storage, fruit in two of the seven coating treatments, Nature-Cote™ (T6A) and Vegan Wax (T7A), did not colour up. All fruit were green (stage 1 of colouring). Fruit treated with NaturCover Avocado (T3A), Teycer™ Originals Prime 18 (T4A) and VitaFresh™ Botanicals AgroFresh, (T6A) resulted in about 5% fruit colouring. The Vegan Longlife™ coating (T2A) resulted in 10% fruit with slightly brown/mostly green colouring (Stage 2) and 5% fruit with purple colouring (Stage 5). Application of the Apeel edible coating (T8A) resulted in 25% of the fruit colouring up with very similar fruit colouring as the fruit of the no coating CA treatment, indicating that this edible coating might not have improved shelf life in this study. The two AgroFresh coatings improved the appearance of the avocado fruit and had a sheen giving fruit a more natural appearance compared to the fruit of other coating treatments.

After 7 weeks of CA storage, only 30% (6/20 fruit per carton) of the fruit (Fig. 3) under CA with no coating treatment (T1A) remained fully green (Stage 1) while the remaining fruit had coloured up with a range of different colours (Stages 2, 3, 4, and 5). Thus in this study CA as a standalone treatment had limited ability in inhibiting premature colouring of 'Hass' fruit. After 7 weeks of storage, applications of Vegan Longlife™ (T2A) and Apeel (T8A) both resulted in only 30% fruit per carton that remained green, and similar to the control, the fruit were at various colouring stages which gave a carton of fruit a "checker box appearance". Application with the NaturCover Avocado (T3A) edible coating resulted in 25% of the fruit with Stages 2 and 3 colouring, while 60% of the fruit remained green. The Teycer™ Originals (T4A) and VitaFresh™ Botanicals (T5A) applications resulted in 30% and 40% of fruit that coloured. The Nature-Cote™ and Vegan Wax coating treatments proved to be effective in reducing premature colouring, with only about 10% of the fruit with slight browning/mainly green colouring (Stage 2, 1 fruit per carton). The CA with no coating control treatment (T1A) had 70% of the fruit which advanced past the Stage 1 colouring.

After 10 weeks of storage, the CA treatment with no coating (T1A, Fig. 3) and four CA coating treatments (Apeel (T8A), Vegan Longlife™ (T2A), Teycer™ Originals Prime 18 (T4A), and VitaFresh™ Botanicals (T5A)) had advanced fruit colouring (95-100%) including mostly green-brown, brown, and purple coloured fruit (Stages 3-5). The NaturCover Avocado (TA3), Vegan Wax (T6A), and Nature-Cote™ (T6A) applications were slightly more effective than the four treatments mentioned above, resulting in 35%, 45%, and 35% green fruit per carton of fruit, respectively.

Figure 3: Visual appearance of 'Hass' Count 20 fruit with and without coatings applied, after 4-, 7-, and 10-weeks storage in controlled atmosphere. The storage temperature was lowered every four weeks in a 3-day step-down manner, from 5.5 °C to 4 °C and from 4 °C to 3 °C.

Although there was a high incidence of colouring with the coating treatments stored under CA, some definitely delayed ripening of fruit during the 10-week storage period. The combined application of CA and coatings did not maintain fruit quality to an acceptable level.

The visual appearance of the combined treatments of CA and 1-MCP with and without coatings applied after 4 weeks, 7 weeks, and 10 weeks of storage can be seen in Figure 4. AgroFresh commercialised the use of SmartFresh™ (1-MCP) on apples and avocados in 2003 in South Africa. Ethylene is a natural plant hormone that controls different physiological processes, including ripening and senescence. However, ethylene can also cause premature ripening and spoilage of produce during storage and transportation. By blocking the ethylene receptors, 1-MCP is an effective plant growth regulator tool and can slow down the ripening process, delay and decreased respiration as well as ethylene production, and extend the shelf life of the produce in the process.

The ability of the combination of CA and 1-MCP (T1B, no coating applied) to control premature ripening was shown by no colour development of the fruit after 4 and 7 weeks of simulated export conditions. When SmartFresh™ is applied to avocados at the commercial application dosage of 300 ppb, premature ripening can be controlled for up to 35 days when stored under regular atmosphere (RA). In the current trial, this could be increased to 49 days when applied in combination with CA storage. After 10 weeks of storage this treatment resulted in 65% coloured fruit per carton, with only low intensity of colouring present (Stage 2). After 10 weeks of CA storage with no coating applied and no 1-MCP applied (T1A, Fig. 2), all fruit were at Stages 4-5 (brown and purple) which illustrates that the combination of CA and 1-MCP extends shelf life beyond that which CA on its own cannot do.

After 4 weeks under CA storage + 1-MCP, fruit treated with six of the seven coating treatments (Vegan Longlife™ (T2B), NaturCover Avocado (T3B), Teycer™ Originals Prime 18 (T4B), VitaFresh™ Botanicals (T5B), Nature-Cote™ (T6B), and Vegan Wax (T7B)) did not show any advancement in colour. The Vegan Longlife™ (T2B) application resulted in 25% of fruit colouring (Stages 2, 3, and 4) after 7 weeks of storage which increased to 45% (Stage 3, 4, and 5) at week 10. Fruit treated with Teycer™ Originals Prime 18 (T4B; a carnauba wax with shellac) first showed signs of colouring after 10 weeks storage (45% at Stages 2 and 3) which is lower than the 1-MCP + CA combination (65% coloured fruit). However, this coating application resulted in higher colour stages (colour Stages 2 and 3) compared to only colour Stage 2 being present in the CA + 1-MCP treatment. The NaturCover (T3B) application resulted in the first fruit colouring after 7 weeks of storage (15% at Stage 2) which increased to 45% at week 10. The Apeel (T8B) edible coating application resulted in 25% fruit colouring up to Stage 2 or 3 after 4 weeks of storage which increased to 35% and 70% after

Figure 4: Visual appearance of 'Hass' Count 20 fruit with and without coatings, after 4, 7, and 10 weeks at 5 °C under controlled atmosphere storage (1-MCP was applied before CA storage started). The storage temperature was lowered every four weeks in a 3-day step-down manner, from 5.5 °C to 4 °C and from 4 °C to 3 °C.

Table 2: Fruit quality parameters of 'Hass' Count 20 fruit with and without coating applications after 4-, 7-, and 10-weeks storage under CA or CA + 1-MCP storage regime, at 5.5 °C, 4 °C and 3 °C (Table continues adjacent page)

Fruit Quality Parameters 'Hass' with or without coatings applied and stored at CA alone or CA + 1-MCP								
Treatments	Coatings applied	Storage	WEEK 4	WEEK 7	WEEK 10	WEEK 4	WEEK 7	WEEK 10
			Average No. of days to ripen (DTR) (Days)			Firmness (iQ)		
T1A	No coating applied	CA	9.0 bc	8.8 ab	8.6 a	56.3 efgh	50.0 bc	47.0 a
T2A	Vegan Longlife™ [1]	CA	10.6 defg	10.1 def	9.8 bcde	59.3 ijklmn	55.8 efgh	53.6 de
T3A	NaturCover Avo. [1]	CA	11.3 ghijk	11.2 ghij	11.0 fghi	62.4 pqrst	54.8 ef	48.6 ab
T4A	Teycer™ [2]	CA	12.7 nopqrs	12.3 jklmnop	11.7 hijklm	62.8 qrst	58.1 hijkl	55.3 efg
T5A	VitaFresh™ [2]	CA	12.7 nopqrs	12.7 mnopqrs	12.6 lmnopqrs	64.8 tuv	58.1 hijkl	56.3 efgh
T6A	Nature-Cote™ [3]	CA	12.8 nopqrst	12.1 jklmno	11.2 ijklm	66.0 uv	56.2 efgh	57.1 cde
T7A	Vegan Wax [3]	CA	12.0 ijklmno	11.8 ijklmn	11.6 hijkl	61.9 nopqrs	57.6 ghijk	59.8 ghijkl
T8A	Apeel [4]	CA	10.0 defg	10.0 cdef	9.6 abcd	59.9 jklmnop	54.2 de	48.6 ab
T1B	No coating applied	CA + 1MCP	11.8 ijklmn	11.4ghijk	10.7 efgh	58.4 hijkl	58.2 hijkl	57.1 fghi
T2B	Vegan Longlife™ [1]	CA + 1MCP	13.2 qrstuv	12.8 nopqrst	12.2 klmnopq	60.6 jklm	61.8 lmnop	59.8 ghijkl
T3B	NaturCover Avo. [1]	CA + 1MCP	14.3 wx	14.2 vwx	13.5 stuv	62.7 nopq	59.6 fghijk	57.1 cde
T4B	Teycer™ [2]	CA + 1MCP	14.0 uvwx	13.5 rstuvw	13.0 pqrst	63.9 pqr	59.8 ghijkl	57.9 defg
T5B	VitaFresh™ [2]	CA + 1MCP	14.8 x	13.9 tuvw	13.1 pqrstu	66.1 s	61.4 klmno	56.6 cd
T6B	Nature-Cote™ [3]	CA + 1MCP	13.9 uvwx	13.6 stuvw	13.4 rstuv	66.5 s	62.8 opq	60.3 hijkl
T7B	Vegan Wax [3]	CA + 1MCP	13.4 tuvw	12.7 mnopqrs	11.5 ijklmn	62.4 mnopq	60.3 hijkl	59.8 ghijkl
T8B	Apeel [4]	CA + 1MCP	12.49 cdef	11.7 hijklm	11.2 ghijk	62.7 nopq	59.1 efghij	53.8 cd
Prob .> F2			0,0000			0,0000		

Coatings of: 1. DECCO 2. AgroFresh 3. JBT Corporation 4. Apeel Sciences

7- and 10-weeks cold storage, respectively. The best results were obtained with the Nature-Cote™ (T6B) and Vegan Wax (T7B) applications which both resulted in no fruit colour advancement after 4- and 7-weeks cold storage and only 15% of fruit colouring (to Stage 2) after 10 weeks.

- **Fruit quality parameters of the CA and CA + 1-MCP treatments with and without coatings (Table 2)**

Number of Days to Ripen (DTR)

Fruit stored under CA (T1A, without coatings) had lower fruit DTR values compared to all other treatments at 9 days after 4 weeks of storage and 8.8 and 8.6 days after 7 and 10 weeks, respectively, with significant differences between weeks 4 and 10.

Fruit from the CA + 1-MCP treatment (T1B, without coatings) with no coating applied resulted in significantly higher fruit DTR values of 11.8 days, 11.4 days, and 10.7 days after 4, 7, and 10 weeks of storage, compared to the storage treatment under CA alone (T1A, without coatings).

The addition of coatings to fruit stored under CA (no 1-MCP) resulted in significantly higher average fruit DTR values ranging between 10.0 and 12.7 days (T2A, T3A, T4A, T5A, T6A, T7A, and T8A) after 4 weeks cold storage, compared to the CA treatment without coatings applied (T1A) which had a DTR value of 9 days.

Fruit treated with the Vegan Longlife™ (T2A), NaturCover Avocado (T3A), and Apeel (T8A) coatings stored under CA without 1-MCP had DTR values of 10.6 days, 11.3 days, and 10.0 days after 4 weeks of storage, which were significantly lower than the other coatings which resulted in DTR values in the range 12-12.8 days.

The addition of coatings to fruit treated with 1-MCP and stored under CA resulted in significantly higher average fruit DTR values in the range 12.5-14.8 days (T2B, T3B, T4B, T5B, T6B, T7B, and T8B), compared to the CA + 1-MCP treatment without coatings applied (T1B) with a value of 11.8 days. The same trend was observed for the week 7 and week 10 evaluations.

Fruit firmness

Fruit stored under CA without a coating (T1A) had lower fruit firmness values compared to fruit treated with coatings, starting at 56.4 iQ after 4 weeks of storage and significantly decreasing as the storage duration increased to 7 and 10 weeks (50.0 iQ and 47 iQ, respectively). However, fruit from the CA + 1-MCP treatment (T1B) with no coating applied resulted in firmness values of 58.4, 58.2, and 57.1 iQ after 4, 7, and 10 weeks of storage, respectively.

The addition of six of the seven coatings (excluding Vegan Longlife™ (T2B)) after 4 weeks storage under CA + 1-MCP resulted in significantly higher fruit firmness values in the range 62.4-66.5 iQ (T3B, T4B, T5B, T6B, T7B, and T8B), compared to the CA

(Table continued) **Table 2:** Fruit quality parameters of 'Hass' Count 20 fruit with and without coating applications after 4-, 7-, and 10-weeks storage under CA or CA + 1-MCP storage regime, at 5.5 °C, 4 °C and 3 °C

Treatments	Coatings applied	WEEK 4	WEEK 7	WEEK 10	WEEK 4	WEEK 7	WEEK 10	WEEK 4	WEEK 7	WEEK 10
		% Moisture Loss (%)			Anthracnose (%)			Stem-end rot (%)		
T1A	**No coating applied**	0.81 fg	1.44 nopq	2.26 w	4.2 a	19.4 ghijk	27.8 lmno	5.6 ab	23.6 hijk	38.4 nop
T2A	**Vegan Longlife™ [1]**	**0.62 bcdef**	1.26 lkmn	**1.87 uv**	6.9 abc	**29.2 mno**	**55.1 s**	5.6 ab	20.8 fghijk	46.4 pqrs
T3A	**NaturCover Avo. [1]**	0.70 def	1.36 lmnop	**1.67 rst**	**15.3 defghij**	**23.6 jklmn**	**40.3 r**	9.7 abcd	26.4 ijkl	**52.1 rs**
T4A	**Teycer™ [2]**	0.70 bcdef	1.32 lmno	**1.62 qrs**	**16.7 efghij**	**22.2 ijklm**	30.6 nop	6.9 abc	26.4 ijkl	41.7 opq
T5A	**VitaFresh™ [2]**	0.63 bcdef	1.32 lmno	**1.67 rst**	**18.1 fghij**	**30.6 nop**	**38.9 qr**	12.5 abcdef	**29.2 klmn**	46.4 pqrs
T6A	**Nature-Cote™ [3]**	**0.59 abcde**	**1.20 ijklm**	**1.58 qrs**	**18.1 fghij**	19.4 ghijk	**39.2 qr**	4.2 a	22.2 ghijk	36.1 mno
T7A	**Vegan Wax [3]**	**0.54 abcde**	**1.19 ijkl**	**1.69 stu**	5.6 ab	16.7 efghij	32.4 opq	12.5 abcdef	18.1 defghi	40.7 opq
T8A	**Apeel [4]**	0.72 ef	**1.23 jklm**	**1.99 v**	6.9 abc	**27.8 lmno**	26.9 klmno	11.1 abcde	**29.2 klmn**	**55.6 s**
T1B	**No coating applied**	**0.81 fg**	1.36 lmnop	1.80 tuv	4.2 a	18.1 fghij	20.8 hijkl	5.6 ab	11.1 abcde	25.0 ijk
T2B	**Vegan Longlife™ [1]**	**0.51 abcd**	**0.97gh**	**1.26 lkmn**	8.3 abcd	19.7ghijk	**30.6 nop**	6.9 abc	**26.1 ijk**	44.1 opqr
T3B	**NaturCover Avo. [1]**	**0.48 abc**	**1.11 hijk**	**1.45 opq**	9.7 abcde	34.9 nopqr	**40.3 r**	11.1 abcde	**35.7 lmno**	**50.0 qrs**
T4B	**Teycer™ [2]**	**0.45 ab**	**1.09 hijk**	**1.49 opqr**	**13.9 cdefgh**	**41.7 r**	**50.2 s**	8.3 abc	**23.6 hijk**	**50.0 qrs**
T5B	**VitaFresh™ [2]**	**0.45 abc**	**1.04 hij**	**1.38 mnop**	9.7 abcde	**38.9 qr**	**40.3 r**	4.3 a	20.8 fghijk	**55.6 s**
T6B	**Nature-Cote™ [3]**	**0.43 a**	**1.04 hij**	**1.34 lmnop**	**12.5 bcdefg**	**32.4 opq**	**39.3 qr**	8.3 abc	19.4 efghij	**40.7 opq**
T7B	**Vegan Wax [3]**	**0.48 abc**	**1.02 hi**	**1.26 lkmn**	9.7 abcde	18.1 fghij	27.0 klmno	8.3 abc	15.3 cdefgh	35.7 lmno
T8B	**Apeel [4]**	0.64 cdef	**1.06 hij**	**1.52 pqrs**	**11.1 bcdef**	**30.6 nop**	**39.0 qr**	14.0 bcdefg	**27.8 jklm**	**55.6 s**
Prob .> F2		**0,0000**			**0,0000**			**0,0000**		

Coatings of: 1. DECCO 2. AgroFresh 3. JBT Corporation 4. Apeel Sciences

+ 1-MCP treatment without coatings applied (T1B, 58.4 iQ). The Vegan Longlife™ application resulted in a firmness of 60.6 iQ which did not differ significantly from the CA + 1-MCP treatment without coatings applied (T1B).

The Teycer™ Originals Prime 18 (T4B), VitaFresh™ Botanicals (T5B), and Apeel (T8B) CA + 1-MCP treatments seemed to decrease fruit firmness at a higher rate as the storage duration increased, compared to the CA + 1-MCP treatment without a coating application. On the other hand, the Nature-Cote™ (T6B) and Vegan Wax (T7B) applications seemed to decrease fruit firmness at a slower rate compared to the other coatings. These two coatings also resulted in the least fruit skin colour progression.

% Moisture loss

Fruit stored under CA (T1A, without coatings) had the highest moisture loss ranging from 0.81% after 4 weeks of storage to 2.26% after 10 weeks storage.

Fruit from the CA + 1-MCP treatments (T1B) with no coating applied resulted in less moisture loss of 0.81%, 1.36%, and 1.80% after 4, 7, and 10 weeks of storage respectively, compared to the 0.08%, 1.44%, and 2.26% obtained for CA storage treatment (T1A, without coatings).

The addition of coatings to fruit under 4 weeks storage under CA resulted in less moisture loss in the range 0.54-0.72% (T2A, T3A, T4A, T5A, T6A, T7A, and T8A), compared to the CA treatment without coatings applied (T1A), with 0.808% moisture loss, although not always significant.

The addition of 6 coatings (excluding Apeel (T8B)) to fruit subsequently stored for 4 weeks under CA + 1-MCP resulted in significantly less fruit moisture loss in the range 0.43-0.51% (T2B, T3B, T4B, T5B, T6B, and T7B), compared to the CA + 1-MCP treatment without coatings applied (T1B) with 0.810%. The same trend was observed for the week 7 and week 10 evaluations.

Anthracnose

Fruit treated with four of the seven coating treatments (NaturCover Avocado, Teycer™, VitaFresh™ Botanicals, and Nature-Cote™; T3A, T4A, T5A, and T6A) after 4 weeks under CA storage had a significant increase in the incidence of anthracnose infection in the range 15.3-18.1%, compared to the CA treatment without coatings applied (T1A) (4.2% anthracnose incidence).

There is a correlation between coatings with higher DTR values that resulted in increased anthracnose incidence. In this regard, Teycer™ (T4A), VitaFresh™ (T5A), and Nature-Cote™ (T6A) with higher DTR values of 12.7 days, 12.7 days, and 12.8 days (Week 4), respectively, had the highest anthracnose incidences of 16.7%, 18.1%, and 18.1%.

After 10 weeks of storage under CA, application of four of the seven coatings resulted in a significant increase in the incidence of anthracnose in the range 38.9-55.1% (Vegan Longlife™, NaturCover, VitaFresh™, and Nature-Cote™ T2A, T3A, T5A, and

Table 3: Fruit quality parameters of 'Hass' Count 20 fruit with and without coating applications (with and without TBZ in the coatings), after 4-, 7-, and 10-weeks storage under CA + 1-MCP storage regime, at 5.5 °C, 4 °C and 3 °C (Table continues adjacent page)

Fruit Quality Parameters 'Hass' with or without coatings applied, with or without TBZ included in the coatings and stored at CA + 1-MCP storage regime									
Treatments	Coatings applied	Storage	TBZ included in coating	WEEK 4	WEEK 7	WEEK 10	WEEK 4	WEEK 7	WEEK 10
				Average No. of days to ripen (DTR) (Days)			Firmness (iQ)		
T1B	No coating applied	CA + 1-MCP	No	11.8 bcde	11.4 abc	10.7 a	58.4 defgh	58.2 defgh	57.1 cde
T2B	Vegan Longlife™ [1]		No	13.2 klmn	12.8 ghijkl	12.2 defg	60.6 jklm	61.8 lmnop	59.8 ghijkl
T3B	NaturCover Avo. [1]			14.3 rs	14.2 pqrs	13.5 lmnop	62.7 nopq	59.6 fghijk	57.1 cde
T4B	Teycer™ [2]		No	14.0 opqrs	13.5 mnopq	13.0 ijklmn	63.9 pqr	59.8 ghijkl	57.9 defg
T5B	VitaFresh™ [2]			14.7s	13.8 nopqr	13.1 jklmn	66.1 s	61.4 klmno	56.6 cd
T6B	Nature-Cote™ [3]		No	13.9 nopqr	13.6 mnopq	13.4 lkmno	66.5 s	62.8 opq	60.3 hijkl
T7B	Vegan Wax [3]			13.4 lkmno	12.7 ghijkl	11.7 bcd	62.4 mnopq	60.3 hijkl	59.8 ghijkl
T8B	Apeel [4]		No	12.5 efghi	11.7 bcd	11.24 ab	62.7 nopq	59.1 efghij	53.8 a
T2B3	Vegan Longlife™ [1]	CA + 1-MCP	Yes	13.3 klmn	12.9 ijklmn	12.1 cdef	60.9 jklmn	60.5 ijklm	59.8 ghijkl
T3B3	NaturCover Avo. [1]			14.2 pqrs	13.2 klmn	12.1 cdef	62.5 nmopq	58.4 defghi	57.2 cd
T4B3	Teycer™ [2]		Yes	14.2 qrs	14.1 pqrs	13.1 jklmn	63.9 qr	60.5 ijklm	58.1 defg
T5B3	VitaFresh™ [2]			14.4 rs	14.1 pqrs	13.3 klmn	65.5 rs	61.8 lmnop	57.1 cde
T6B3	Nature-Cote™ [3]		Yes	13.5 mnopq	13.2 klmn	13.2 klmn	65.7 rs	63.4 opq	62.8 opq
T7B3	Vegan Wax [3]			13.3 klmn	12.8 hijkl	12.4 efgh	64.0 qr	62.8 opq	62.4 mnopq
T8B3	Apeel [4]		Yes	12.5 efghi	11.9 bcde	11.4 bc	61.2 jklmn	58.0 defg	53.8 a
				Prob .> F2 = 0.0000			Prob .> F2 = 0.0000		

Coatings of: 1. DECCO 2. AgroFresh 3. JBT Corporation 4. Apeel Sciences

T6A), compared to the CA treatment without coatings applied (T1A, 27.8%).

The addition of all coatings under 4 weeks storage with CA + 1-MCP resulted in an increase in the incidence of anthracnose infection in the range 8.3-13.9% (T2B, T3B, T4B, T5B, T6B, T7B, and T8B), compared to the CA + 1-MCP treatment without coatings applied (T1B, 4.2%).

After 10 weeks of storage under CA + 1-MCP, fruit from six of the seven coatings tested had a significant increase in anthracnose incidence in the range 30.6-50.2% (T2A, T3A, T4A, T5A, T6A, and T8A), compared to the CA + 1-MCP treatment without coatings applied (T1B, 27.8%).

Fruit treated with Vegan Wax (T7A, CA storage without coating) had fruit anthracnose incidence values of 5.6%, 16.7%, and 32.4% (Weeks 4, 7, 10) that did not differ significantly from the CA treatment without coatings (T1A) (4.2, 19.4, and 27.8%, respectively). The same was also true for the CA + 1-MCP treatments.

Stem-end rot

After 10 weeks of storage under CA, fruit treated with all coating treatments had an increase in stem-end rot incidence in the range 36.1-55.6%. With the NaturCover Avocado and Apeel coatings, the increase was significant with values of 52.1% and 55.6%, respectively. The CA treatment without coatings applied (T1A) had an incidence of 38.4% stem-end rot.

After 10 weeks of storage under CA + 1-MCP, fruit treated with all coating applications had a significant increase in stem-end rot incidence in the range 35.7-50.0% (T2A, T3A, T4A, T5A, T6A, and T8A), compared to the CA treatment without coatings applied (T1A, 25%).

- **Fruit quality parameters of CA + 1-MCP treatments with and without coatings with TBZ included in the coating or not (Table 3)**

In this additional trial TBZ was included in the coatings in an attempt to control the expected increased incidence of pathological disorders associated with the increased number of days to ripen when coatings are included as a postharvest treatment.

Anthracnose

Fruit treated with five of the seven coatings applied with TBZ under CA + 1-MCP after 4 weeks of storage (T2B3, T3B3, T5B3,T6B3, and T7B3) had reduced incidence of anthracnose (1.4%, 1.4%, 4.2%, 4.2%, and 2.8%, respectively) compared to the treatments with no TBZ included in the coatings (T2B, T3B, T5B, T6B, and T7B; 8.3%, 9.7%, 9.7%,12.5%, and 9.7%, respectively).

Fruit treated with six coatings with TBZ included (excluding VitaFresh™ Botanicals, T5B3) under CA + 1-MCP treatments after 10 weeks of storage (T2B3, T3B3, T4B3, T6B3, T7B3, and T8B3) had reduced incidence of anthracnose (19.1%, 34.9%, 38.24%, 21.0% 18.1%, and 30.6%, respectively) compared

(Table continued) **Table 3:** Fruit quality parameters of 'Hass' Count 20 fruit with and without coating applications (with and without TBZ in the coatings), after 4-, 7-, and 10-weeks storage under CA + 1-MCP storage regime, at 5.5 °C, 4 °C and 3 °C

Treatments	Coatings applied	Storage	TBZ included in coating	% Moisture Loss (%)			Anthracnose (%)			Stem-end rot (%)		
				WEEK 4	WEEK 7	WEEK 10	WEEK 4	WEEK 7	WEEK 10	WEEK 4	WEEK 7	WEEK 10
T1B	**No coating applied**	CA + 1-MCP	**No**	**0.81 de**	**1.36 jklm**	**1.80 o**	**4.2 ab**	**18.1 ef**	**20.8 fghi**	5.6 abcd	11.11 cdefg	25.00 klm
T2B	**Vegan Longlife™ [1]**		**No**	0.51 ab	0.97 ef	1.34 jklm	8.3 bc	19.7 fg	30.6 klm	6.9 abcde	**26.1 lm**	**44.1 pq**
T3B	**NaturCover Avo. [1]**			0.48 ab	1.11 fghi	1.45 lmn	9.7 cd	34.9 mn	40.3 o	11.1 cdefg	**35.7 no**	**50.0 pq**
T4B	**Teycer™ [2]**		**No**	0.45 a	1.09 fgh	1.49 mn	13.9 de	41.0 o	50.2 p	8.3 cdef	**23.6 jklm**	**50.0 pq**
T5B	**VitaFresh™ [2]**			0.45 a	1.04 fg	1.38 jklmn	9.7 cd	38.9 no	40.3 o	4.3 abc	**20.8 ijklm**	**55.6 r**
T6B	**Nature-Cote™ [3]**		**No**	0.43 a	1.04 fg	1.34 jklm	12.5 cd	32.4 mn	39.3 no	8.3 cdef	**19.4 hijkl**	**40.7 pq**
T7B	**Vegan Wax [3]**			0.48 ab	1.02 fg	1.26 ijk	9.7 cd	**18.1 ef**	**27.0 jkl**	8.3 cdef	15.3 fghi	**35.7 no**
T8B	**Apeel [4]**		No	0.64 bc	1.06 fg	1.52 n	11.1 cd	30.6 klm	38.9 no	**14.0 efghi**	**27.8 m**	**55.6 r**
T2B3	**Vegan Longlife™ [1]**	CA + 1-MCP	**Yes**	0.52 ab	1.02 fg	1.23 hij	1.4 a	**18.1 ef**	**19.1 efg**	**2.8 ab**	12.5 defgh	26.1 lm
T3B3	**NaturCover Avo. [1]**			0.49 ab	1.04 fg	1.42 klmn	1.4 a	25.8 ijk	34.9 mn	**2.8 ab**	16.7 ghij	**36.8 nop**
T4B3	**Teycer™ [2]**		**Yes**	0.50 ab	1.07 fgh	1.40 lkmn	9.7 cd	23.6 ghij	38.24 no	**0.0 a**	18.1 ghijk	**36.1 nop**
T5B3	**VitaFresh™ [2]**			0.48 ab	1.09 fgh	1.34 jklm	4.2 ab	27.8 jkl	39.3 no	**2.8 ab**	**19.4 hijkl**	**40.8 pq**
T6B3	**Nature-Cote™ [3]**		**Yes**	0.44 a	1.04 fg	1.23 hij	**4.2 ab**	**19.4 fg**	**21.0 fghi**	0.00 a	13.9 efghi	26.9 mno
T7B3	**Vegan Wax [3]**			0.43 a	1.00 ef	1.14 ghi	**2.8 ab**	**8.8 cd**	**18.1 efg**	1.4 ab	11.1 cdefg	19.1 hijkl
T8B3	**Apeel [4]**		**Yes**	0.69 cd	1.12 fghi	1.48 mn	8.3 bc	23.6 ghij	30.6 klm	8.3 bcdef	19.4 hijkl	44.1 pq
				Prob .> F2 = 0.0000			**Prob .> F2 = 0.0000**			**Prob .> F2 = 0.0000**		

Coatings of: 1. DECCO 2. AgroFresh 3. JBT Corporation 4. Apeel Sciences

to the treatments with no TBZ included in the coatings (T2B, T3B, T4B,T5B, T6B, T7B, and T8; 30.6%, 40.3%, 50.2%, 40.3%, 27.0%, and 38.9%, respectively).

Stem-end rot

Fruit treated with four of the seven coatings with TBZ included under CA + 1-MCP treatments after 4 weeks of storage (T3B3, T4B3, T6B3, and T7B3) had reduced incidence of stem-end rot (2.8%, 0.0%, 0.0%, and 1.4%, respectively) compared to the treatments with no TBZ included in the coatings (T3B, T4B, T6B, and T7B; 11.1%, 8.3%, 8.3%, and 8.3%, respectively).

Fruit treated with four of the seven coatings with TBZ included under CA + 1-MCP after 10 weeks of storage (T2B3, T6B3, T7B3, and T8B3) had reduced incidence of stem-end rot (26.1%, 26.9%, 19.1%, and 44.2%, respectively) compared to the treatments with no TBZ included in the coatings (T2B, T6B, T7B, and T8; 44.1%, 40.1%, 35.7%, and 55.6%, respectively).

- **New green fungicide of DECCO tested for efficacy (Table 4)**

Table 4: The incidence of anthracnose and stem-end rot of 'Hass' Count 20 fruit with and without the application of two DECCO coatings, with and without the inclusion of TBZ, as well as two green fungicides (BCE and UPL-1) in the coatings, after 4-, 7-, and 10-weeks storage under CA + 1-MCP storage, at 5.5 °C, 4 °C and 3 °C

Pathological disorders: Ca +1-MCP storage with coatings applied, with and without fungicides in coatings											
Treatments	Coatings applied		Storage	Fungicide included in coating	Anthracnose (%)			Stem-end rot (%)			
					WEEK 4	WEEK 7	WEEK 10	WEEK 4	WEEK 7	WEEK 10	
T1B	No coating		CA + 1-MCP	No	4.2 abc	18.1 fgh	18.1 fgh	6.9 abc	11.1 cd	25.0 fgh	
T2B	DECCO	Vegan Longlife™		No	8.3 bcd	19.7 ef	19.7 ef	6.9 abc	26.1 fghi	44.1 l	
T3B		NaturCover Avocado			9.7 cde	34.9 lm	34.9 lm	11.1 cd	35.7 ijk	50.0 m	
T2B3	DECCO	Vegan Longlife™	CA + 1-MCP	Yes	4.2 abc	18.1 fgh	**23.5 ij**	6.9 abc	**16.7 de**	**26.5 fghi**	
T3B3		NaturCover Avocado			5.6 abc	**22.2 hij**	**27.8 jk**	8.3 bc	**19.4 ef**	**35.7 ijk**	
T4B3	DECCO	Vegan Longlife™		Yes	2.8 ab	18.1 fgh	**19.4 fghi**	2.8 ab	**16.7 de**	**27.8 ghij**	
T5B3		NaturCover Avocado			5.6 abc	**22.2 hij**	**20.6 ghi**	**2.8 ab**	**19.4 ef**	**35.7 ijk**	
T6B3	DECCO	Vegan Longlife™		Yes	**1.4 a**	18.1 fgh	**19.1 efg**	2.8 a	**11.1 cd**	**27.8 ghij**	
T7B3		NaturCover Avocado			**1.4 a**	**25.8 ijk**	34.9 mn	**2.8 a**	**16.7 de**	**32.6 ijk**	
					Prob .> F2 = 0.0000			**Prob .> F2 = 0.0000**			

Coatings of: 1. DECCO 2. AgroFresh 3. JBT Corporation 4. Apeel Sciences

- **Two DECCO green fungicides were tested for efficacy with TBZ as a reference fungicide**

Fruit treated with the Vegan Longlife™ and NaturCover Avocado coatings without fungicides included in the coating under CA + 1-MCP (T2B and T3B) had 8.3% and 9.7% anthracnose incidences, respectively, after 4 weeks of storage.

- When the BCE (T2B1) green fungicide was included in these coatings, fruit had lower anthracnose incidences of 4.2% and 5.6%, respectively, although this did not differ significantly.
- When the UPL-1 (T3B2) green fungicide was included in these coatings, fruit had lower anthracnose incidences of 2.8% and 5.6%, respectively, although these did not differ significantly.
- When the TBZ fungicide was included in these coatings, fruit had significantly lower anthracnose incidences of 1.4% (TB2B3 and TB3B3) compared to the coating treatments without a fungicide added.

Fruit treated with Vegan Longlife™ and NaturCover Avocado without fungicide included in the coatings under CA + 1-MCP (T2B and T3B) had 30.6% and 40% incidences of anthracnose, respectively, after 10 weeks of storage.

- When the BCE green fungicide was included in these coatings, fruit had significantly lower anthracnose incidences of 23.5% (T2B1) and 27.8% (T3B1).
- When the UPL-1 green fungicide was included in these coatings, fruit had significantly lower anthracnose incidences of 19.4% (T2B2) and 20.6% (T3B2).
- When the TBZ fungicide was included in the Vegan Longlife™ coating, fruit had significantly lower anthracnose incidence of 19.1% (T2B3). When TBZ was included in the NaturCover Avocado coating, fruit had a slightly lower incidence of anthracnose of 34.9% (T3B3), although this was not significantly different when compared to the coating treatment without a fungicide.

Stem-end rot

Fruit treated with the Vegan Longlife™ and NaturCover Avocado coatings without fungicides included under CA + 1-MCP (T2B and T3B) had stem-end rot incidences of 26.1% and 35.7%, respectively, after 7 weeks of storage.

- When the BCE green fungicide was included in these coatings (T2B1 and T3B1), fruit had significantly lower stem-end rot incidences of 16.7% and 19.4%, respectively.
- When the UPL-1 green fungicide was included in these coatings (T2B2 and T3B2), fruit had lower stem-end rot incidences of 16.7% and 19.4%, respectively, although these were not significant.
- When the TBZ fungicide (T2B3 and T3B3) was included in these coatings, fruit had significantly lower anthracnose incidences of 11.1% and 16.7%, respectively.

Fruit treated with the Vegan Longlife™ and NaturCover Avocado coatings without fungicides included under CA + 1-MCP (T2B and T3B), had stem-end rot incidences of 44.11% and 50.0%, respectively, after 10 weeks of storage.

- The same trend was noted regarding reduced stem-end rot as was noted after 7 weeks cold storage.

SUMMARY

Fruit skins of 'Hass' avocados change colour in different stages from green to purple/black as fruit ripen. The fruit of the CA treatment (no coating and no 1-MCP was applied) coloured up, indicating premature ripening that started during cold storage (± 65% remained green). Normally CA effectively controls premature colouring during 4 weeks of storage. The coating applications were done at room temperature to ensure all treatments were applied under the same conditions, whereafter cartons were placed into cold storage. Thus no 33% DM 'Hass' fruit stored under CA for 4 weeks were green. After 4 weeks under CA storage, all the fruit treated with Nature-Coat™ and Vegan Wax were green, with no colouring present. About 5% of fruit treated with NaturCover Avocado, Teycer™ Originals Prime 18, and VitaFresh™ Botanicals coloured up. 15% of fruit treated with the Vegan Longlife™ coating were slightly brown/mostly green in colour (Stage 2) while 5% were purple (Stage 5). Fruit treated with Apeel coating had very similar colouring composition as the fruit of the no coating CA treatment, indicating that in this study this coating might not improve shelf life.

After 7 weeks under CA storage, 30% of fruit (6/20 fruit per carton) with no coatings were still fully green. In this study, the CA postharvest treatment therefore had a limited period to control premature colouring of 'Hass' fruit. Only 30% of fruit treated with the Vegan Longlife™ and Apeel coatings remained green, similar to the control. 60% of fruit treated with the NaturCover Avocado coating were still green. Some of the fruit treated with the Teycer™ Originals and VitaFresh™ Botanicals coatings coloured up (30% and 40%, respectively). Fruit treated with the Nature-Cote™ and Vegan Wax coatings had reducing premature colouring, with only about 10% of fruit with slight browning/mainly green colouring (Stage 2, 1 fruit per carton), compared to fruit under CA with no coating treatment.

After 10 weeks storage under CA, fruit treated with no coatings, the Apeel, Vegan Longlife™, Teycer™ Originals Prime 18, and VitaFresh™ Botanicals coatings had advanced fruit colouring (95-100%). The NaturCover Avocado, Vegan Wax, and Nature-Cote™ coating treatments were more effective, with 35%, 45%, and 35% of fruit per carton remaining green. The high incidence of colouring up indicates that the addition of coatings under CA storage might not maintain fruit quality to withstand a 10-week voyage to an export market.

Fruit under CA and 1-MCP did not colour up after 4 and 7 weeks. In avocados, application of SmartFresh™ at the commercial application dosage of 300 ppb enables control of premature ripening for up to 35 days when stored under regular atmosphere (RA). In the current trial, premature ripening was controlled for up to 49 days under CA. After 10 weeks of storage, only 65% of fruit coloured up, with a low intensity of colouring present (Stage 2). In comparison, after 10 Weeks of CA storage with no coating applied and no 1-MCP applied, all fruit were at colour stages 4-5 (brown and purple).

After 4 weeks under CA storage + 1-MCP, fruit treated with the Vegan Longlife™, NaturCover Avocado, Teycer™ Originals Prime 18, VitaFresh™ Botanicals, Nature-Cote™, and Vegan Wax coatings did not colour up. 25% of the fruit treated with the Vegan Longlife™ coating coloured up after 7 weeks of storage which increased to 45% (Stage 3, 4, and 5) after 10 weeks of storage. 45% of fruit treated with the Teycer™ Originals Prime 18 (a carnauba wax with shellac) coating coloured up after 10 weeks of storage, although this was still lower than the CA + 1-MCP combination where 65% of fruit coloured up. 15% of fruit treated with the NaturCover coating coloured up (Stage 2) after 7 weeks of storage, and this increased to 45% after 10 weeks storage. 25% of fruit treated with the Apeel coating coloured up after 4 weeks of storage, and this increased to 35% and 70% after 7- and 10-weeks storage, respectively. The best results were obtained with fruit treated with the Nature-Cote™ and Vegan Wax coatings where fruit remained green after 4- and 7-weeks storage and only 15% of fruit coloured up (Stage 2) after 10-weeks storage. This is a significant improvement over the CA + 1-MCP treatment (T1B) where 65% of fruit coloured up.

Fruit stored under CA (without any coatings) ripened after 9 days after 4 weeks of storage and this decreased to 8.8 and 8.6 days after 7 and 10 weeks storage, respectively. Fruit under CA + 1-MCP with no coating applied required more days to ripen (DTR) of 11.8 days, 11.4 days, and 10.7 days after 4, 7, and 10 weeks of storage, respectively. Regardless of the coating formulation, after 4 weeks storage under CA, fruit needed significantly higher average DTR with coating treatments (10.0-12.7 days) compared

to the fruit under the CA treatment without a coating (9 days). After 4 weeks, fruit treated with the Teycer™ Originals Prime 18, VitaFresh™ Botanicals, Nature-Cote™, and Vegan Wax coatings (under CA alone) took 12.0-12.8 days to ripen, significantly longer than the fruit treated with the Vegan Longlife™, NaturCover Avocado, and Apeel coatings (10.0-11.3 days).

Fruit treated with all coatings under CA + 1-MCP after 4 weeks of storage had significantly longer DTR values in the range 12.5-14.8 days, compared to the control group of fruit under CA + 1-MCP treatment without coatings applied (T1A) that had a value of 11.8 days. The same trend was observed after 7- and 10-weeks storage.

The firmness of fruit stored under CA without a coating treatment decreased progressively with longer storage periods (47-56.4 iQ), which was also the lowest of all treatments. Fruit from the CA + 1-MCP treatment with no coating applied had flesh firmness levels between 57.1 iQ and 58.4 iQ over the three storage periods. 1-MCP effectively maintained flesh firmness over the 10-week storage duration. Fruit from all coating treatments, except those treated with Vegan Longlife™, had significantly firmer fruit after 4 weeks storage under CA + 1-MCP (62.4-66.5 iQ), compared to the control group under CA + 1-MCP treatment without coatings applied (58.4 iQ). Fruit treated with the Vegan Longlife™ coating had a firmness of 60.6 iQ that did not differ significantly from the control group. Fruit treated with the Teycer™ Originals Prime 18, VitaFresh™ Botanicals, and Apeel coatings under CA + 1-MCP, seem to have a higher rate in fruit firmness loss during storage compared to the control group. In contrast, fruit treated with the Nature-Cote™ and Vegan Wax coatings had the lowest firmness loss over the 10-week storage period. Fruit treated with these two coatings also had the least colour advancement. This suggests that for some coating formulations, the efficacy of 1-MCP was negatively affected due to inhibited absorption through the coating barrier into the fruit.

Fruit stored under CA (without coating) had the highest moisture loss at 0.808% after 4 weeks of storage which increased significantly as the storage duration increased (1.44% and 2.26% after 7- and 10-weeks storage, respectively). Fruit from the CA + 1-MCP treatment with no coating applied had lower moisture losses of 0.81%, 1.36%, and 1.80% after 4-, 7-, and 10-weeks of storage, respectively. Regardless of the coating, the addition of a coating to fruit under CA after 4 weeks storage resulted in less moisture loss (0.54% and 0.72%), compared to fruit under CA treatment without a coating applied (0.808% moisture loss). Fruit treated with all coatings, except Apeel, had significantly less moisture loss (0.43-0.51%) after 4-weeks storage under CA + 1-MCP compared to the control group with no coatings applied (0.81%). A similar trend was observed after 7- and 10-weeks storage.

Fruit treated with the NaturCover Avocado, Teycer™, VitaFresh™ Botanicals, and Nature-Cote™ coatings under CA after 4 weeks had significantly higher incidences of anthracnose in the range 15.3-18.1%, compared to fruit under CA without coatings applied (4.2% incidence). The same coatings that lengthened the DTR values also contributed to increased anthracnose infection. In this regard, fruit treated with the Teycer™, VitaFresh™ Botanicals, and Nature-Cote™ coatings with higher DTR values had the highest anthracnose incidences. After 10 weeks of storage under CA, fruit treated with the Vegan Longlife™, NaturCover, Nature-Cote™, and VitaFresh™ Botanicals coatings had significantly higher incidences of anthracnose in the range 38.9-55.1% compared to fruit under CA without a coating applied (27.8%). Fruit treated with the Vegan Wax coating (under CA only) had the lowest anthracnose incidence values of 5.6%, 16.7% and 32.4% (after 4-, 7-, and 10-weeks, respectively) but this did not differ significantly from fruit under CA without coatings applied.

Fruit under CA + 1-MCP treated with all coatings except NaturCover had increased anthracnose incidences in the range 8.3-3.9% after 4 weeks compared to fruit under CA + 1-MCP treatment without a coating applied (4.2%). After 10 weeks of storage, fruit with coatings applied under CA + 1-MCP, except for Vegan Wax, had significantly higher incidences of anthracnose (30.6-50.2%) compared to fruit under CA + 1-MCP treatment without a coating applied (20.8%). Fruit treated with Vegan Wax (CA + 1-MCP) had the lowest anthracnose incidences (9.7%, 18.1%, and 27.0% after 4-, 7-, and 10-weeks storage, respectively) but did not differ significantly from fruit under CA + 1-MCP without a coating applied (4.2%, 18.1%, and 27.8%, respectively).

After 10 weeks of storage under CA, fruit from all coating treatments had similar or higher stem-end rot incidences (36.1-55.6%) compared to fruit under CA without a coating applied (38.4%). However, after 10 weeks of storage under CA + 1-MCP, fruit treated with all coating treatments had significantly higher stem-end rot incidences in the range 35.7-50.0% when compared to fruit under CA treatment without a coating applied (25% incidence).

In an additional trial, TBZ was included in fruit coatings in an attempt to control the expected increased incidence of pathological disorders associated with the increased number of days to ripen when coatings are applied. Fruit treated with the Vegan Longlife™, NaturCover Avocado, VitaFresh™ Botanicals, Nature-Cote™, and Vegan Wax coatings with TBZ added under CA + 1-MCP treatments after 4-weeks of storage, had lower incidences of anthracnose (1.4-4.2%) when compared to the same treatments without TBZ included in the coatings (8.3-12.5%).

Fruit treated with all coating treatments with TBZ added, except VitaFresh™ Botanicals, under CA + 1-MCP after 10-weeks of storage (including the Vegan Longlife™, NaturCover Avocado, Teycer™, Nature-Cote™, Vegan Wax, and Apeel coatings), had reduced incidences of anthracnose when compared to the same treatments with no TBZ added.

Fruit treated with the NaturCover Avocado, Teycer™, Nature-Cote™, and Vegan Wax coatings with TBZ added under CA + 1-MCP after 4-weeks of stor-

age, had lower incidences of stem-end rot when compared to fruit under CA + 1-MCP from the same treatments where no TBZ was included in the coatings.

Fruit treated with the Vegan Longlife™, Nature-Cote™, Vegan Wax, and Apeel coatings with TBZ added under CA + 1-MCP after 10-weeks of storage, had lower incidences of stem-end rot compared to the same treatments where no TBZ was included in the coatings.

Two DECCO green fungicides (BCE and UPL-1) were tested for their efficacy with TBZ as the reference fungicide. Fruit treated with the Vegan Longlife™ and NaturCover Avocado coatings without a fungicide included in the coating under CA + 1-MCP, had incidences of anthracnose at 8.3% and 9.7%, respectively, after 4 weeks of storage. The addition of the BCE and UPL-1 green fungicides in these coatings resulted in lower incidences of anthracnose, although these were not significantly different compared to the control. When TBZ was included in these coatings, fruit had significantly lower incidences of anthracnose when compared to the control.

Fruit treated with the Vegan Longlife™ and NaturCover Avocado coatings without a fungicide included in the coating, under CA + 1-MCP, had 30.6% and 40% incidences of anthracnose, respectively, after 10 weeks of storage. The addition of the BCE and UPL-1 green fungicides resulted in significantly lower incidences of anthracnose. When TBZ was included in the Vegan Longlife™ coating, significantly lower incidences of anthracnose were noted, and when TBZ was included in the Teycer™ coating, fruit had lower incidences of anthracnose that did not differ significantly. These green fungicides proved to be just as effective as TBZ in controlling anthracnose when applied in coatings, even up to 10 weeks of storage. The same trend was noted with incidences of stem-end rot.

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