APPENDIX B – Supporting Materials

A1. Summary of export and domestic consignment monitoring

Over the life of the project (2020-2023), 51 Ecoganic® and organic banana consignments were monitored along seven supply chains from Pacific Coast Eco Banana growers in north Queensland to domestic (Adelaide, Brisbane, Melbourne, Sydney) and export (Hong Kong, Singapore, Japan) markets. During this period, over 70,000 individual time and temperature records were captured by real-time loggers in the consignments. This document provides a summary of the consignment monitoring data and the risk of fruit quality loss and waste.

Overview of monitored consignments

Table 1 summarises the distribution of the 51 monitored consignments among the seven destinations. Sydney received the largest number of monitored consignments (25), followed by Hong Kong (10), Brisbane (6), Singapore (5), Adelaide (2), Melbourne (2) and Tokyo (1).

Table 1. Destination vs number of monitored consignments.

Destination	Number of consignments
Adelaide	2
Brisbane	6
Melbourne	2
Sydney	25
Hong Kong	10
Singapore	5
Tokyo	1

Temperature and location monitoring

Real-time autonomous-reporting data loggers were included in a random box of fruit within each monitored consignment (Figure 1). The loggers continuously recorded the in-transit temperature and relative humidity experienced by fruit and provided data on the consignment location via the mobile phone network. Figure 2 shows the mean temperature profiles for 37 representative consignments during both transport and general handling stages.

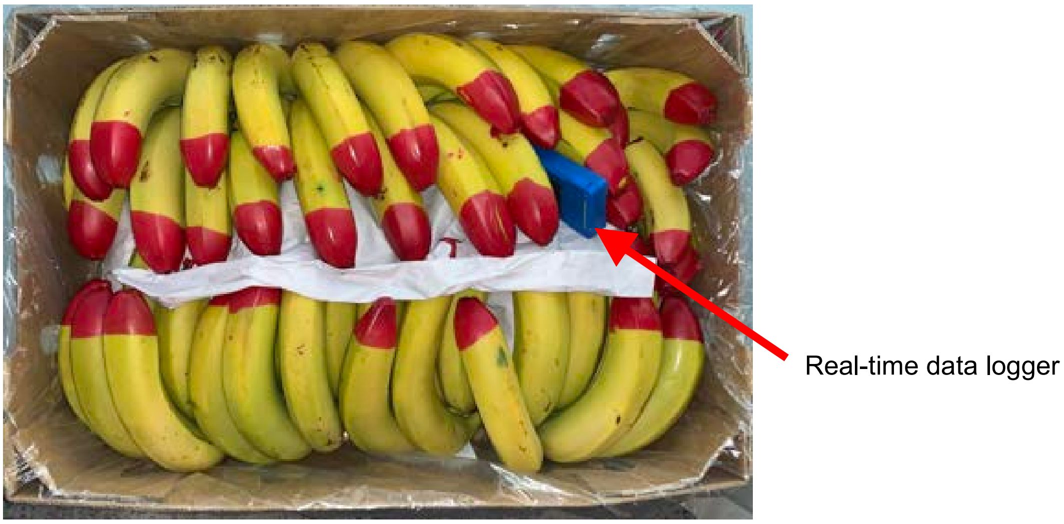


Figure 1. Photograph showing a real-time data logger within a box of Ecoganic® banana fruit.

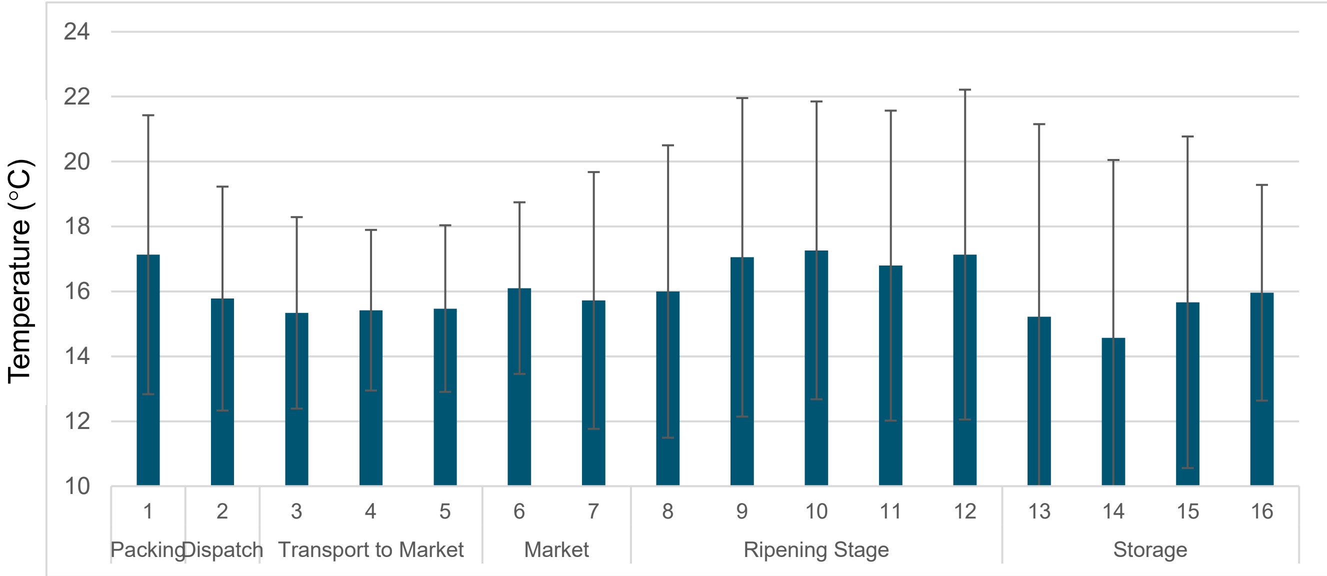


Figure 2. Average monitored temperature for logged banana consignments during transport and general storage. Vertical bars represent the standard deviation of the mean. The recommended dispatch, transport and storage temperature is 13-14°C while banana fruit are typically ripened at 15-17°C. Numbers reflect the average number of days spent at each step.

Of the 37 monitored consignments, seven were exposed to temperatures below 13°C, placing the bananas at risk of potential chilling injury (Table 2). Table 3 displays the seven monitored consignments that experienced chilling temperatures, and the predicted chilling injury based on a decision support tool developed by the project team. Additionally, the predictions indicate that three of these consignments could have been rejected by supermarkets in Australia due to severe chilling damage to 10% or more of the consignment. Figure 3 shows the comparison of bananas at full colour, showing chilling injury outcomes as predicted in Table 2.

Table 2. List of banana consignments that were exposed to <13°C and could result in fruit chilling injury.

Consignment name
Eco Banana domestic shipment #21 2022
Eco Banana domestic shipment #11 2022
Eco Banana domestic shipment #8 2022
Eco Bananas to Coles Brisbane #1 2022
QLD1
Eco Banana export 12
Eco Banana domestic shipment #3 2022
VIC1
Eco Banana domestic shipment #17 2022

Table 3. Predicted chilling injury for banana consignments that were exposed to <13°C.

Shipment Name	Mean Chilling Temperature (°C)	Duration at Chilling Temperature (hours)	Predicted Chilling Injury Index (0 to 3)	Predicted Rejection Percentage (%)
Eco Banana domestic shipment #14 2022	11.2	64.8	0.6	15.8%
Eco Banana domestic consignment #16 2022	12.2	17.2	0.4	2%
Eco Banana domestic consignment #3 2022	11.5	71.5	0.5	8.4%
Eco Banana Export consignment 12b	10.4	48.3	0.9	42.1%
Eco Banana Export consignment 13	11.7	143	0.5	7.5%
Eco Banana export consignment 4	11.4	7.6	0.5	4.2%
Eco Banana to Coles Brisbane #1 2022	8.55	2.5	1	21.8%

This table utilises the Chilling Injury Decision Support Tool to predict potential damage to fruit consignments. It includes mean chilling temperatures experienced during transit, duration of exposure, calculated injury indices, and the estimated percentage of the consignment affected.

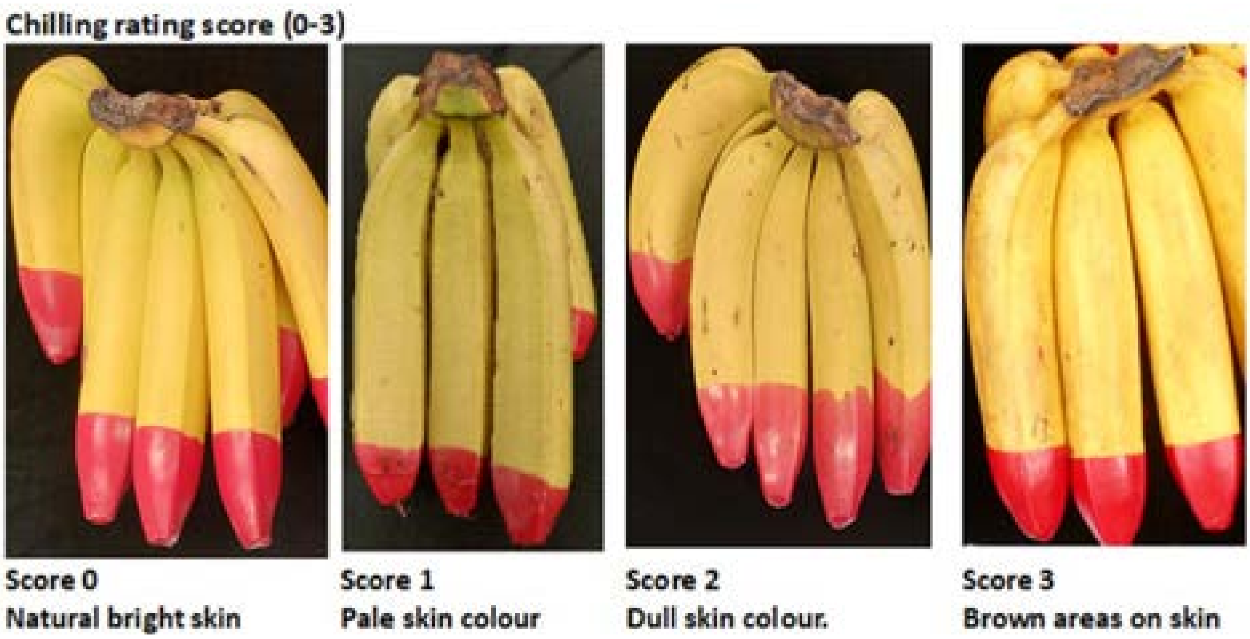


Figure 3. Comparison of bananas exhibiting chilling injury at full colour, scored from 0 to 3.

Figure 4 shows consignment 13, which was exposed to a chilling temperature of 11.7°C for 143 hours during storage at a freight forwarder prior to export. This resulted in a predicted chilling injury index of 0.5, with an estimated 7.5% of the fruit likely to be rejected by supermarkets. This figure is below the 10% threshold at which supermarkets would reject the consignment.

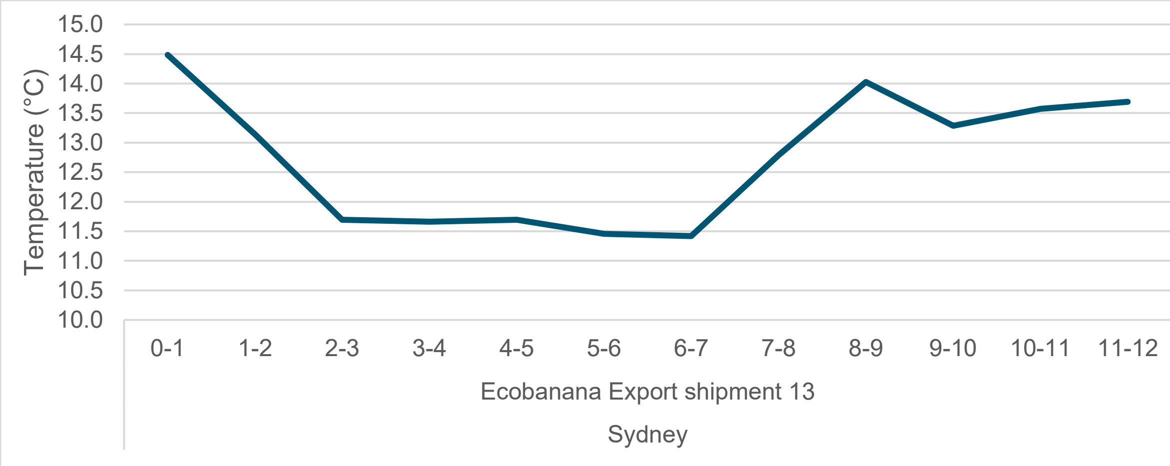


Figure 4. Supply chain temperatures encountered by Eco Banana export consignment 13. The x-axis represents different handling steps and days along the supply chain as per Figure 2.

Table 3 shows a summary of all monitored consignments and conditions encountered by fruit.

Table 4. Statistics for all monitored consignments, destinations, and average temperatures during transport.

Destination	Consignment Name	Time Since Dispatch (days)	Average of Temperature	StdDev of Temperature
Adelaide	**1**	0-1	11.2	0.15
		1-2	11.0	0.23
		2-3	12.3	0.93
		3-4	13.5	0.19
		4-5	13.3	1.29
		5-6	16.9	0.23
		6-7	10.5	6.68
		7-8	3.1	0.08
	2	0-1	18.8	3.80
		1-2	15.4	1.02
		2-3	17.0	0.38
		3-4	14.4	1.78
		4-5	14.3	2.81
		5-6	14.7	0.19
		6-7	12.7	0.90
		7-8	11.3	0.86
		8-9	11.9	0.57
		9-10	16.2	0.67
		10-11	16.1	0.40
		11-12	15.4	0.63
		12-13	13.3	0.12
		13-14	13.1	0.17
		14-15	13.7	0.39
		15-16	13.4	0.61
		16-17	11.3	1.49

Table 3 continued				
Destination	**Consignment Name**	**Time Since Dispatch (days)**	**Average of Temperature**	**StdDev of Temperature**
Brisbane	**2**	0-1	28.6	1.86
		1-2	20.9	3.79
		2-3	14.7	0.43
		3-4	14.0	0.13
		4-5	14.2	0.24
		5-6	15.0	0.22
	3	0-1	13.6	0.11
		1-2	13.5	0.23
		2-3	13.6	0.50
		3-4	15.6	0.19
		4-5	16.3	0.24
		5-6	16.3	0.46
	4	0-1	19.9	4.91
		1-2	23.4	1.89
		2-3	22.0	0.95
		3-4	22.2	1.27
		4-5	20.8	0.06
		5-6	20.7	0.07
Hong Kong	**1**	0-1	16.9	1.23
		1-2	15.4	0.78
		2-3	14.4	0.40
		3-4	14.8	0.26
		4-5	15.0	0.29
		5-6	14.9	1.39
		6-7	13.0	0.42
		7-8	12.3	0.29
		8-9	12.0	0.14
		9-10	11.9	0.13
		10-11	11.8	0.12
		11-12	13.5	1.50
	2	0-1	21.1	2.48
		1-2	17.0	2.42
		2-3	15.5	1.34
		3-4	15.5	0.78
		4-5	13.6	0.45
		5-6	13.5	0.56
		6-7	15.2	0.34
		7-8	14.6	0.39
		8-9	15.5	0.45
		9-10	16.4	0.19
		10-11	16.6	0.27
		11-12	15.9	0.24
		12-13	16.5	0.37

Table 3 continued Destination	Consignment Name	Time Since Dispatch (days)	Average of Temperature	StdDev of Temperature
Hong Kong	**3**	0-1	23.5	0.63
		1-2	21.0	0.84
		2-3	18.7	0.40
		3-4	17.3	0.39
		4-5	17.7	0.64
		5-6	19.5	0.35
		6-7	19.2	1.98
		7-8	13.5	0.43
		8-9	16.1	1.47
		9-10	18.3	0.80
		10-11	14.3	1.35
		11-12	15.7	3.16
	4	0-1	22.7	0.71
		1-2	19.8	1.40
		2-3	16.5	0.44
		3-4	16.9	0.23
		4-5	17.7	0.71
		5-6	19.4	0.25
		6-7	18.9	1.88
		7-8	13.8	0.99
		8-9	17.0	1.05
		9-10	17.1	2.02
		10-11	10.0	1.96
		11-12	6.4	0.27
	5	0-1	12.3	0.41
		1-2	11.7	0.10
		2-3	13.6	1.65
		3-4	14.8	0.27
		4-5	13.7	0.84
		5-6	16.2	1.54
		6-7	16.8	3.36
		7-8	20.4	0.78
		8-9	21.3	0.74
		9-10	21.2	0.74
		10-11	21.7	0.66
		11-12	21.6	0.55

Table 3 continued				
Destination	**Consignment Name**	**Time Since Dispatch (days)**	**Average of Temperature**	**StdDev of Temperature**
Hong Kong	**6**	0-1	14.5	0.77
		1-2	11.3	0.73
		2-3	9.9	0.79
		3-4	15.2	1.95
		4-5	17.2	0.50
		5-6	19.3	0.55
		6-7	20.9	0.86
		7-8	20.6	0.39
		8-9	20.7	0.43
		9-10	20.9	0.53
		10-11	21.0	0.60
		11-12	20.7	0.32
	7	0-1	17.7	0.80
		1-2	17.7	0.30
		2-3	17.0	0.11
		3-4	16.4	0.27
		4-5	16.0	0.08
		5-6	16.0	0.07
		6-7	13.5	0.89
		7-8	12.8	0.38
		8-9	12.7	0.25
		9-10	12.9	0.60
	8	0-1	23.4	1.75
		1-2	20.7	0.59
		2-3	16.0	1.37
		3-4	14.2	0.20
		4-5	14.0	0.15
		5-6	13.6	0.11
		6-7	13.7	0.11
		7-8	13.9	0.17
		8-9	13.6	0.13
		9-10	13.7	0.14
		10-11	13.7	0.15
		11-12	13.8	0.16
		12-13	13.7	0.29
		13-14	12.2	0.60
		14-15	18.3	3.38
		15-16	14.2	1.83
		16-17	18.5	2.11
		17-18	18.2	2.98

Table 3 continued				
Destination	**Consignment Name**	**Time Since Dispatch (days)**	**Average of Temperature**	**StdDev of Temperature**
Hong Kong	**9**	0-1	16.5	0.91
		1-2	18.0	0.68
		2-3	16.0	1.81
		3-4	16.8	0.87
		4-5	19.5	0.61
		5-6	17.7	1.37
		6-7	16.8	0.56
Melbourne	**1**	0-1	24.8	1.90
		1-2	17.4	2.53
		2-3	13.6	0.31
		3-4	13.8	0.42
		4-5	11.7	0.31
		5-6	11.3	0.15
		6-7	11.6	0.96
		7-8	16.5	0.37
		8-9	17.0	0.22
		9-10	16.4	0.42
		10-11	14.8	0.95
		11-12	13.7	1.01
		12-13	14.2	1.35
		13-14	15.4	0.41
		14-15	15.9	0.14
		15-16	16.0	0.12
		16-17	16.0	0.18
		17-18	15.8	0.13
		18-19	15.7	0.11
Singapore	**1**	0-1	15.7	1.14
		1-2	14.7	0.10
		2-3	14.2	0.68
		3-4	12.7	0.10
		4-5	13.1	0.76
		5-6	15.7	0.13
		6-7	14.1	1.72
		7-8	8.5	1.15

Table 3 continued				
Destination	Consignment Name	Time Since Dispatch (days)	Average of Temperature	StdDev of Temperature
Singapore	**2**	0-1	15.3	0.26
		1-2	13.7	0.68
		2-3	13.3	0.13
		3-4	13.4	0.35
		4-5	13.5	0.84
		5-6	15.0	0.07
		6-7	10.3	4.22
		7-8	4.3	0.52
		8-9	3.7	0.26
		9-10	3.5	0.21
		10-11	3.4	0.22
		11-12	3.5	0.16
		12-13	3.4	0.21
		13-14	3.6	0.28
		14-15	5.8	3.19
		15-16	13.8	2.62
		16-17	14.0	1.04
		17-18	15.4	0.39
	3	0-1	15.9	1.61
		1-2	14.4	0.15
		2-3	14.2	0.11
		3-4	13.1	0.26
		4-5	15.4	0.75
		5-6	16.3	0.22
		6-7	16.3	1.21
		7-8	17.1	2.34
		8-9	15.5	1.56
		9-10	15.6	0.64
		10-11	18.5	2.95
		11-12	24.5	2.88
		12-13	27.6	0.82
	4	0-1	15.8	0.58
		1-2	15.4	0.65
		2-3	15.2	1.90
		3-4	14.9	2.66
		4-5	18.5	0.66
		5-6	19.7	0.54
		6-7	20.5	1.15
		7-8	23.5	4.12
		8-9	30.5	1.11
		9-10	26.3	0.45

Table 3 continued				
Destination	Consignment Name	Time Since Dispatch (days)	Average of Temperature	StdDev of Temperature
Sydney	**1**	0-1	26.2	2.99
		1-2	16.5	1.37
		2-3	14.4	0.15
	2	0-1	20.8	1.76
		1-2	20.2	2.56
		2-3	19.6	2.66
		3-4	19.4	3.08
		4-5	17.5	3.79
		5-6	16.9	4.22
		6-7	17.0	4.12
		7-8	18.7	3.66
	3	0-1	20.0	3.24
		1-2	16.5	0.14
		2-3	16.4	0.15
		21-22	12.0	0.65
		22-23	11.3	0.56
		23-24	11.2	1.01
		24-25	11.7	0.62
		25-26	12.2	0.63
		26-27	12.2	0.66
		27-28	11.7	0.23
		28-29	12.1	0.14
	4	0-1	21.5	2.65
		1-2	17.0	0.23
		20-21	10.8	1.64
		21-22	12.5	4.64
		22-23	20.3	1.03
		23-24	19.5	1.02
		24-25	17.4	0.22
		25-26	17.8	0.92
		26-27	21.7	0.44
	5	0-1	23.4	1.76
		1-2	22.5	1.37
		2-3	23.0	0.77
		3-4	18.8	1.32
		4-5	15.6	0.56
		5-6	14.8	0.15
		6-7	14.7	0.12
		7-8	14.6	0.12
		8-9	14.9	0.17
		9-10	14.7	0.31
		10-11	13.9	0.17
		11-12	14.1	0.20
		12-13	14.6	0.19

Table 3 continued				
Destination	Consignment Name	Time Since Dispatch (days)	Average of Temperature	StdDev of Temperature
Sydney	6	0-1	17.4	0.49
		1-2	16.5	1.28
		2-3	13.7	0.28
		3-4	13.2	0.25
		4-5	13.1	0.12
		5-6	13.3	0.23
		6-7	13.3	0.12
		7-8	13.3	0.16
		8-9	13.2	0.11
		9-10	14.1	1.92
		10-11	12.9	1.39
		11-12	13.2	1.33
	7	0-1	17.1	0.87
		1-2	16.5	0.40
		2-3	14.5	1.44
		3-4	13.2	0.13
		19-20	21.1	0.16
		20-21	20.9	0.79
		21-22	18.4	1.00
		22-23	24.7	2.72
		23-24	26.2	2.15
		24-25	25.9	0.62
	8	0-1	21.3	1.50
		1-2	15.8	0.97
		2-3	15.4	0.23
		3-4	16.2	0.27
		4-5	15.6	0.44
		5-6	14.0	0.36
		6-7	14.8	1.47
		7-8	18.4	2.36
		8-9	23.2	1.05
		9-10	22.8	0.50
		10-11	21.7	1.88
		11-12	23.4	0.50
	9	0-1	17.8	0.84
		1-2	17.9	0.54
		2-3	20.5	2.94
		3-4	18.7	2.24
		4-5	18.3	2.58
		5-6	19.0	3.14
		6-7	21.7	2.48
		7-8	19.1	2.93
		8-9	16.8	1.93
		9-10	18.8	1.58

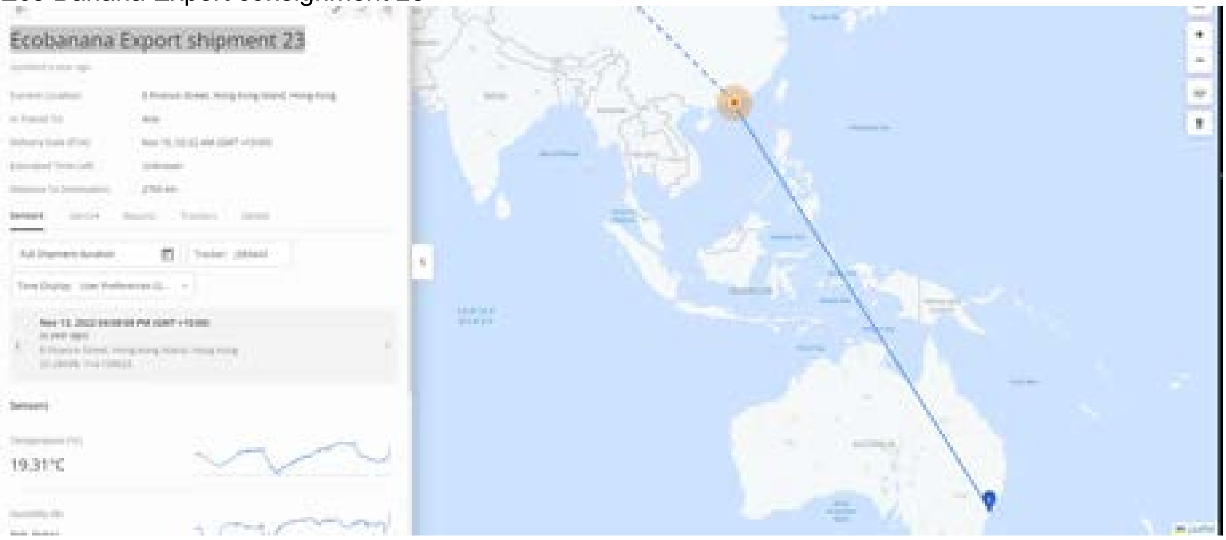
Table 3 continued				
Destination	**Consignment Name**	**Time Since Dispatch (days)**	**Average of Temperature**	**StdDev of Temperature**
Sydney	**10**	0-1	18.0	0.75
		1-2	13.5	1.37
		2-3	13.6	0.39
		3-4	13.7	0.16
		4-5	13.8	0.16
		5-6	13.9	0.16
		6-7	14.1	0.16
		7-8	14.3	0.16
		8-9	13.4	0.96
		9-10	12.9	0.55
		10-11	12.4	0.57
		11-12	11.9	0.54
	11	0-1	14.5	0.32
		1-2	13.1	0.74
		2-3	11.7	0.20
		3-4	11.7	0.11
		4-5	11.7	0.12
		5-6	11.5	0.13
		6-7	11.4	0.12
		7-8	12.8	1.17
		8-9	14.0	0.55
		9-10	13.3	0.17
		10-11	13.6	0.30
		11-12	13.7	0.63
	12	0-1	22.9	0.30
		1-2	19.0	2.55
		2-3	14.2	0.13
		3-4	13.9	0.04
		23-24	16.7	0.34
		24-25	17.5	0.84
		25-26	15.9	1.19
		26-27	14.2	0.44
		27-28	15.5	1.66
		28-29	14.9	1.04
		29-30	15.4	1.34
		30-31	16.3	1.20
		31-32	18.3	1.02
		32-33	17.3	0.97
		33-34	17.0	0.91
		34-35	16.6	0.91
		35-36	16.6	0.26

Table 3 continued

Destination	Consignment Name	Time Since Dispatch (days)	Average of Temperature	StdDev of Temperature
Sydney	**13**	0-1	17.3	0.77
		1-2	17.3	1.11
		2-3	14.9	0.53
		3-4	14.5	0.78
		4-5	15.4	1.44
		5-6	15.2	1.30
		6-7	16.0	1.51
		7-8	17.0	1.49
		8-9	18.1	0.99
		9-10	17.2	0.78
		10-11	16.6	0.60
		11-12	16.3	0.81
	14	0-1	17.2	1.31
		1-2	16.1	0.76
		2-3	14.1	0.50
		3-4	14.4	1.22
		4-5	14.5	1.12
		5-6	15.0	1.34
		6-7	15.7	1.27
		7-8	17.2	1.74
		8-9	18.4	1.09
	15	0-1	22.3	3.75
		1-2	16.1	1.04
		2-3	14.7	0.12
		3-4	14.4	0.13
		4-5	14.4	0.13
		5-6	13.9	0.15
		6-7	12.7	0.55
		7-8	13.6	0.60
		8-9	14.6	0.13
		9-10	14.7	0.11
		10-11	14.7	0.20
		11-12	14.2	0.11
		12-13	14.5	0.13
		13-14	14.7	0.15
		14-15	14.6	0.14
		15-16	14.6	0.11
		16-17	14.5	0.14
		17-18	14.7	0.10
		18-19	14.8	0.17

Table 3 continued				
Destination	Consignment Name	Time Since Dispatch (days)	Average of Temperature	StdDev of Temperature
Sydney	16	0-1	17.0	2.02
		1-2	15.0	0.21
		2-3	14.7	0.31
		3-4	13.8	0.13
		4-5	15.9	0.67
		5-6	14.0	2.24
	17	0-1	13.1	0.08
		1-2	13.3	0.11
		2-3	13.5	0.15
		3-4	13.6	0.13
		4-5	13.7	0.15
		5-6	13.5	0.26
		6-7	13.2	0.11
		7-8	12.9	0.12
		8-9	13.1	0.18
		9-10	13.2	0.12
		10-11	15.3	1.61
		11-12	14.2	1.75
Tokyo	1 lower layer	0-1	17.4	2.93
		1-2	16.6	0.62
		2-3	15.1	0.87
		3-4	14.3	1.10
		4-5	16.3	0.50
		5-6	17.1	0.33
		6-7	15.8	2.88
		7-8	15.4	1.09
	1 middle layer	0-1	23.7	0.92
		1-2	18.8	1.60
		2-3	17.7	0.44
		3-4	17.4	0.90
		4-5	17.2	1.08
		5-6	17.1	1.33
		6-7	17.1	1.93
		7-8	16.1	0.58

Eco Banana Export consignment 23



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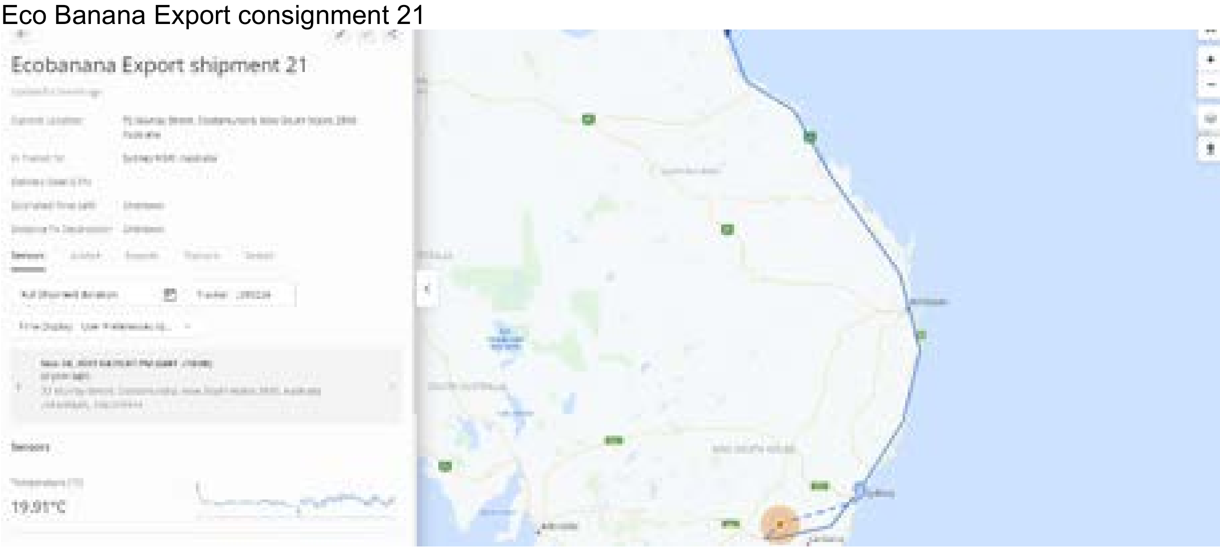

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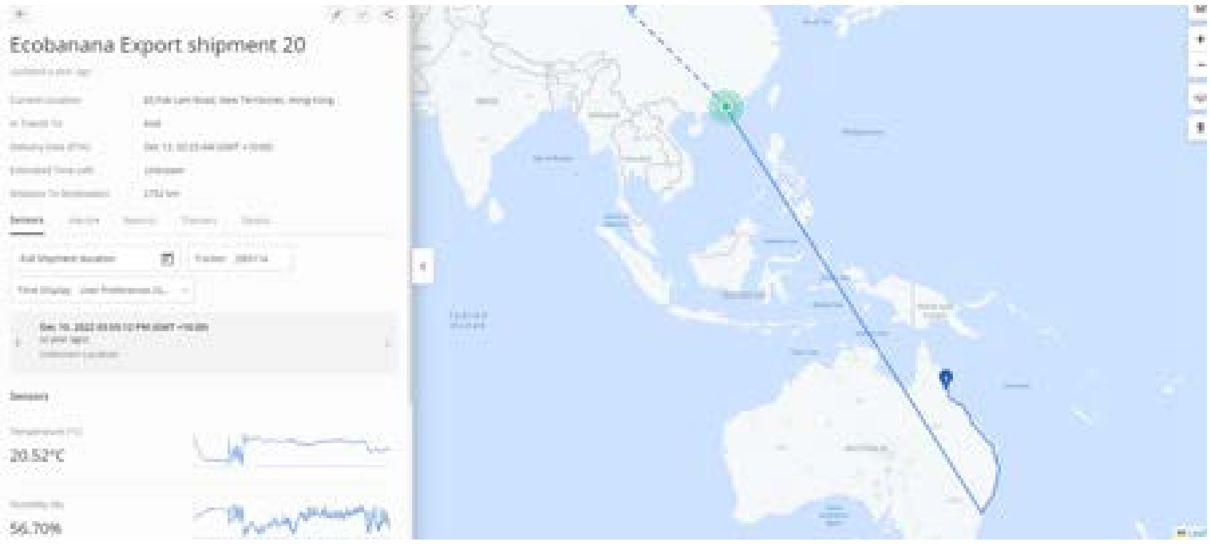

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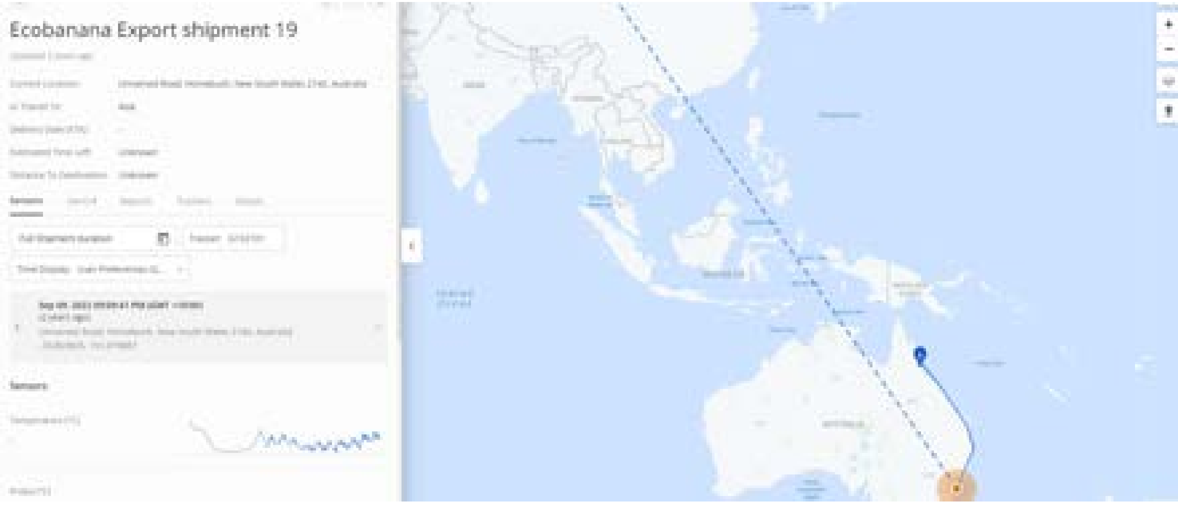

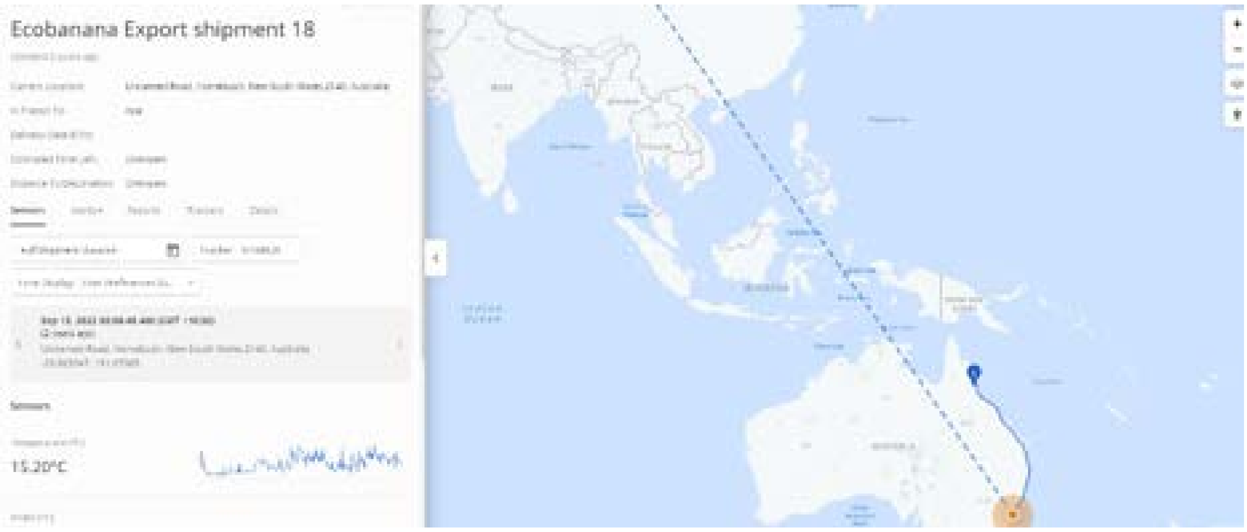

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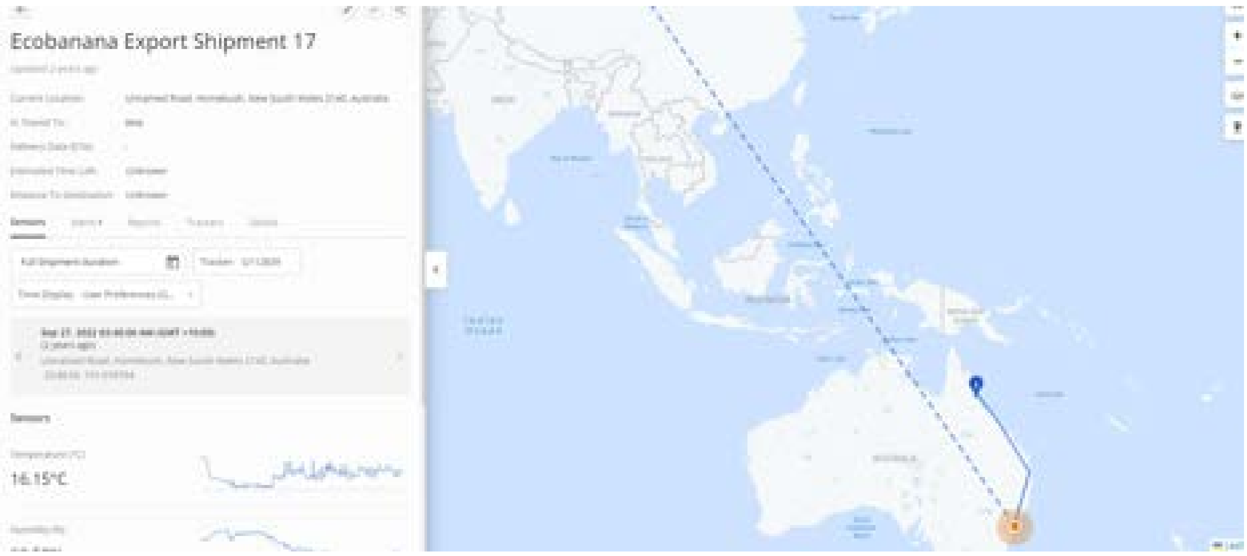

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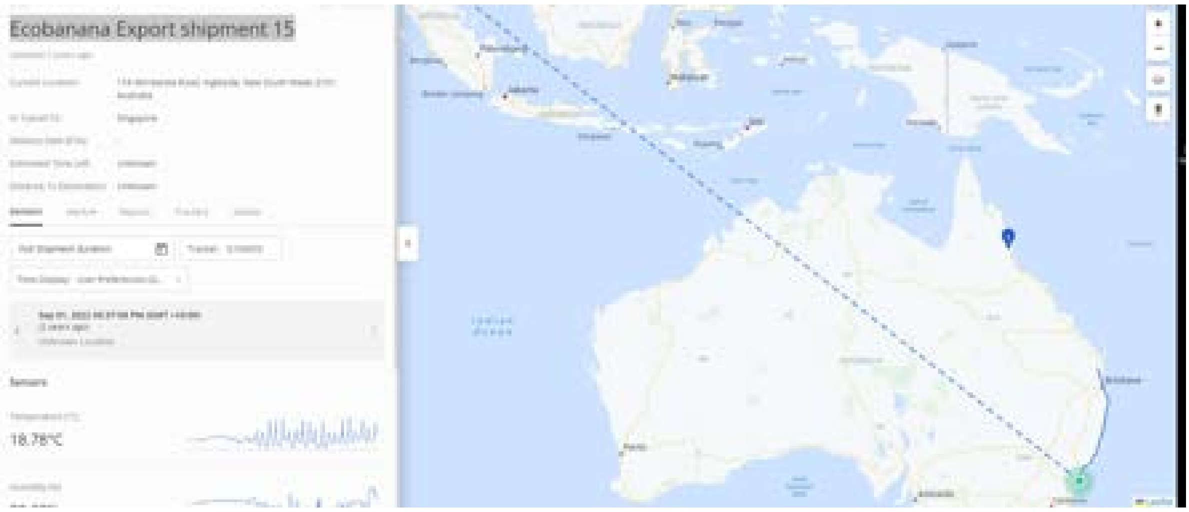

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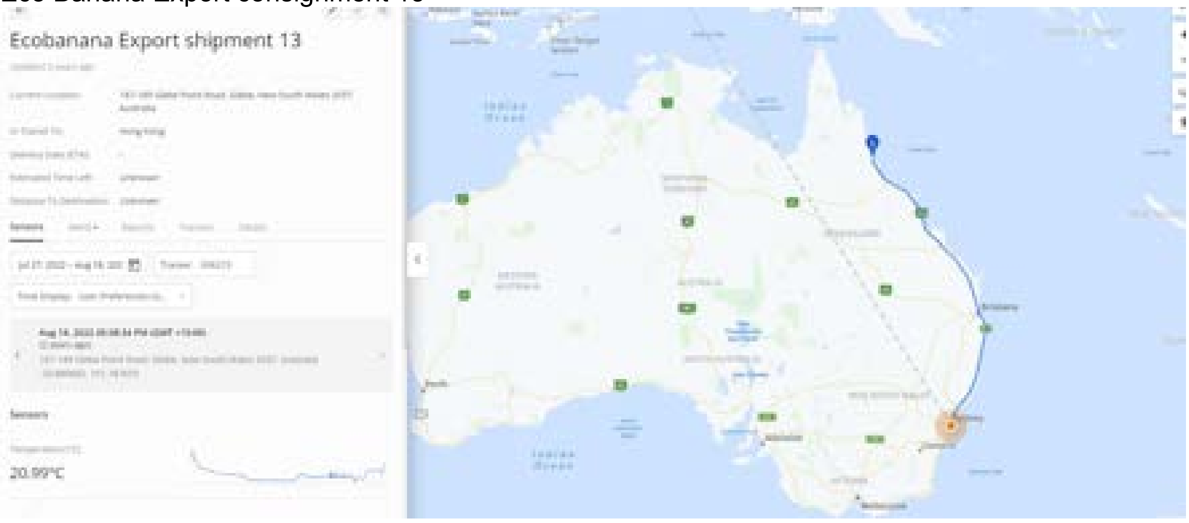

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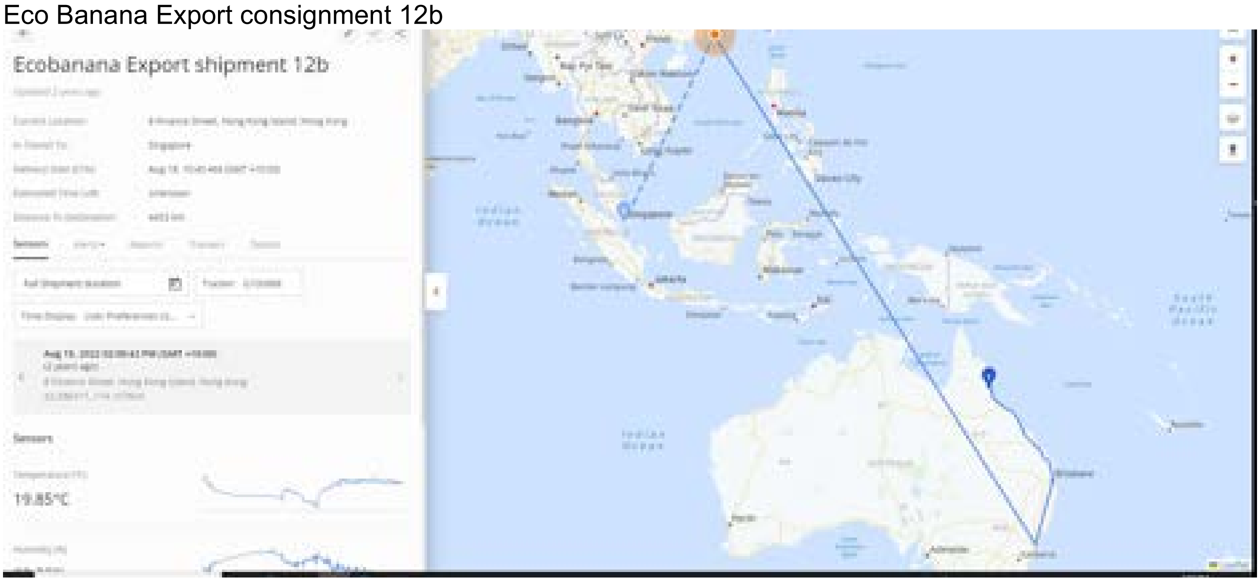

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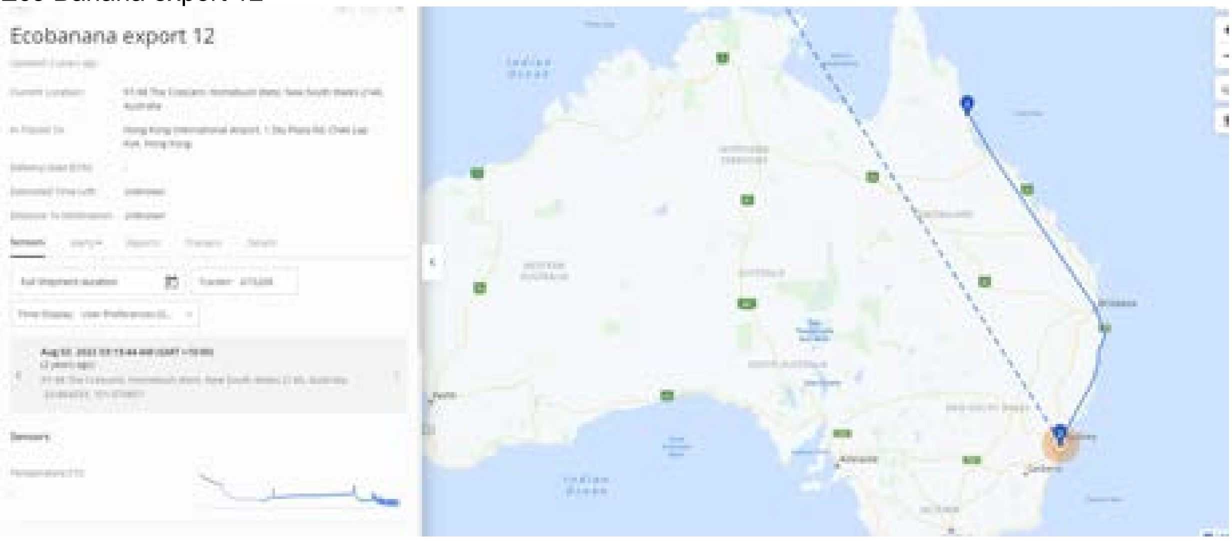

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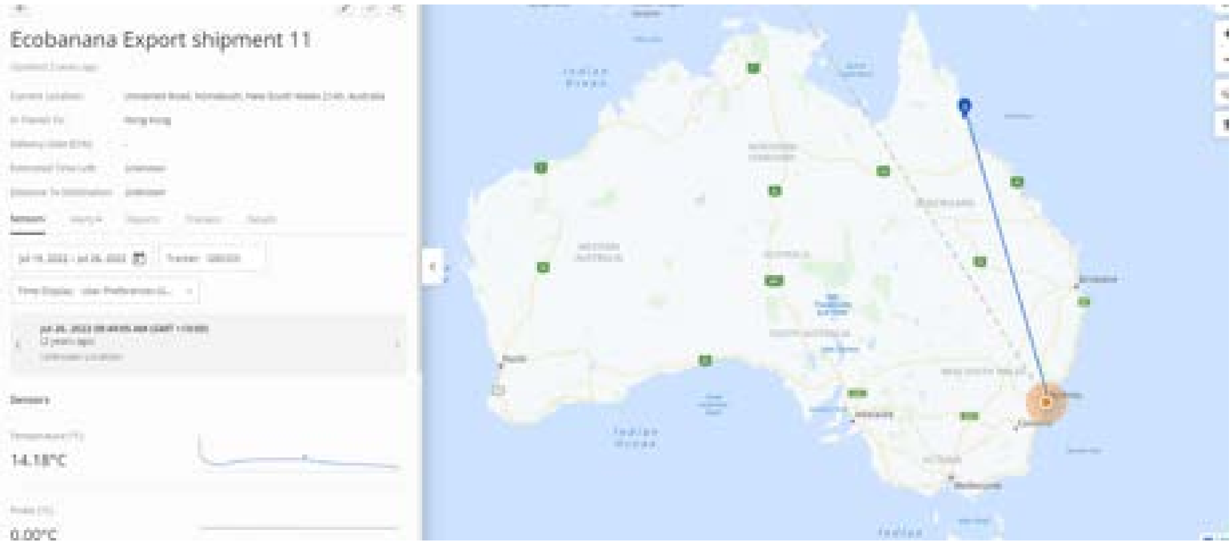

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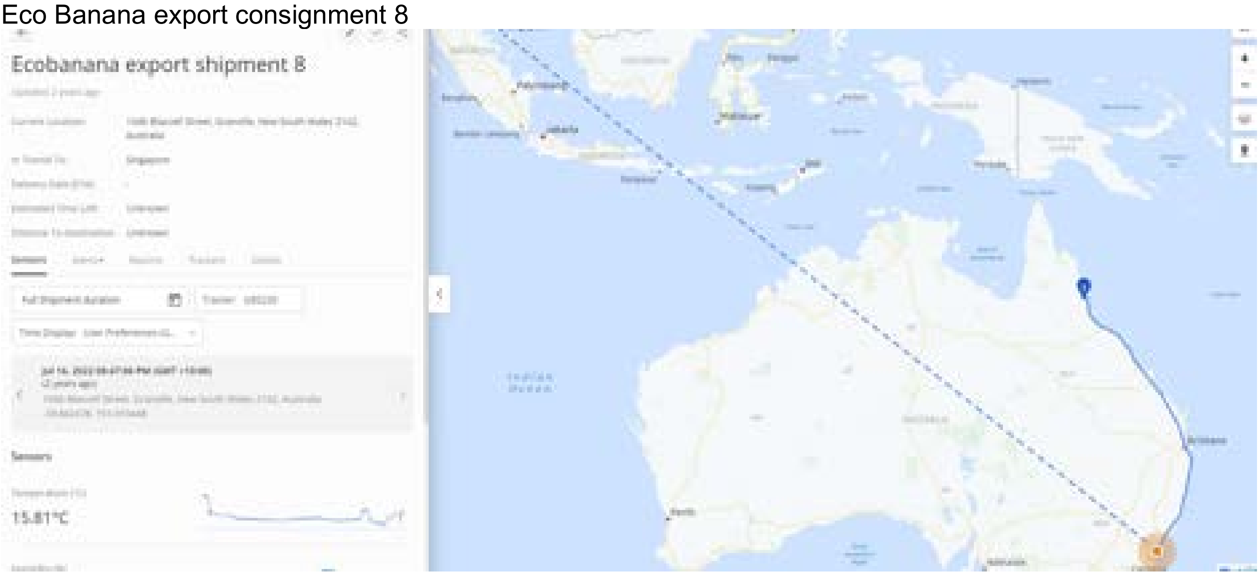

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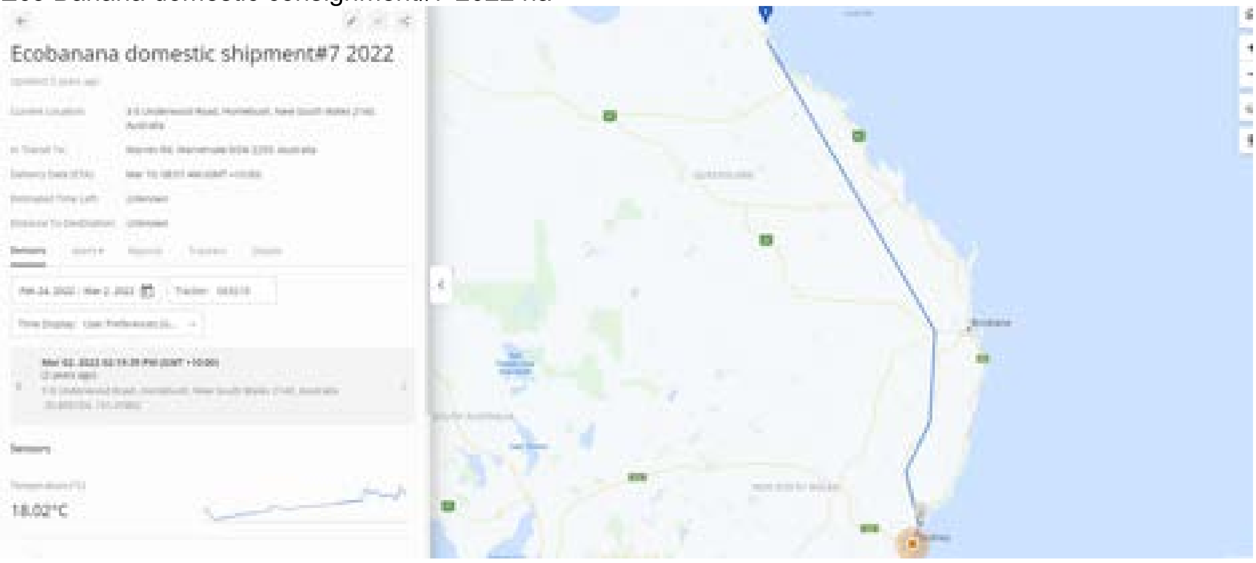

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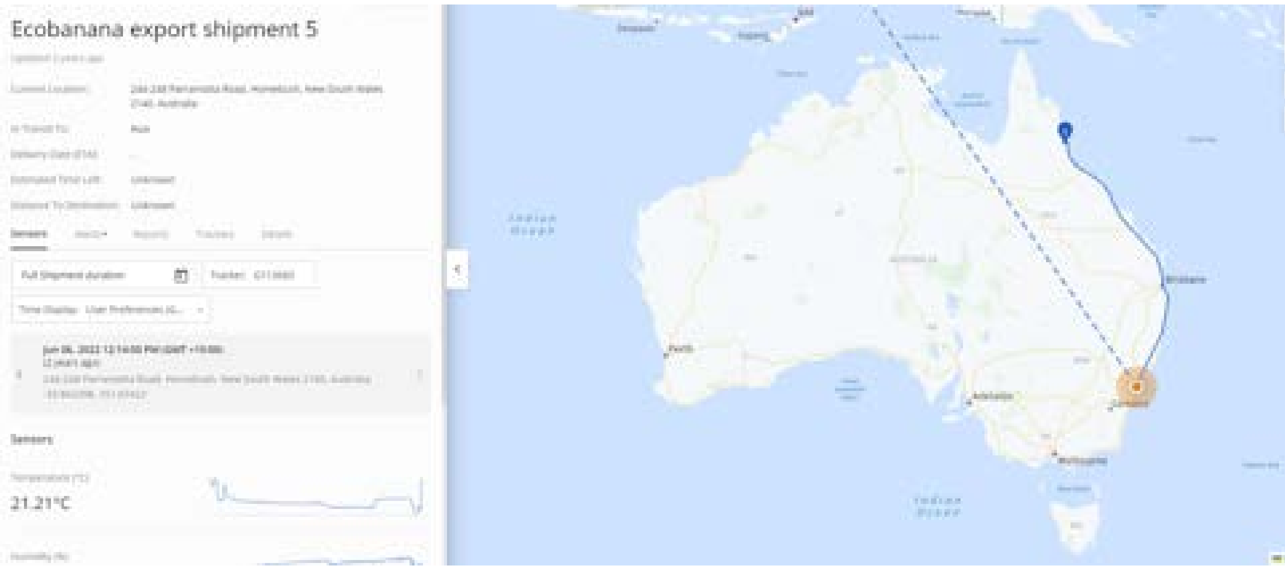

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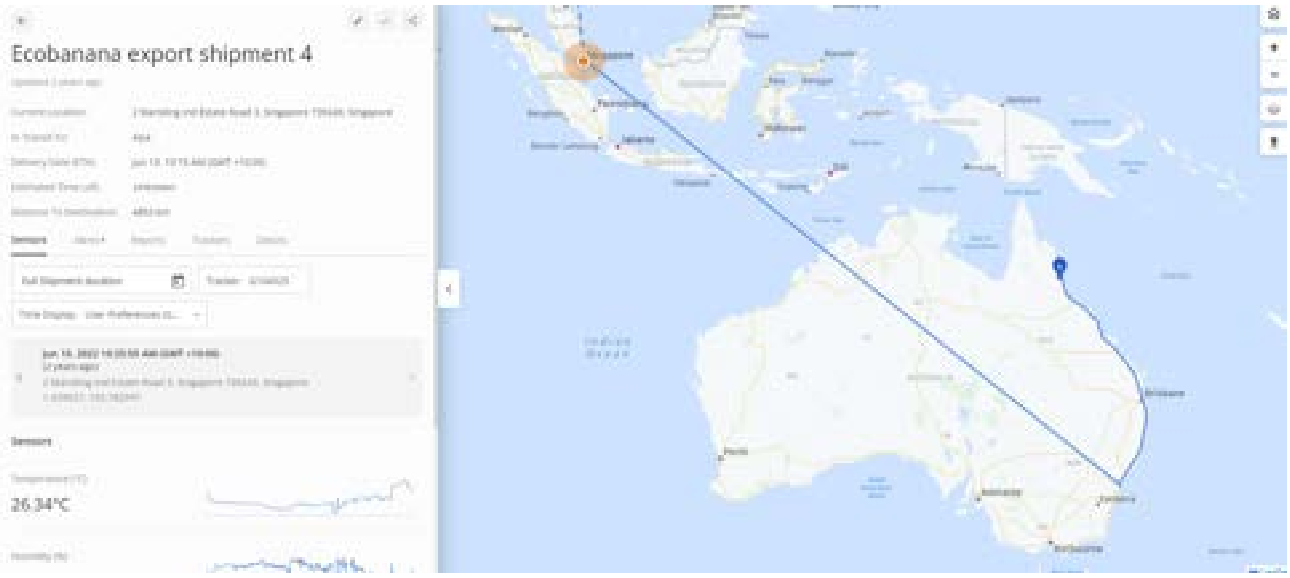

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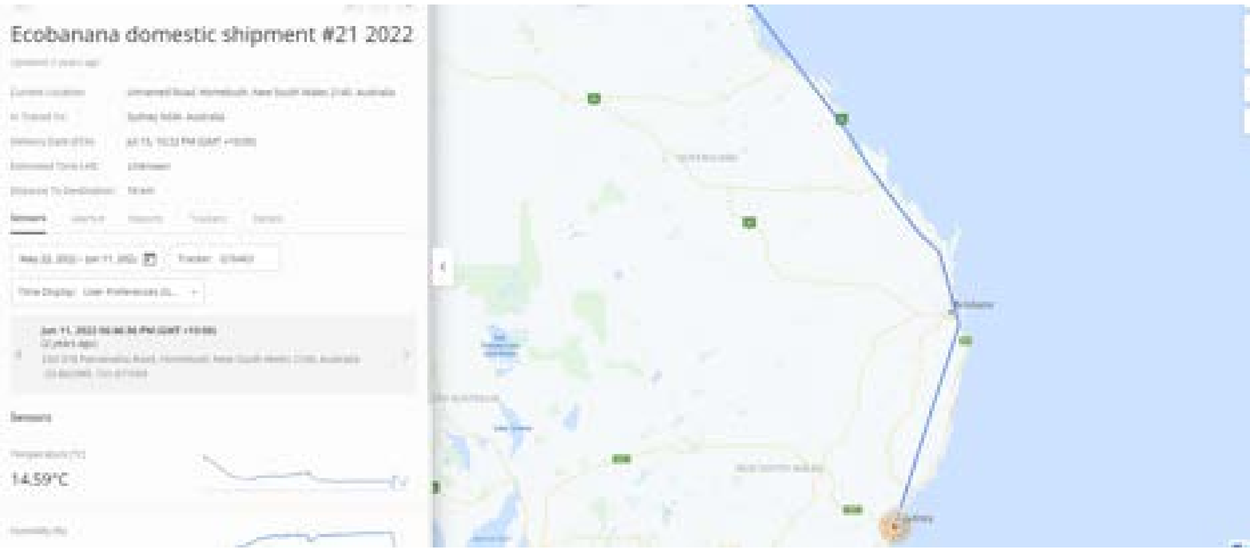

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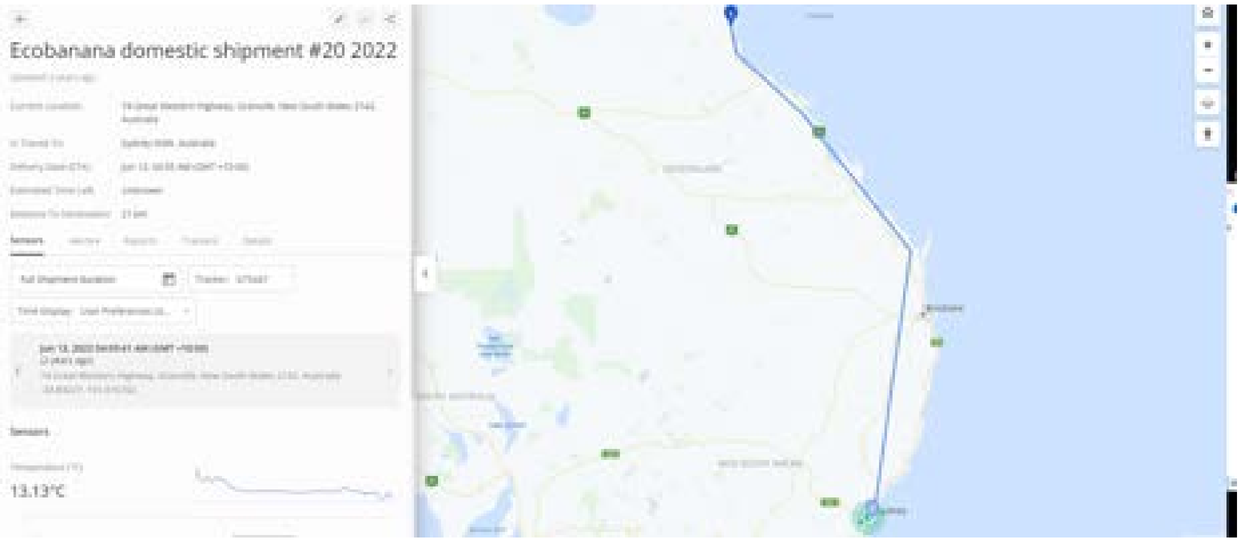

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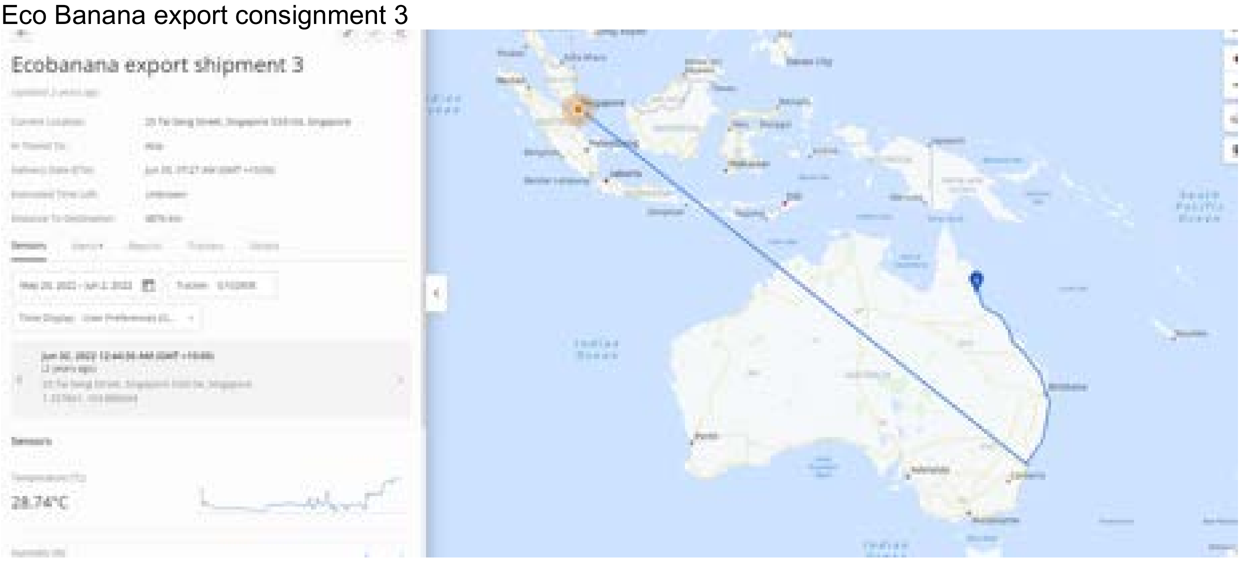

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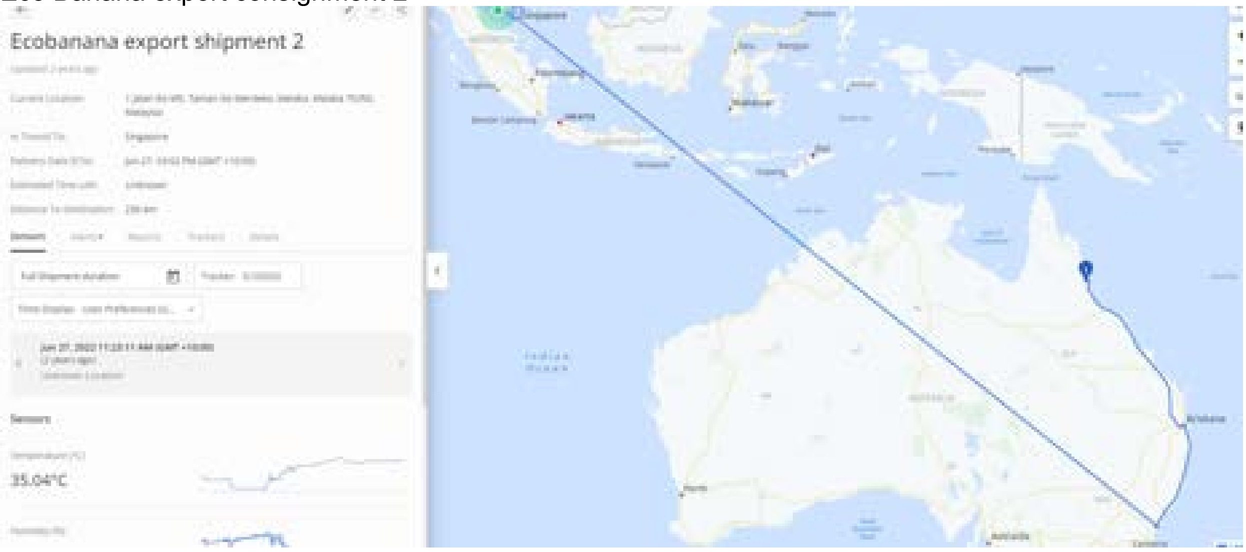

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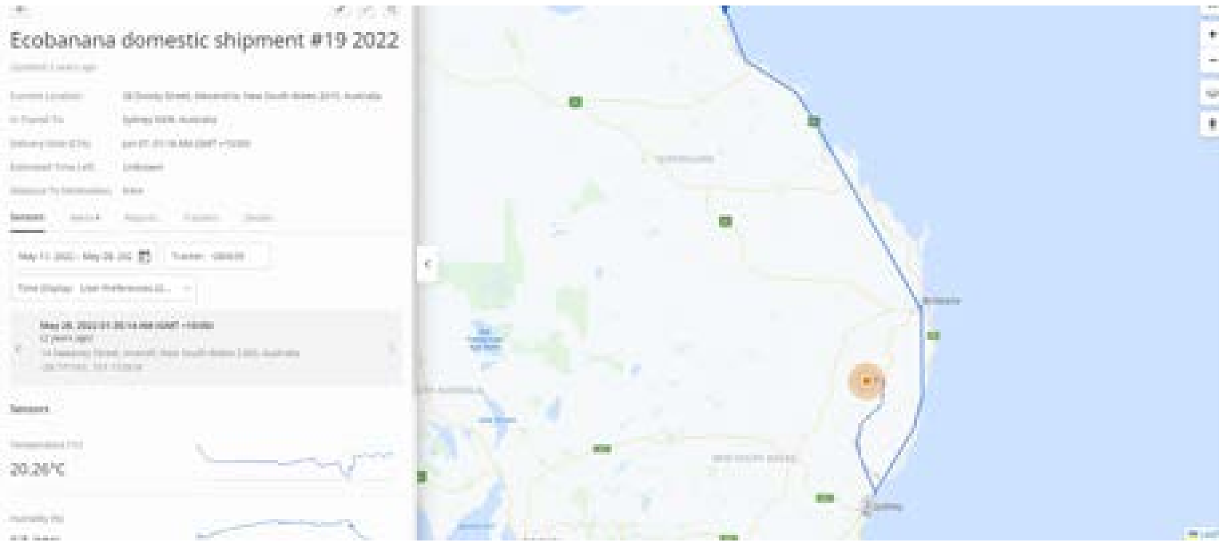

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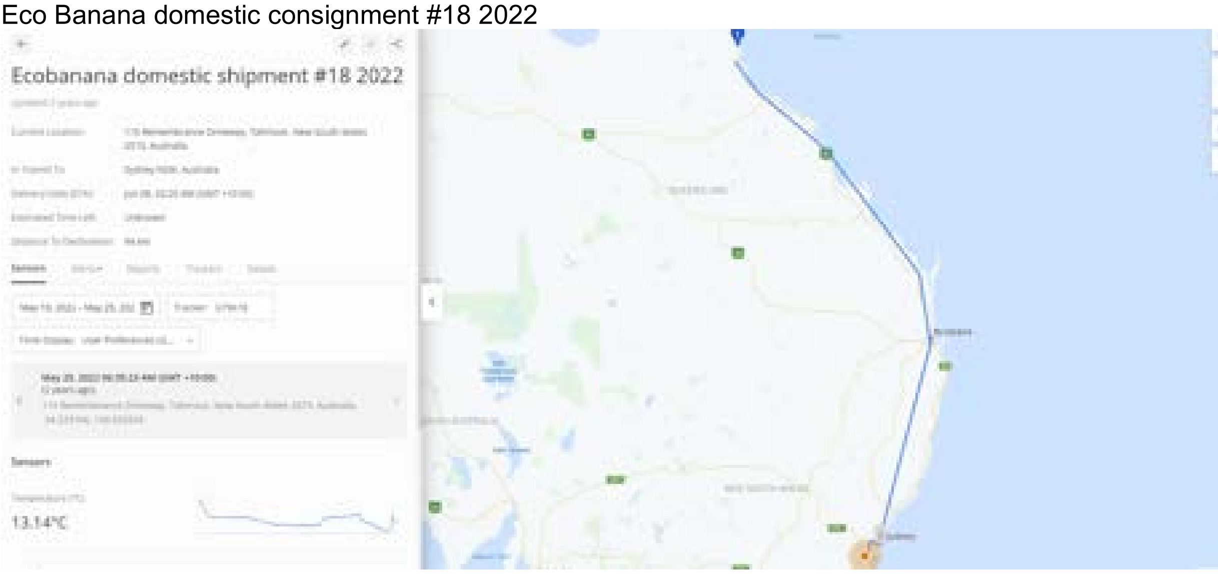

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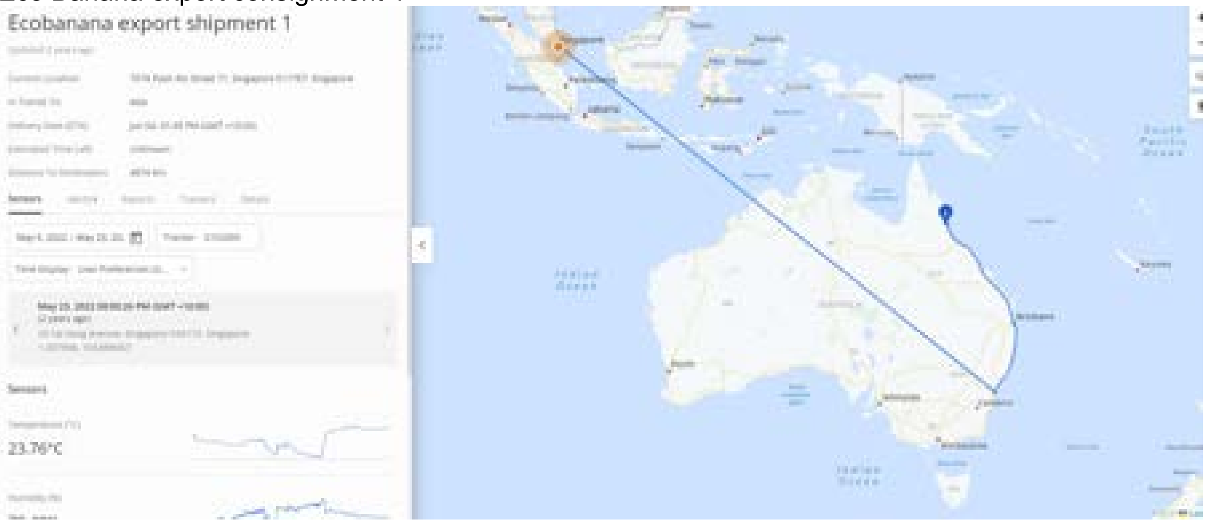

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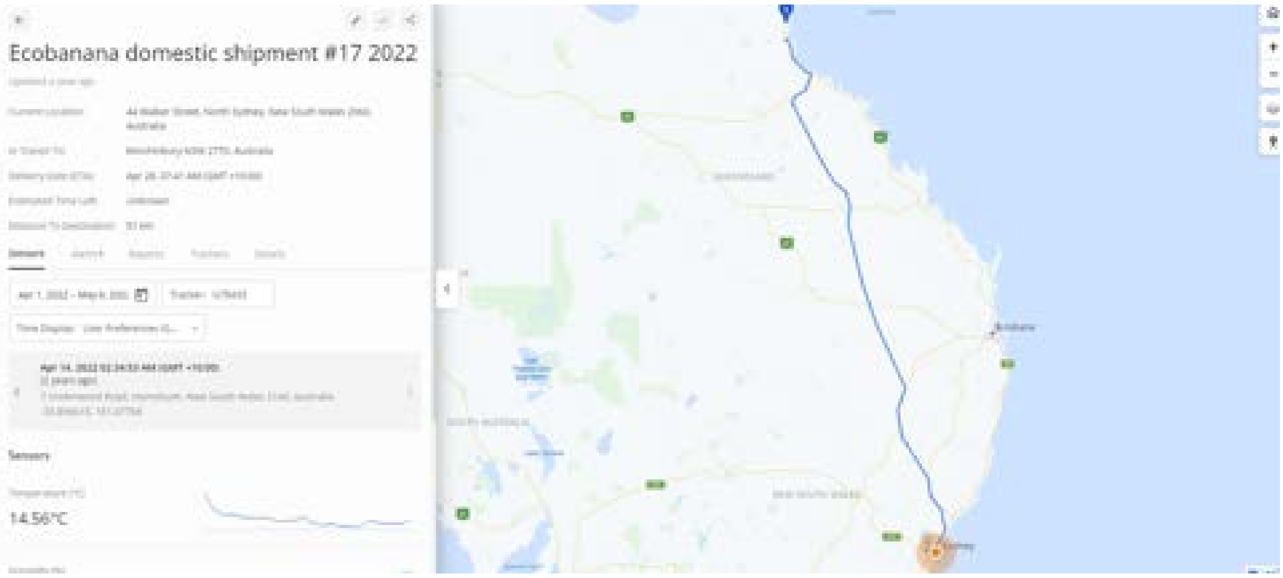

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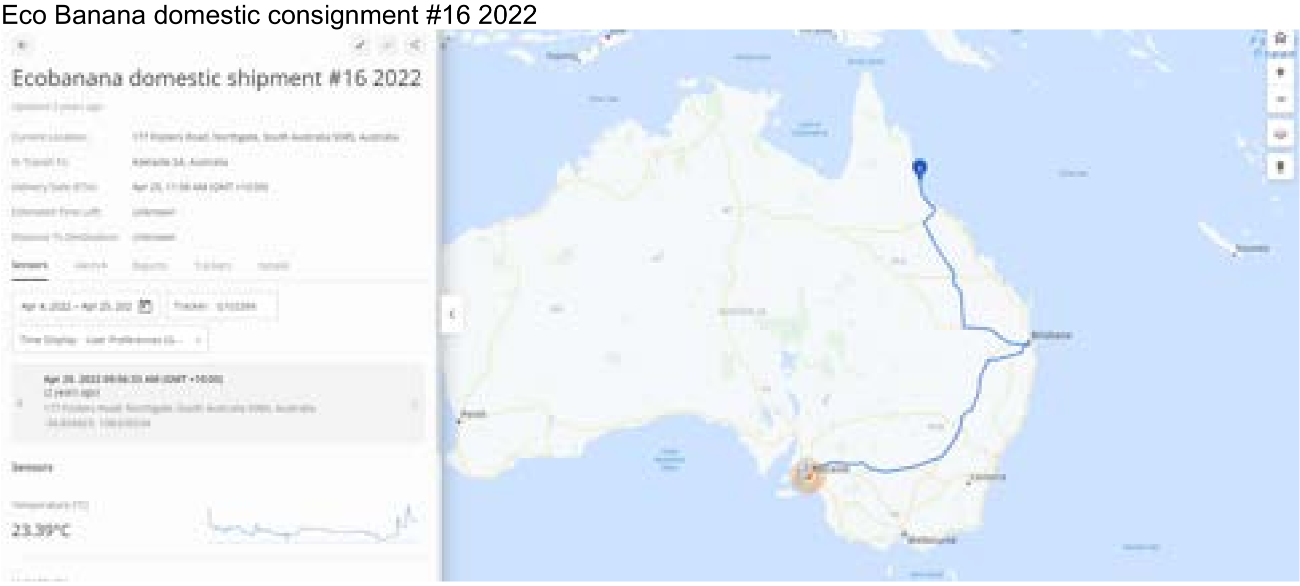

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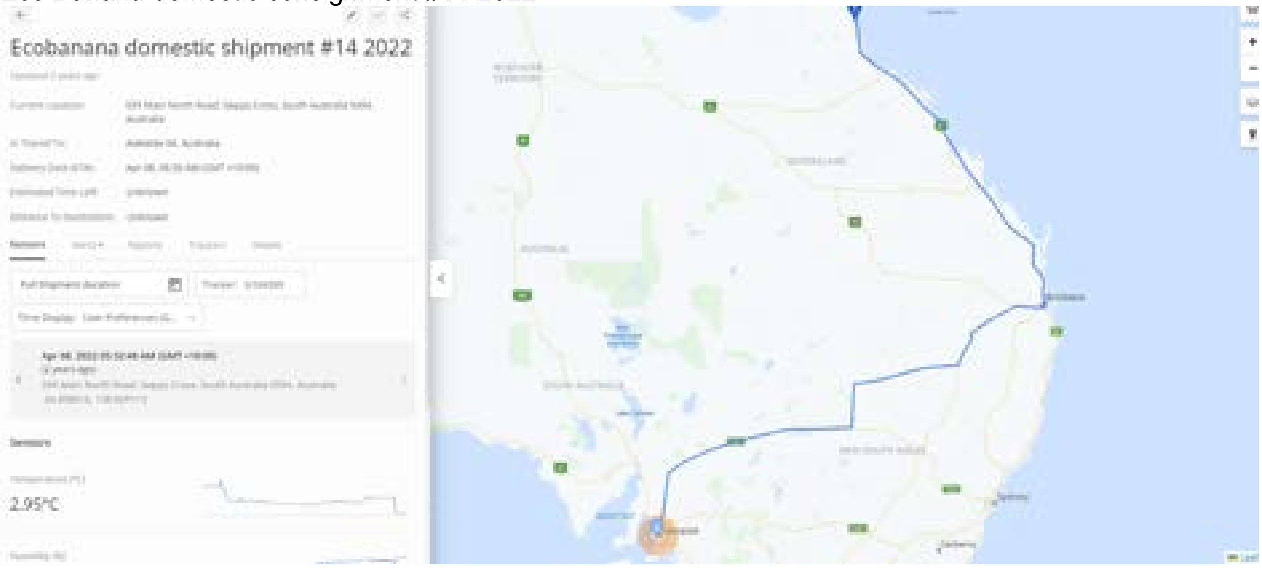

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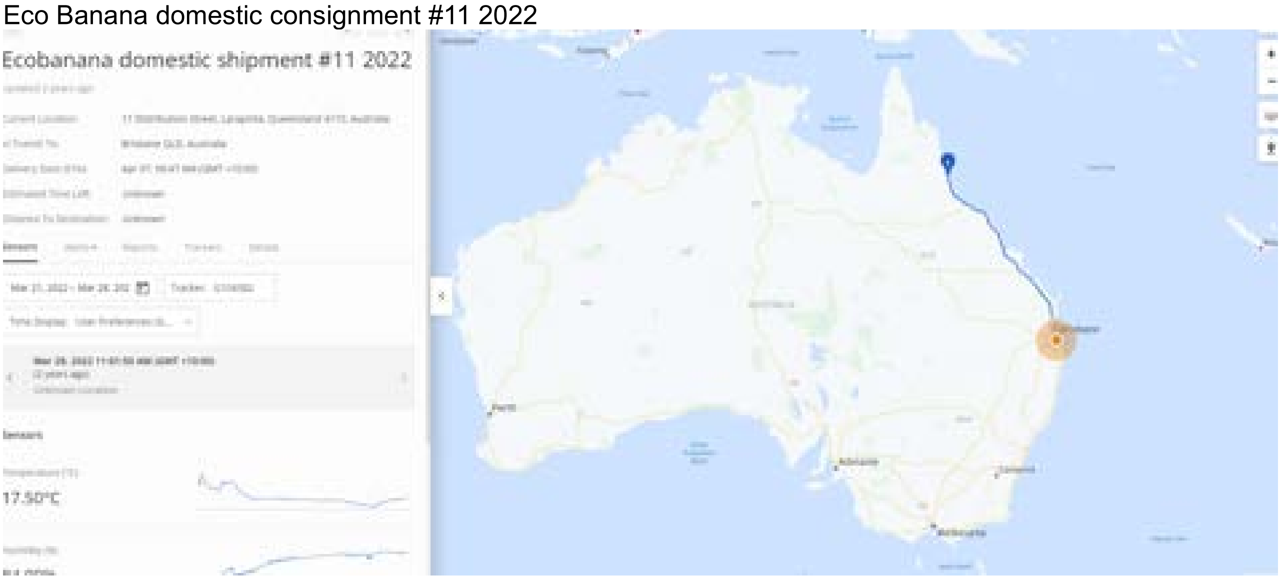

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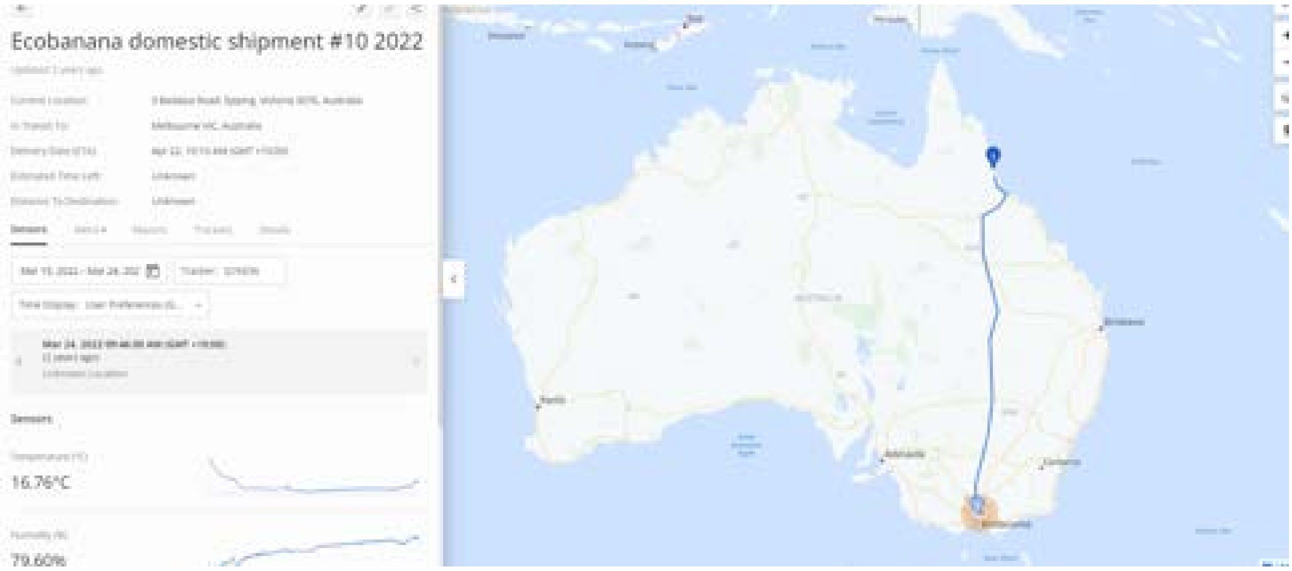

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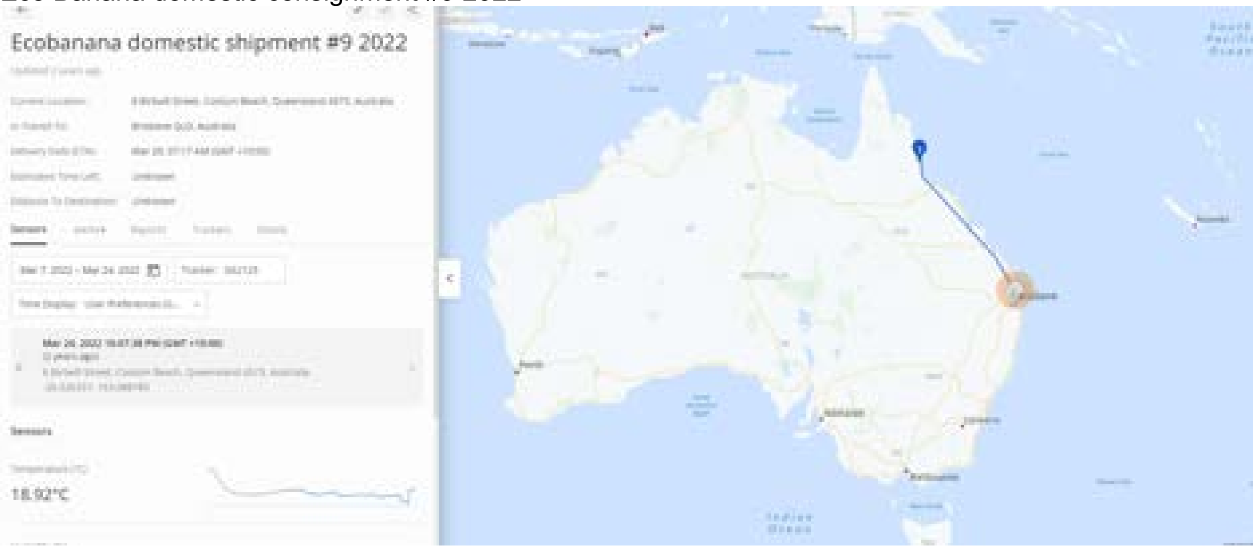

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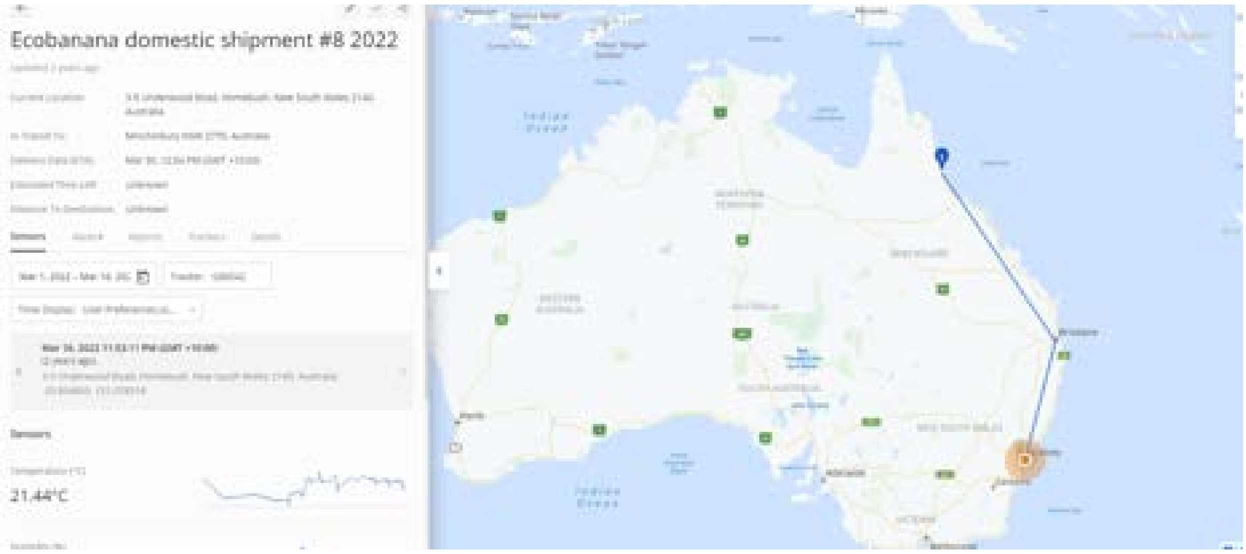

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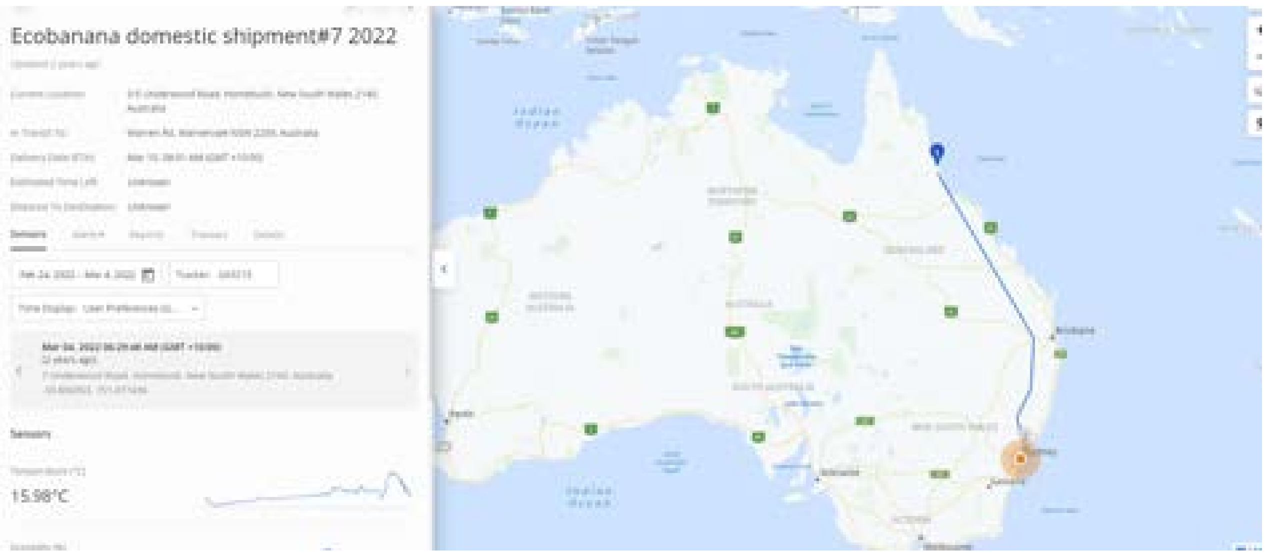

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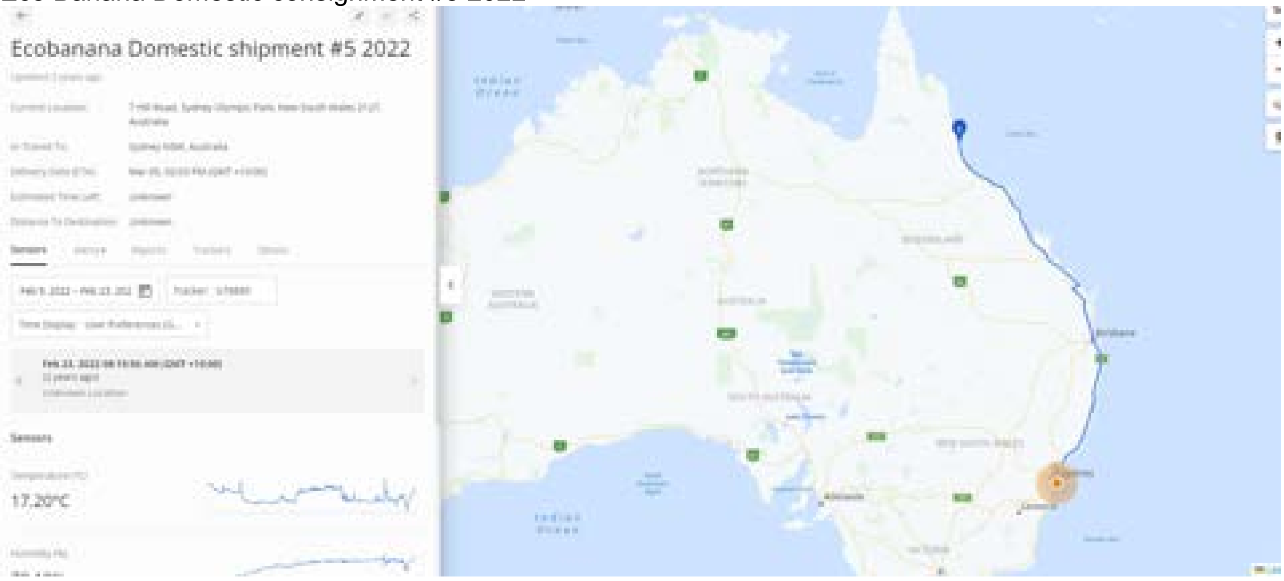

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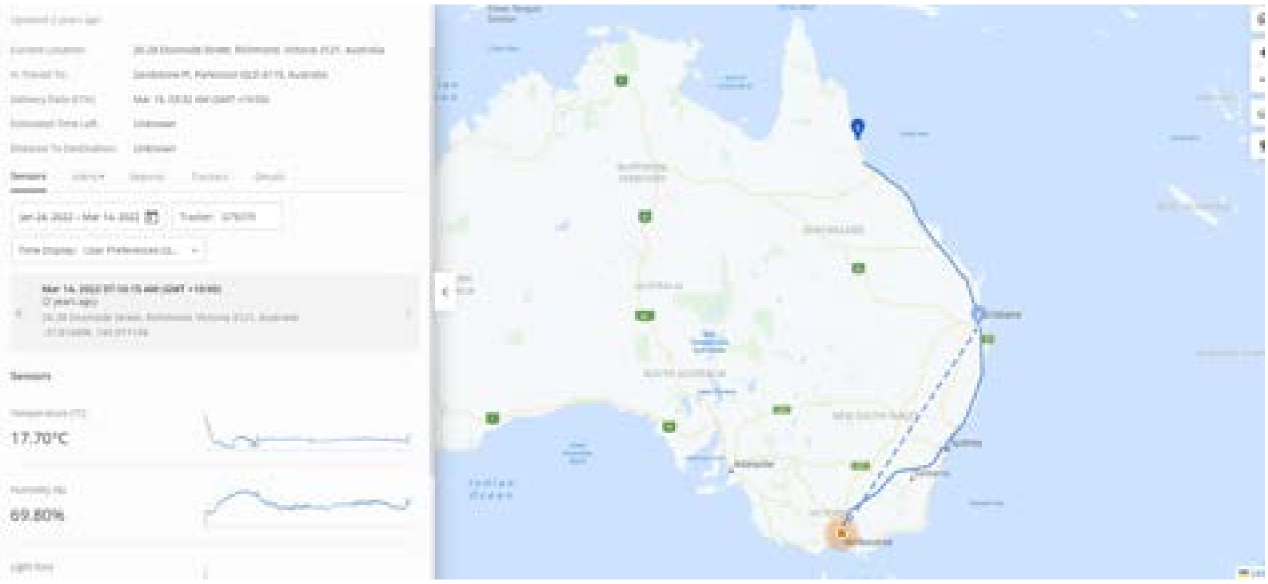

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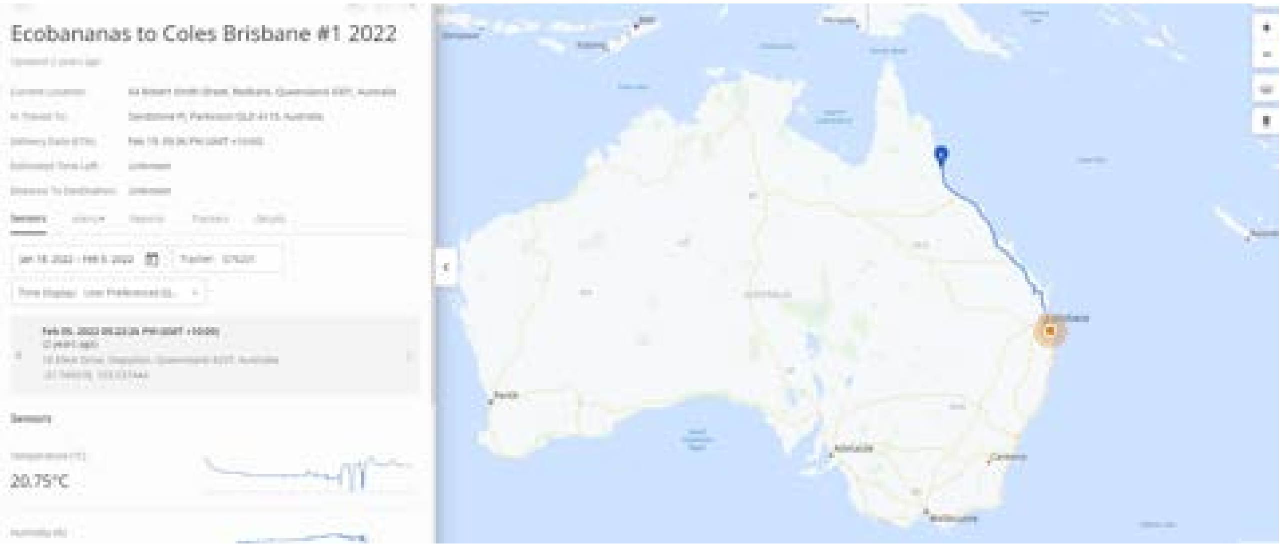
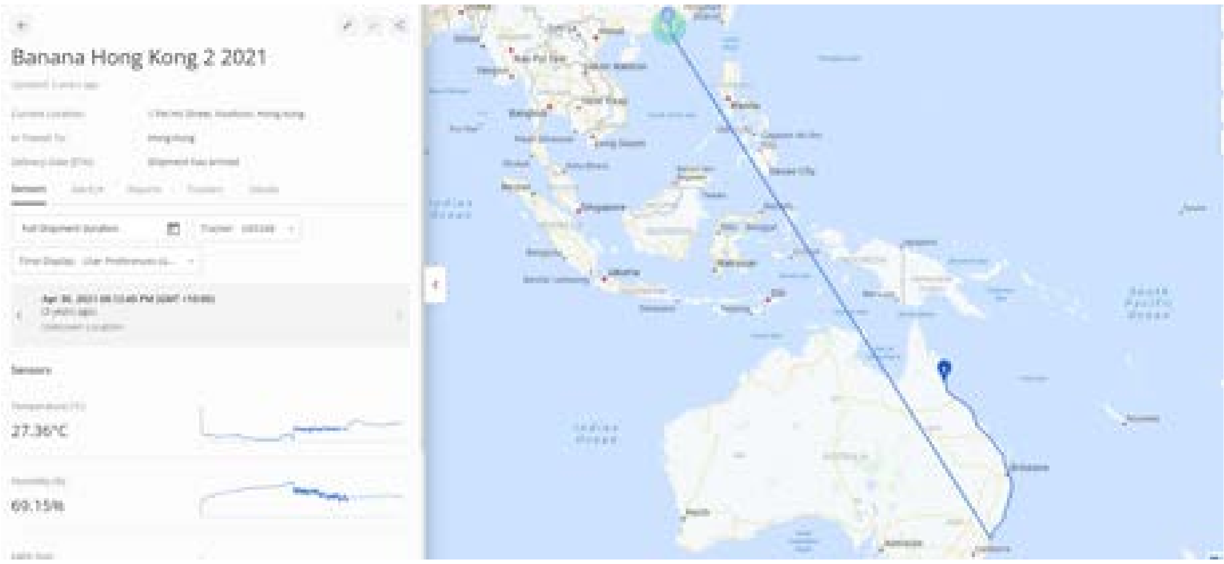


Banana Hong Kong 2 2021



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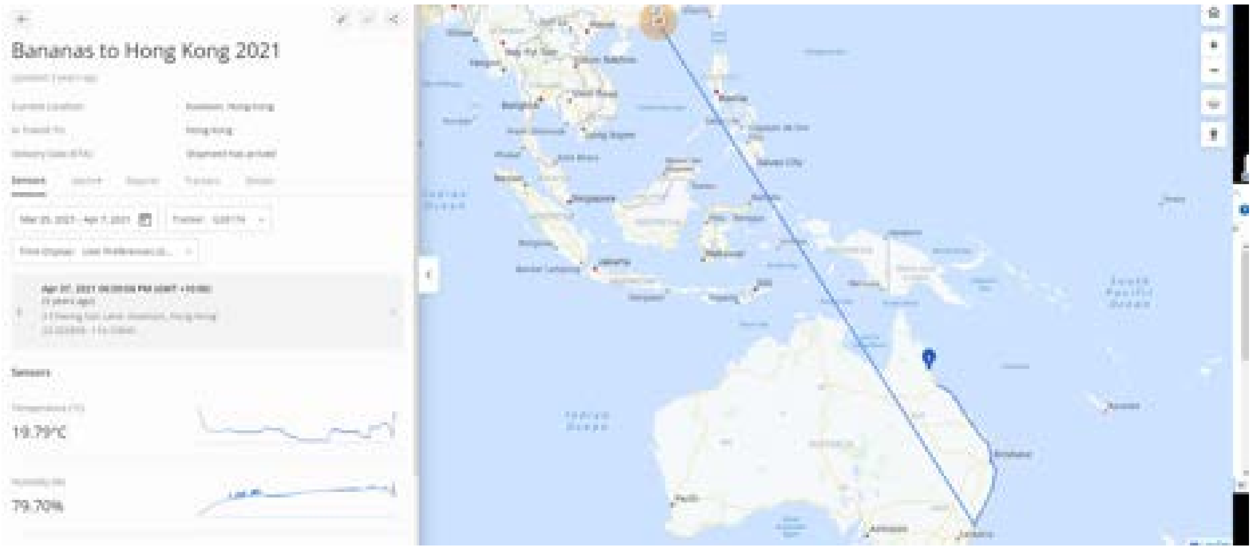
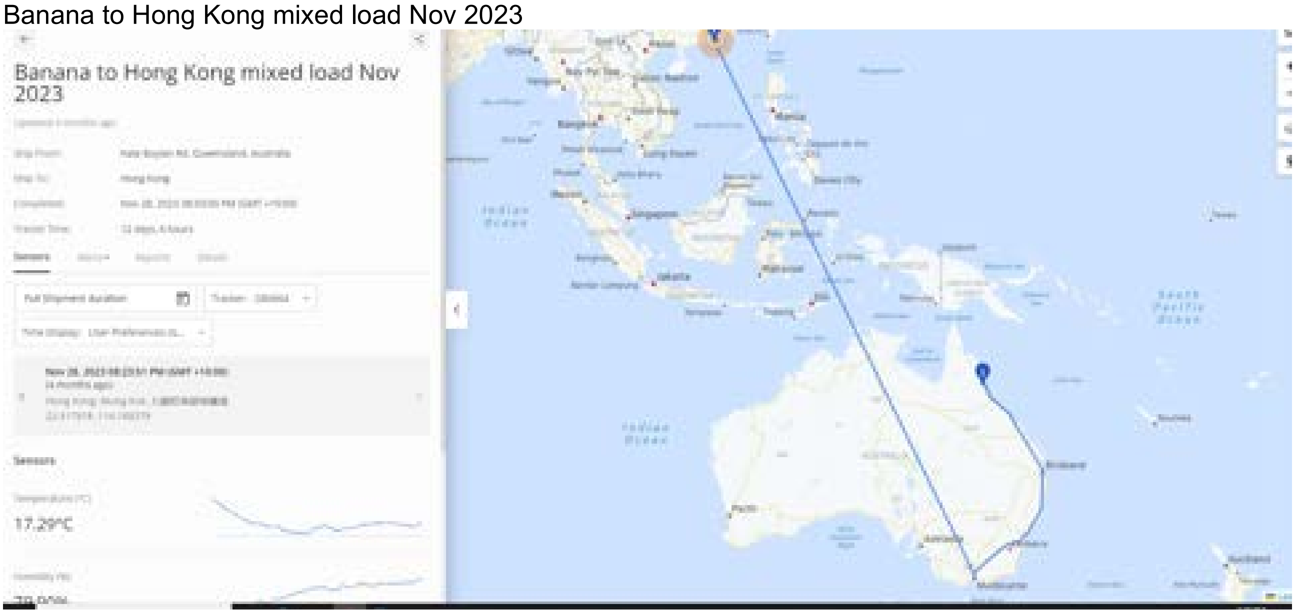


Banana to Hong Kong mixed load Nov 2023



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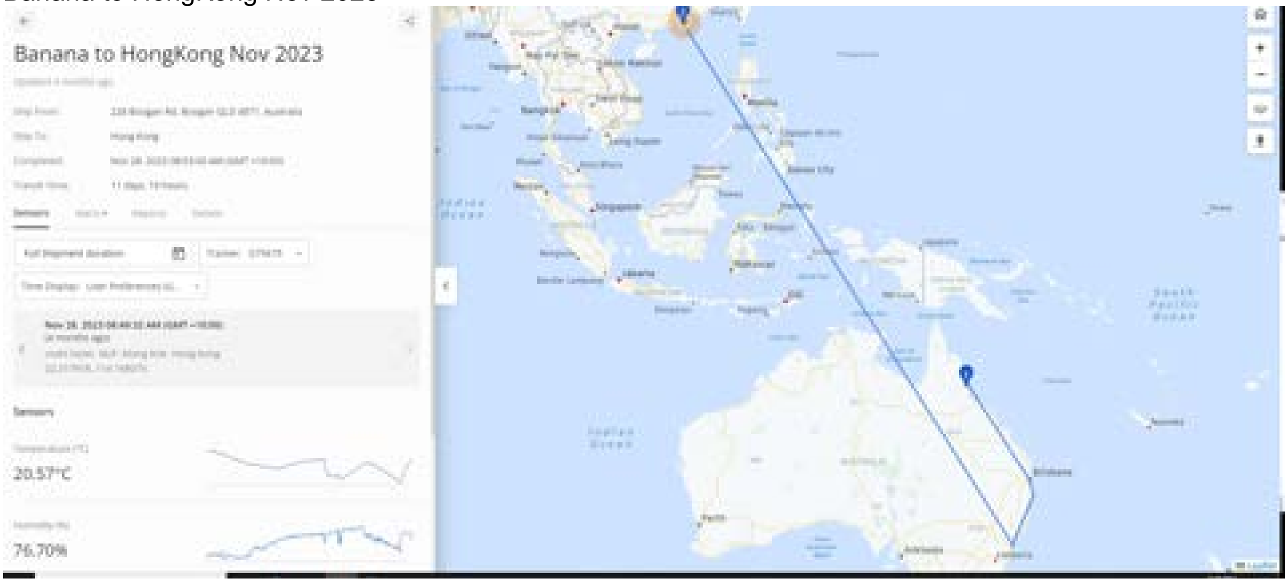
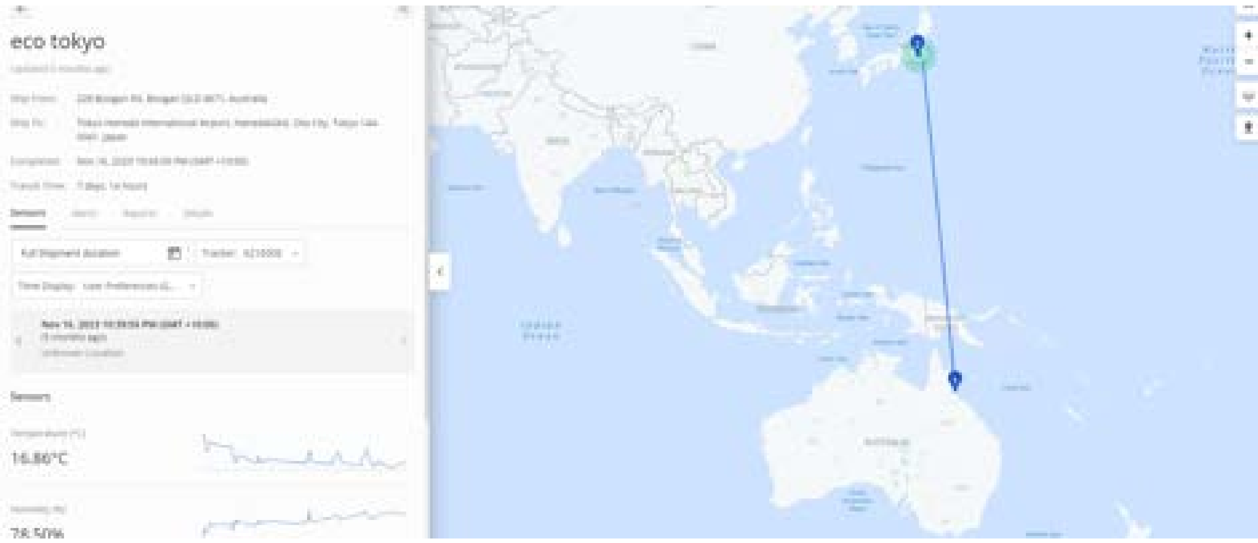
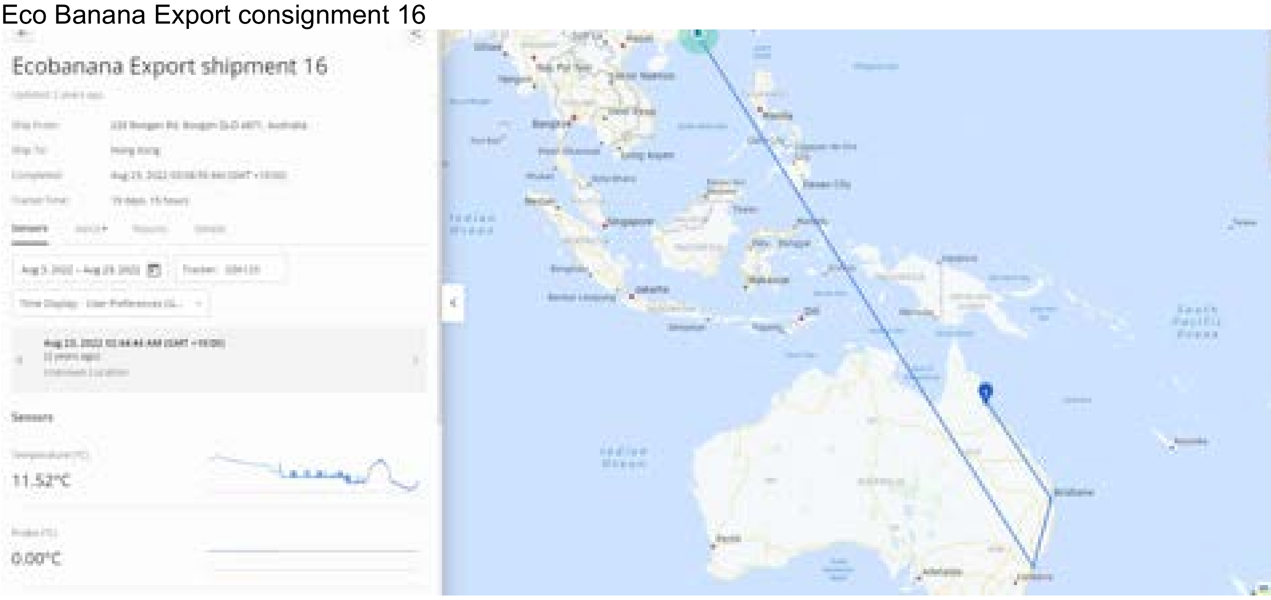


eco tokyo



Eco Banana Export consignment 16



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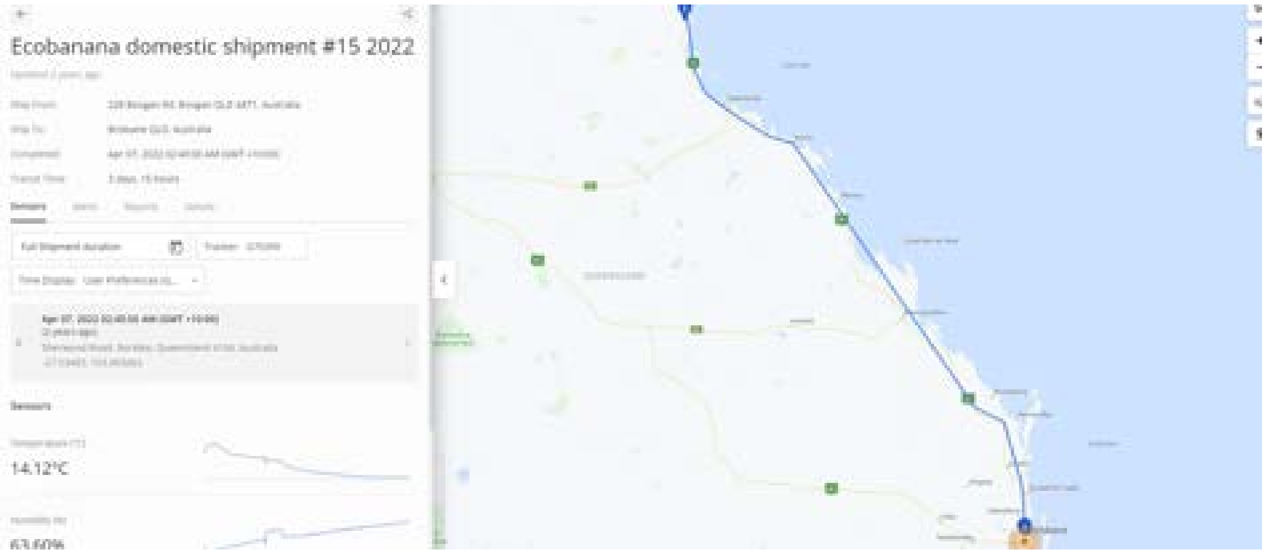
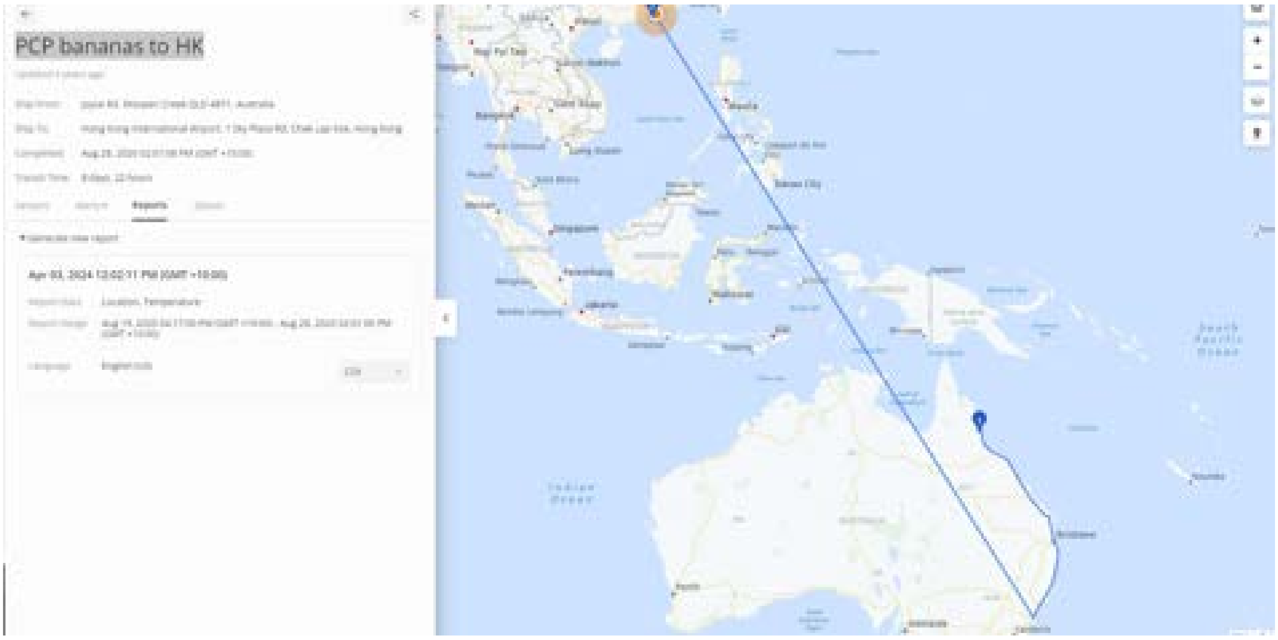
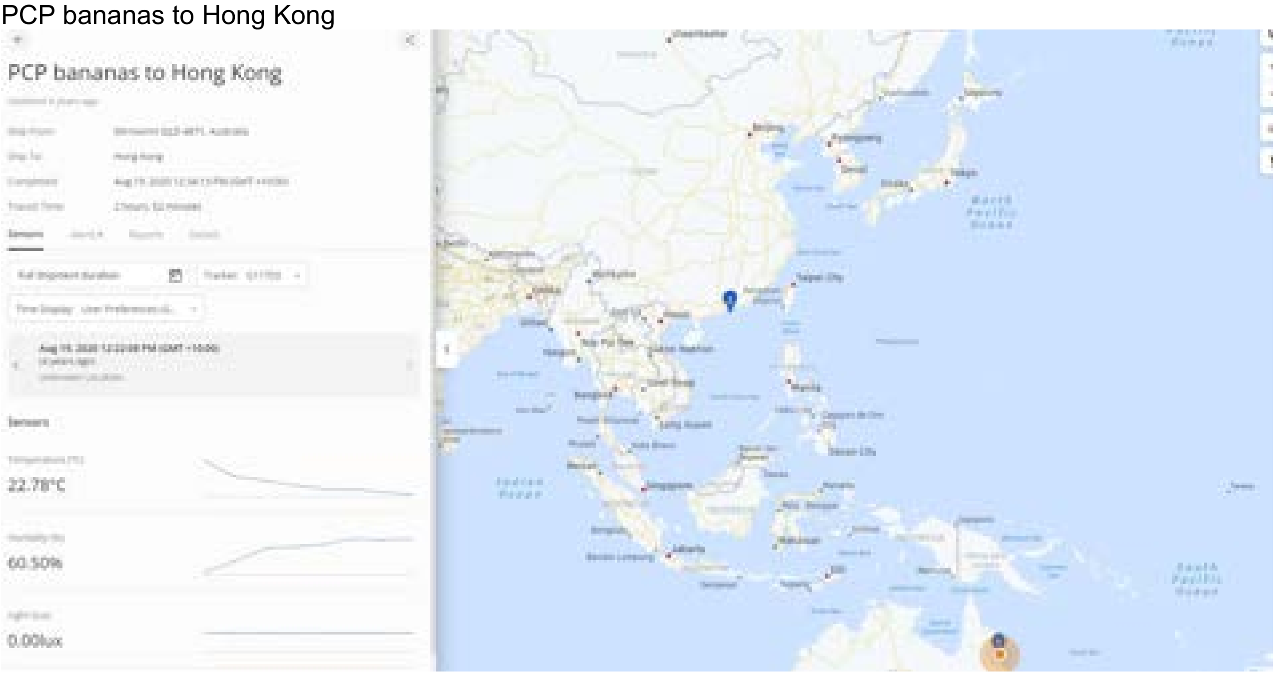


PCP bananas to HK



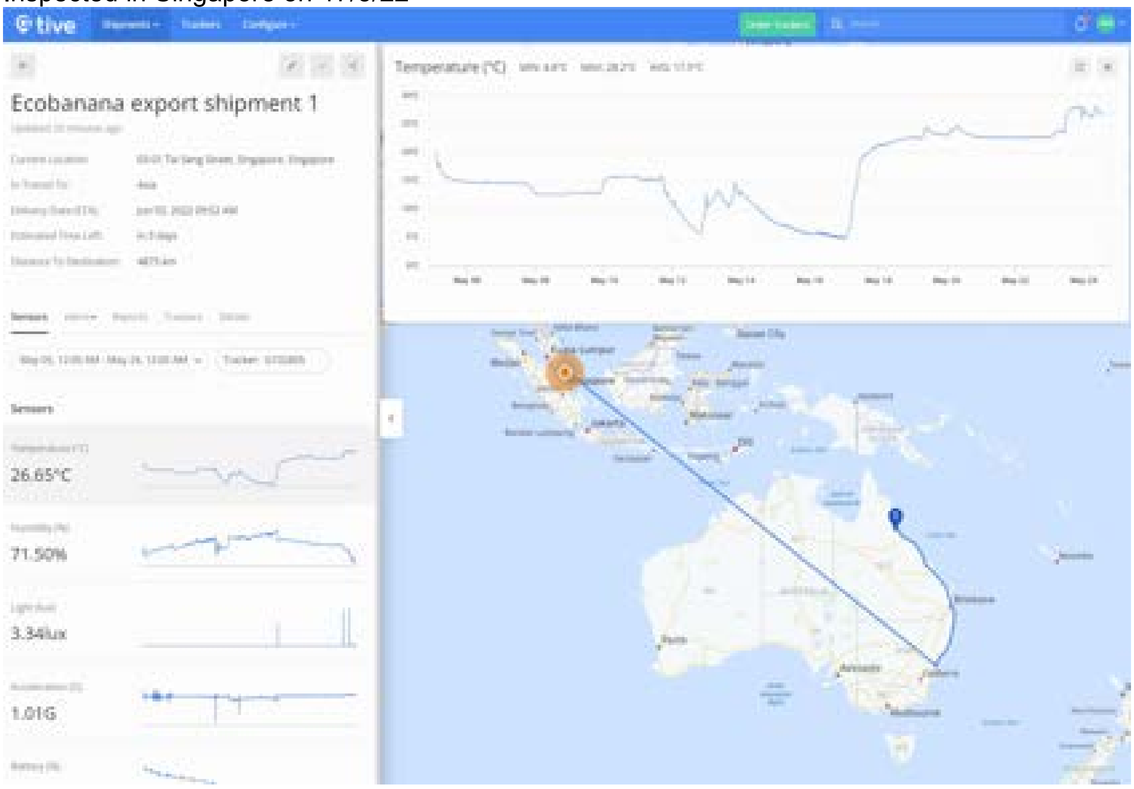
PCP bananas to Hong Kong

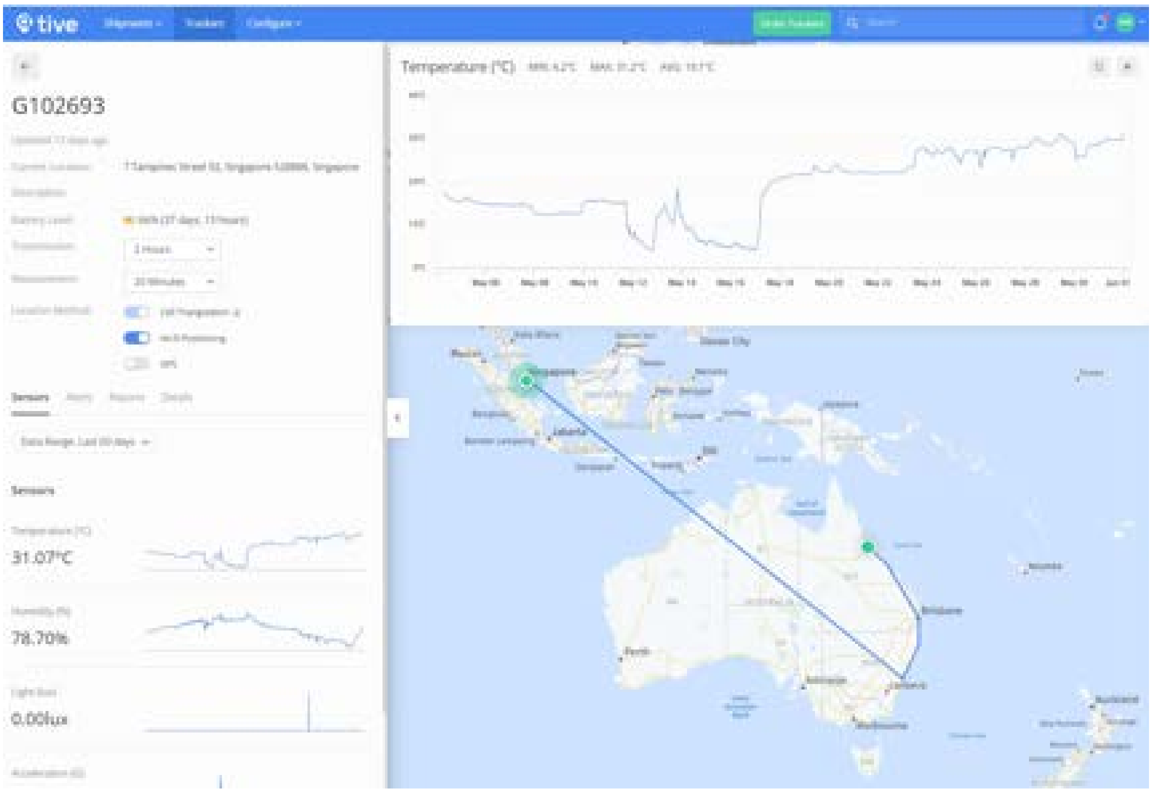


Monitoring of Eco Banana export shipments 2022

Five export consignments were tracked from north Queensland to an importer in Singapore during 2022. Real-time data loggers were included in boxes to quantify handling temperatures. Assessors in Singapore were trained to provide feedback on fruit arrival quality, shelf life and any quality defects that led to consignment downgrading or rejection and associated food waste. The project team identified that exposure to low (<13°C) temperature during consolidation before and after airfreight from Sydney to Singapore was a major risk to fruit chilling and quality loss. By working with the supply chain partners and increasing knowledge about recommended handling temperatures for bananas, fruit in subsequent consignments were handled appropriately and arrived in premium condition. The following is a summary of key observations during the 2022 monitoring activity.

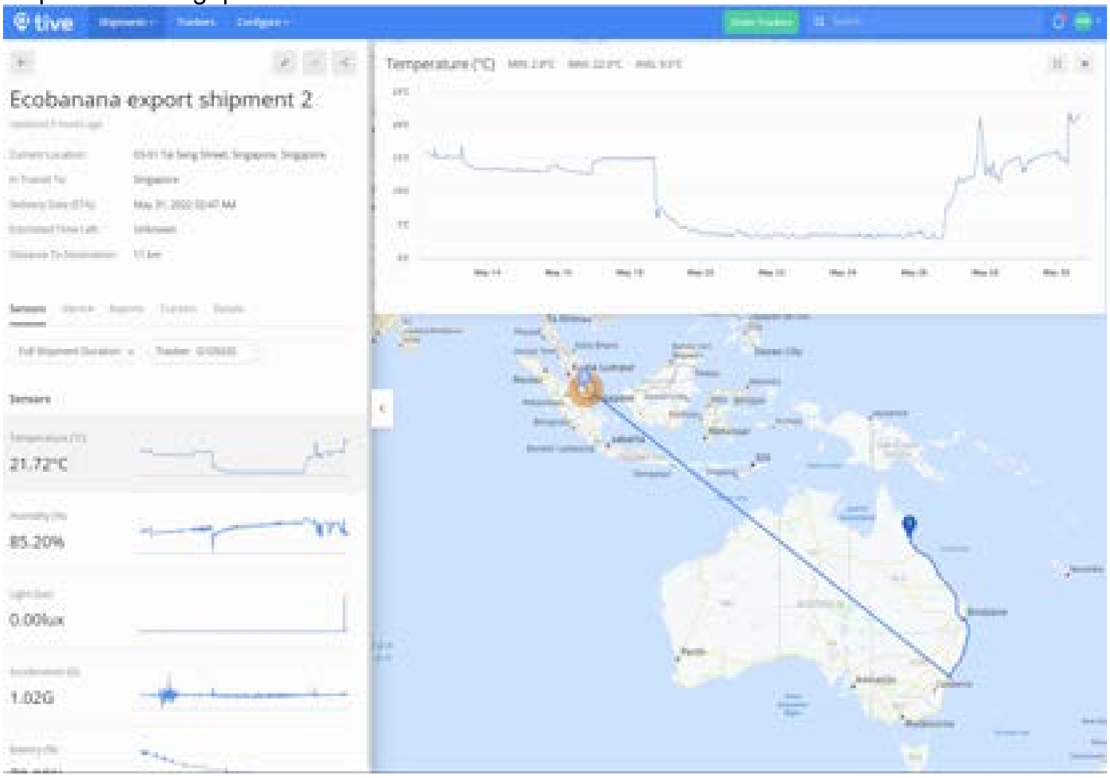
<u>Shipment 1 (Tive loggers G102805 core, G102693 against box wall)</u>
Green-tip fruit packed at Poppi's on 4/5/22, dispatched 5/5/22 at 15°C
Transported to Sydney at 15°C for 2.5 days, arriving early 8/5/22
Ripening for 24 hours in Sydney 10-11/5/22 plus 1 day at 15°C
Transported to FF early on 12/5/22
Held at FF in Sydney for 1 day at 5°C
Exported from Sydney on 13/5/22
Held at importers for 3 days at 5-6°C
Inspected in Singapore on 17/5/22





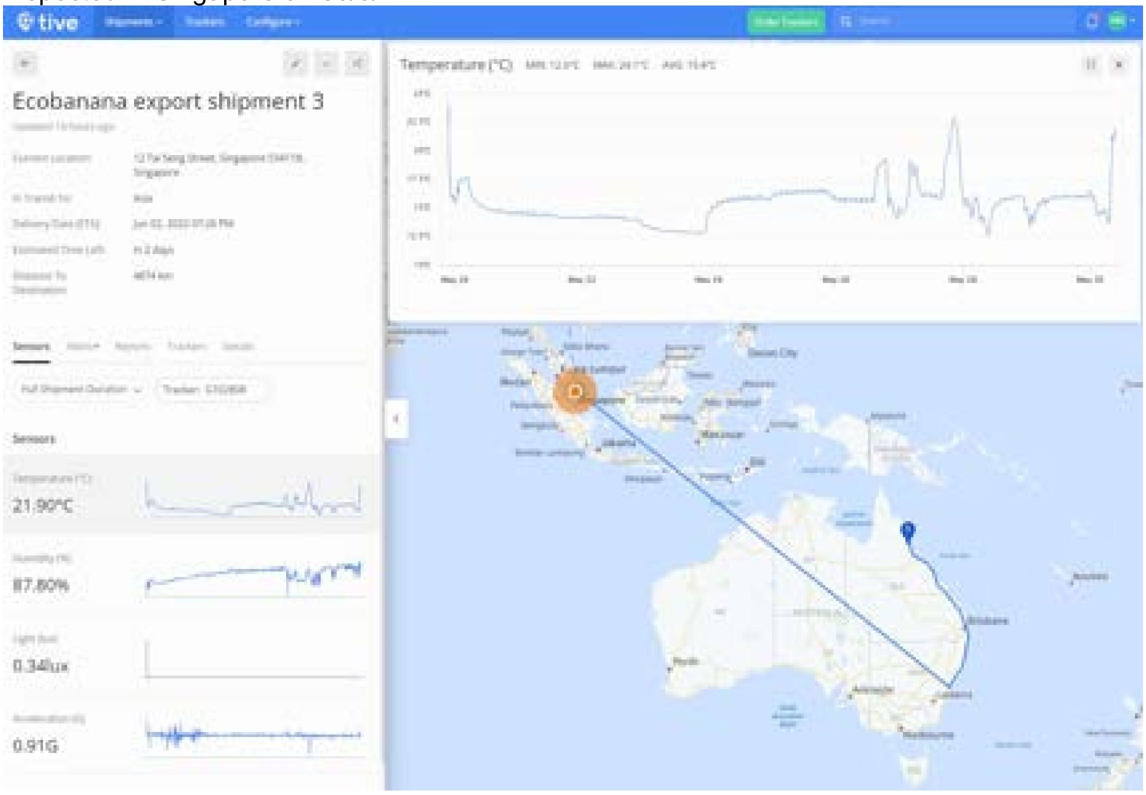
Fruit at inspection in Singapore on 17/5/22 arriving with mild-moderate chilling injury

Shipment 2 (Tive logger G105020)
Red-tip fruit packed at Poppi's on 12/5/22, dispatched at 15°C
Transported to Sydney at 13°C for 2.5 days, arriving early 16/5/22
Ripening for 48 hours in Sydney 17-19/5/22 at 15°C
Transported to FF early on 20/5/22
Held at FF in Sydney for 8 days (missed weekly shipment) at 3°C
Exported from Sydney on 27/5/22
Held at importer for 2 days at 13-15°C
Inspected in Singapore on 30/5/22



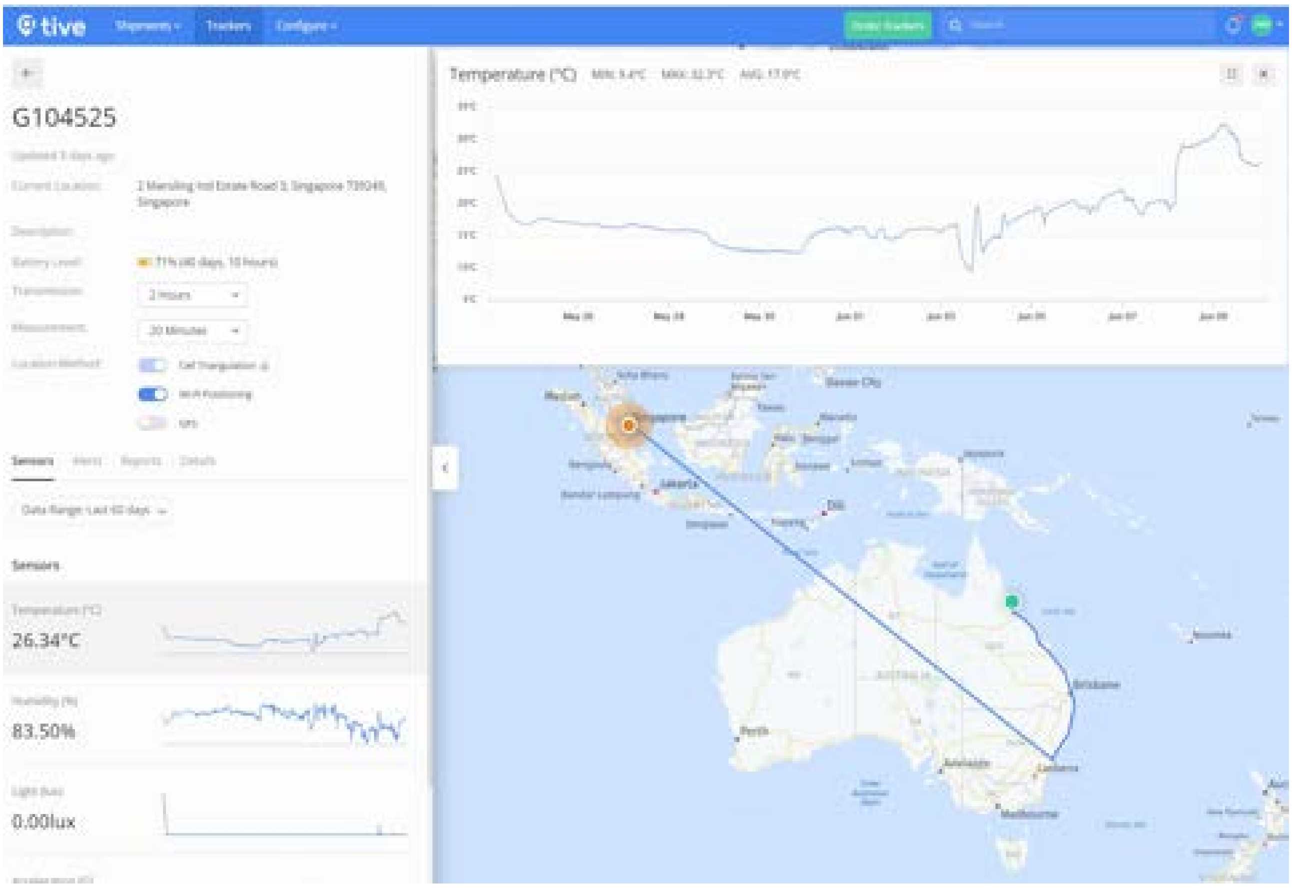
Fruit at inspection in Singapore on 30/5/22 arriving with severe chilling injury

Shipment 3 (Tive logger G102808)
Red-tip fruit packed at Poppi's on 20/5/22, dispatched at 15°C
Transported to Sydney at 14°C for 2.5 days, arriving early 23/5/22
Ripening for 48 hours in Sydney 24-26/5/22 at 15-16°C plus 1 day at 16°C
Transported to FF early on 27/5/22
Held at FF in Sydney for 1 day at 13-18°C
Exported from Sydney on 27/5/22
Held at importer for 2 days at 13-15°C
Inspected in Singapore on 30/5/22



Fruit at inspection in Singapore on 30/5/22 arriving too ripe

<u>Shipment 4 commercial (Tive logger G104525)</u>
Logger started on 24/5/22, fruit dispatched from Innisfail early 27/5/22 at 17°C
Transported to Sydney at 16°C for 2 days, arriving early 29/5/22
Held for 48 hours in Sydney 29-31/5/22 at 12.5°C plus 2 days at 16°C
Transported to FF early on 2/6/22
Held at FF in Sydney for 1 day at 16°C
Exported from Sydney late afternoon on 3/6/22
Held and ripened at importer for 3 days at 16-22°C



Fruit at inspection in Singapore on 6/6/22 arriving at desired intermediate ripening stage

<u>Shipment 5 commercial (Tive logger – no logger)</u>

Fruit harvested on 31/5/22, fruit dispatched from Innisfail early 1/6/22
Exported from Sydney late afternoon on 10/6/22
Arrived Singapore on 11/6/22
Fruit at inspection in Singapore on 13/6/22 arriving at an advanced ripening stage

Export monitoring of Australian bananas 2023

Introduction

Pacific Coast Eco Bananas are a cooperative of five growers in north Queensland. They produce Ecoganic® Williams Cavendish fruit using a certified non-chemical farming system. While most Ecoganic® bananas are produced for the Australian domestic market, small volumes have been regularly exported to high-end retailers in Singapore and Hong Kong since 2009.

Ecoganic® banana export orders and logistics are usually managed by third-party market consolidators in Sydney without the knowledge of the growers. The fruit are typically exported as part of a mixed commodity airfreight consignment. Because the consignments often include highly perishable fruit (e.g. strawberries) and vegetables (e.g. spinach) with a lower storage temperature requirement, the bananas are at risk of being held below the recommended 13°C. Anecdotal reports of fruit being stored too cold before or after airfreight and developing under-peel chilling injury were recently confirmed during monitoring of random export consignments. It is estimated that at least 10% of Ecoganic® banana exports are either downgraded or rejected due to poor arrival quality associated with chilling injury. This represents significant physical food waste plus economic and reputational loss for the Ecoganic® brand.

In the current study, we compared the performance of Ecoganic® bananas that were airfreighted to Hong Kong either as single or mixed commodity consignments. We hypothesised that optimal temperatures would be more effectively maintained in a dedicated banana consignment and lead to more consistent fruit quality outcomes. An additional consignment was airfreighted as a single pallet to Japan to evaluate fruit quality, shelf life and consumer reaction in this potential new market. Specific study objectives were:

- Quantify export handling conditions and fruit quality in single versus mixed commodity consignments
- Identify opportunities for improving supply chain practices to deliver consistent fruit quality
- Survey Hong Kong and Japan consumer preferences for Australian banana quality
- Document the retail quality and price of competing imported bananas
- Promote Australian bananas to high-end retailers

Materials and Methods

Plant material

Hard-green mature Williams Cavendish banana fruit were harvested from a commercial plantation near Innisfail in north Queensland on 9 and 16 November 2023. The fruit were produced under the Ecoganic® farming system that relies on non-chemical growing practices. Harvested banana bunches were transferred to a nearby pack shed where they were de-handed and separated into clusters of 4-5 fruit each using a sharp knife. Fruit were immediately submerged into a chlorinated water bath to remove latex that exudes from the cut surface. The fruit were graded for the absence of external defects and for uniform size. The distal tip of each fruit was dipped in red food-grade paraffin wax, a signature of the Ecoganic® brand.

Fruit packing

Fruit clusters were packed on the same day of harvest into two-piece (i.e. base + lid) corrugated cardboard boxes lined with perforated polyethylene film to a capacity of 13 kg. Paper sheets were layered between the clusters to reduce abrasion damage. Real-time data loggers (Solo 5G; Tive Inc., USA) that record temperature and relative humidity conditions were inserted into randomly selected boxes (**Figure 1**). The packed boxes were palletised for shipment. Six boxes were assembled on a pallet base. Up to 11 layers of boxes were built onto each pallet. The pallets were maintained in a cold room operating at 14-16°C for about 3-4 hours.

Figure 1. Photograph of Frank Sciacca from Pacific Coast Eco Banana with a real-time data logger and palletised boxes of Ecoganic® banana fruit prior to export from the pack shed.

Commercial shipment to export markets
Japan AKE

The consignment for Japan consisted of 100 boxes. On 9 November, the boxes were transported from the pack shed to a depot in Innisfail about 10 km away and maintained in a cold room at 15-17°C for 3.5 days. On 13 November, it was then transported to a freight forwarder in Cairns within 2 hours inside a refrigerated truck trailer. The boxes were then restacked into an AKE airplane container. The two boxes containing the data loggers were positioned at the base and centre of the AKE. Once assembled, the AKE was covered in a layer of reflective insulation film (**Figure 2**). The AKE was held in a cold room at about 13°C for 24 hours prior to delivery to the nearby Cairns airport. On 14 November, there was an attempt to airfreight the AKE, however, there was no capacity on the airplane. The AKE was transported back to the freight forwarder facility. The AKE returned to Cairns airport on 15 November and was loaded into the cargo section of a Boeing 787 airplane (**Figure 2**). It was airfreighted from Cairns to Tokyo (Narita) directly in 7 hours. Once cleared through Customs, the consignment was transported to a ripening facility near Yokohama on 16 November (**Figure 2**). There, the fruit were treated with ethylene gas for 2 days at 16°C. A sample box was transported to a hotel room about 5 km away and held at 22°C to simulate retail display. All other boxes from the consignment remained at the ripening facility until distribution to a retailer.

Figure 2. Photographs showing the layer of insulation applied to the AKE container (left), loading of the AKE onto the airplane (centre) and boxes of Ecoganic® bananas in storage at the ripener in Japan (right).

Hong Kong AKE

Two consignments for Hong Kong were prepared and consisted of 102 boxes in total. On 16 November, the boxes transported from the pack shed to depot in Innisfail about 10 km away and maintained in a cold room at 17°C for 24 hours. They were loaded into a refrigerated truck trailer set at about 15°C and transported by road to a ripening facility at the wholesale markets in Sydney in 2 days. Fruit in all boxes were treated with ethylene gas for 3 days at 18°C (**Figure 3**). The fruit were then cooled to 14°C over the next 24 hours. Two boxes within the consignment that contained loggers were removed from the consignment and prepared for export as a mixed commodity load (see below). The remaining 100 boxes were transported to a freight forwarder near the Sydney airport. The boxes were stacked inside an AKE airplane container. Two boxes containing the data loggers were positioned at the base and centre of the AKE (**Figure 4**). Once assembled, the AKE was covered in a layer of reflective insulation film. Within 6 hours, the AKE was delivered to the Sydney airport. On the afternoon of 24 November, the AKE was loaded into the cargo section of an Airbus A350 airplane. It was airfreighted directly from Sydney to Hong Kong in 9 hours. Within 12 hours of landing in Hong Kong on 25 November, the consignment cleared Customs and was transported to the Cheung Sha Wan wholesale vegetable markets. The boxes were stored in a cold room operating at about 10°C. A sample box was transported to a hotel room about 2 km away and held at 22°C to simulate retail display. All other boxes from the AKE consignment were maintained in the cold room for 48 hours prior to wholesale and retail distribution.

Figure 3. Arrival quality of Ecoganic® bananas in Sydney (top left), ethylene gas ripening treatment (bottom left) and peel colour of fruit following gas ripening (right).

Figure 4. Photographs showing placement of Ecoganic® banana boxes within an AKE air freight container at the base layer 1 (left) and centre layer 3 (right) prior to export.

Hong Kong mixed load

The two boxes containing loggers that were separated from the AKE consignment in Sydney were road freighted in a refrigerated truck trailer at about 15°C to the wholesale markets in Melbourne in 12 hours. The cartons were held at about 16°C for 2 days at a freight forwarding facility before being built into a mixed commodity pallet that included broccolini and melons (**Figure 5**). On 27 November, the pallet was transported to the nearby Melbourne airport. It was loaded into the cargo section of a Boeing 747 airplane. The pallet was airfreighted from Melbourne to Hong Kong directly in 9 hours. Within 16 hours of landing, the mixed pallet was cleared through Customs and transported to the wholesale vegetable markets in Cheung Sha Wan. The two sample boxes was transported to a nearby hotel and maintained at 22°C as described above.

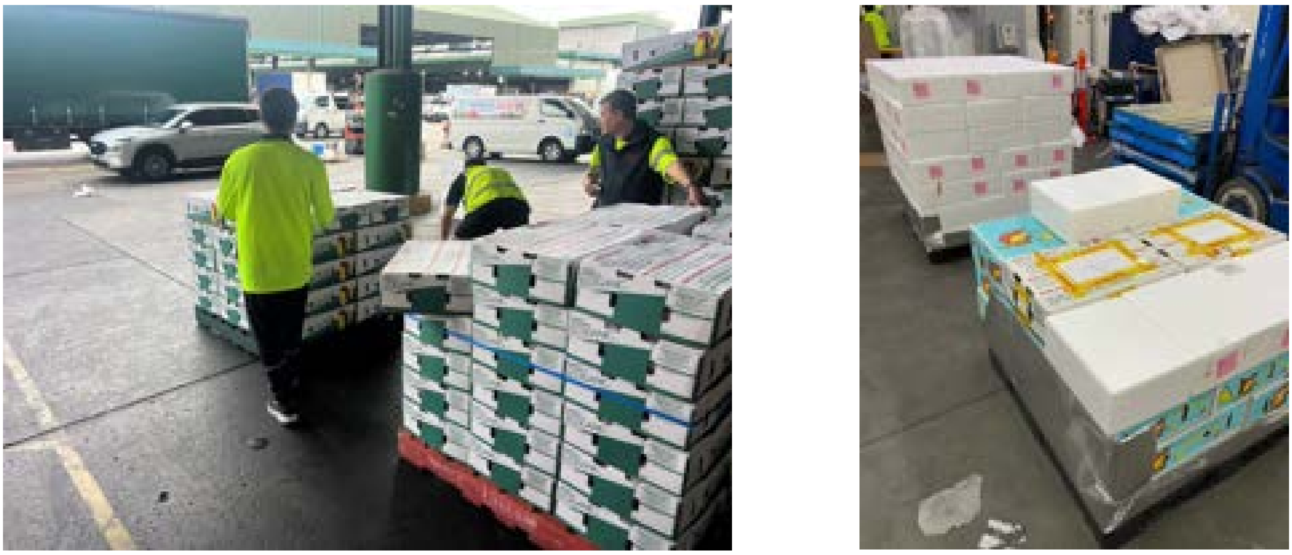


Figure 5. Photographs of palletised Ecoganic® bananas comprising the Hong Kong consignments (left) and placement of two sample boxes at layer 3 in the mixed air freight pallet (right) prior to export.

Library fruit

At each harvest, an additional box of fruit was randomly selected from the pack shed and transported to the DAF laboratory in Cairns to act as library fruit. The fruit were moved between controlled environment cabinets operating at different temperatures to replicate handling conditions in the commercial consignments as informed by real-time reports from the data loggers. The library fruit were treated with ethylene either before or after simulated airfreight to represent conditions encountered by bananas exported to Hong Kong or Japan, respectively.

Competitor analysis

At least eight clusters with five or more fruit from other exporting countries were purchased from retail stores in Hong Kong and Tokyo. Fruit were selected at an equivalent ripening stage to that of the Ecoganic® fruit samples from consignments. Data on fruit price, origin and display peel colour stage were collected.

Fruit quality assessments

Eight clusters with at least five fruit each were selected from each sample box in the export consignments for quality assessment. Peel colour, fruit firmness and skin defects were assessed on arrival at the importer facility and again at ripe (colour stage 6) using subjective rating scales (**Figure 6, Tables 1,2**). Brix and titratable acidity was determined using a hand-held PAL-BX/ACID6 meter (Atago Co. Ltd, Japan). Fruit length and diameter were measured using a flexible tape measure. The shelf life of fruit was judged as the time (days) following storage at the importer until the peel reached colour stage 7. Some shelf life assessments were completed by trained fresh produce surveyors in Hong Kong.

1	2	3	4	5	6	7
Dark green	Light green	50% yellow	75% yellow	Green tips	100% yellow	Brown flecks

Figure 6. Banana peel 1-7 colour scoring system (Dole Food Company Inc.).

Table 1. Banana fruit firmness scoring system.

Firmness score	**Description**
0	Hard
1	Rubbery (slight give in flesh)
2	Sprung (deforms under extreme pressure
3	Firm soft (deforms with moderate pressure)
4	Eating soft (deforms with slight pressure)

Table 2. Banana fruit skin defect severity scoring system

Defect score	**Description**
1	Extreme (more than 25% of surface affected)
2	Severe (10-25% of surface affected)
3	Moderate (10% of surface affected)
4	Slight (5% of surface affected)
5	None

Fruit sensory testing

In Hong Kong, ripe Ecoganic® and imported Cavendish bananas were evaluated by 104 consumers who were randomly recruited from shoppers at the Yau Ma Tei fruit wholesale market (**Figures 7,8**). Fruit were peeled and 1 cm thick cross-sections of pulp were cut using a knife. The flesh sections were placed into clear plastic containers. Consumers were asked to rate the flesh sections for overall acceptability, taking into account fruit flavour and texture. A 0-9 hedonic scale, whereby 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither dislike or like, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely, was used by consumers to assess fruit. An additional pulp segment per fruit was kept for brix and acids analysis (described above).

In Japan, ripe Ecoganic® and imported Cavendish bananas were evaluated by 18 taste testers (8 men and 10 women) from the General Food Inspection Foundation based at the Metropolitan area offices in Ota City, Tokyo. Assessments consisted of two parts. First, whole fruit appearance was compared by placing them on blue cloth (**Figure 9**). Second, the fruit were peeled, and 1 cm thick cross-sections of pulp were cut using a knife and placed onto white plastic plates. The panellists were asked to score fragrance, appearance, texture, flavour, and overall liking on a 5-point hedonic scale whereby 1 = dislike, 2 = dislike slightly, 3 = neither dislike or like, 4 = like slightly, 5 = like. An additional pulp segment from each fruit was combined for Brix and acidity analysis, conducted by the Food Inspection Corporation.

Figure 7. Photographs showing Australian Pacific Coast Eco Banana Ecoganic® (left) and Philippine Dole Sweetio (right) Williams Cavendish banana fruit used for sensory testing.

Figure 8. Photographs showing the Yau Ma Tei fruit wholesale market in Hong Kong (left) and a market stall (centre, right) where a sensory evaluation of Australian Pacific Coast Eco Banana Ecoganic® and Philippine Dole Sweetio bananas was completed.

Figure 9. Photographs showing the General Food Inspection Foundation setting up for the whole fruit appearance assessment.

Retail and wholesale promotion

Additional boxes of fruit from the commercial consignments were provided to wholesalers and retailers in Hong Kong and Japan. The fruit were removed and placed on display at the fruit wholesale markets or in high-end retail stores. The retail sale price was negotiated with wholesalers and retailers.

Results

Japan AKE

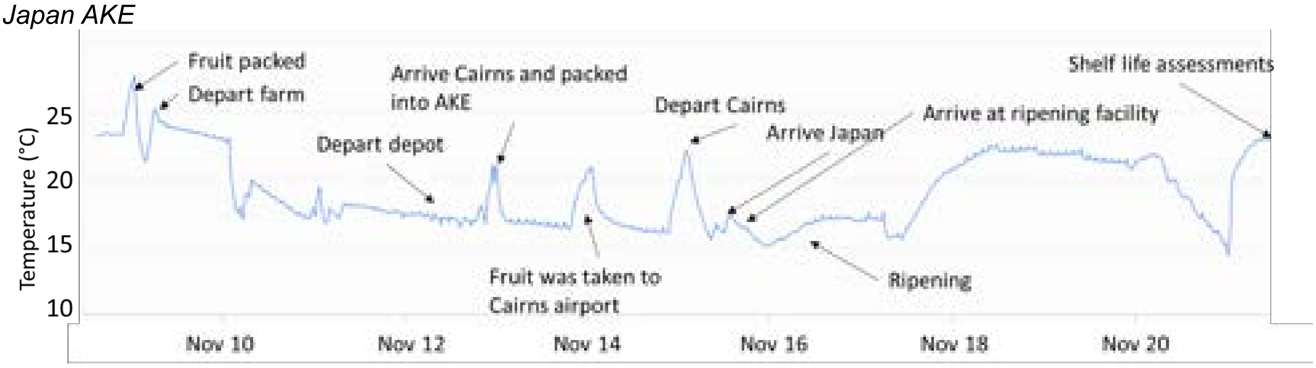


Figure 10. Changes in air temperatures within a box of Ecoganic® bananas from packing at a north Queensland farm, road freight to Cairns, air freight to Japan, ripening, through to display at a wholesale market. Data are representative of a box packed at layer 1 (base) in an AKE air freight container.

Figure 11. Changes in air temperatures within a box of Ecoganic® bananas from packing at a north Queensland farm, road freight to Cairns, air freight to Japan, ripening, through to display at a wholesale market. Data are representative of a box packed at layer 3 (centre) in an AKE air freight container.

Table 3. Time and temperature statistics for each stage of an Ecoganic® banana export supply chain from a north Queensland farm to a Tokyo supermarket. Data represent conditions experienced by sample boxes at two locations within an AKE air freight container. Coloured cells provide an indication of the relative temperature with respect to recommended handling conditions.

Stage	Time (hr)	Edge layer 1 of AKE Temperature (°C)			Centre layer 3 of AKE Temperature (°C)		
		Avg	Min	Max	Avg	Min	Max
At pack shed	5	24.1	21.2	27.7	24.1	22.9	26.9
At depot	40	21.6	16.4	23.2	15.7	13.6	24.1
Storage temperature – Cairns	24	18.1	16.0	21.0	13.8	11.2	18.2
Storage temperature – airport	20	19.4	15.5	22.1	16.6	15.9	18.2
Airfreight and Customs	20	16.0	15.4	19.4	17.7	16.8	19.2
Ripening Storage Temperature:	72				14.3	13.8	14.9
Ripening Process Temperature	72	15.5	15.0	16.2			
Ripening Storage Temperature:	72				21.8	21.2	22.3
Retail Store Temperature	24				21.1	14.1	23.8
Room Temperature	48	20.7	19.7	22.6			

- Too warm
- Warm
- Optimal
- Too cold

Table 4. Ecoganic® banana fruit quality upon arrival in Hong Kong following export from Australia in an air freight AKE container. Fruit were sampled from two boxes at different locations in the container.

Quality attribute	Box 1 (Layer 3)	Box 2 (Layer 1)
Peel colour score	1 ± 0	1 ± 0
Firmness score	0 ± 0	0 ± 0.1
Data are Mean ± standard error (n=45) Colour score: 1 = 100% green Firmness score: 0 = hard		

Figure 12. Photograph of a box of Ecoganic® banana fruit after export from Australia in an air freight AKE container to Japan. (Left) Unripened fruit after arrival at the ripeners, (centre) fruit at full colour, and (right) showing no rub damage or chilling injury.

Table 5. Shelf life of Ecoganic® bananas at 20°C following export from Australia to Hong Kong in an air freight AKE container.

Sample	Shelf life (days)
Box 1	6.0 ± 0.0
Data are Mean ± standard error (n=45)	

Hong Kong AKE

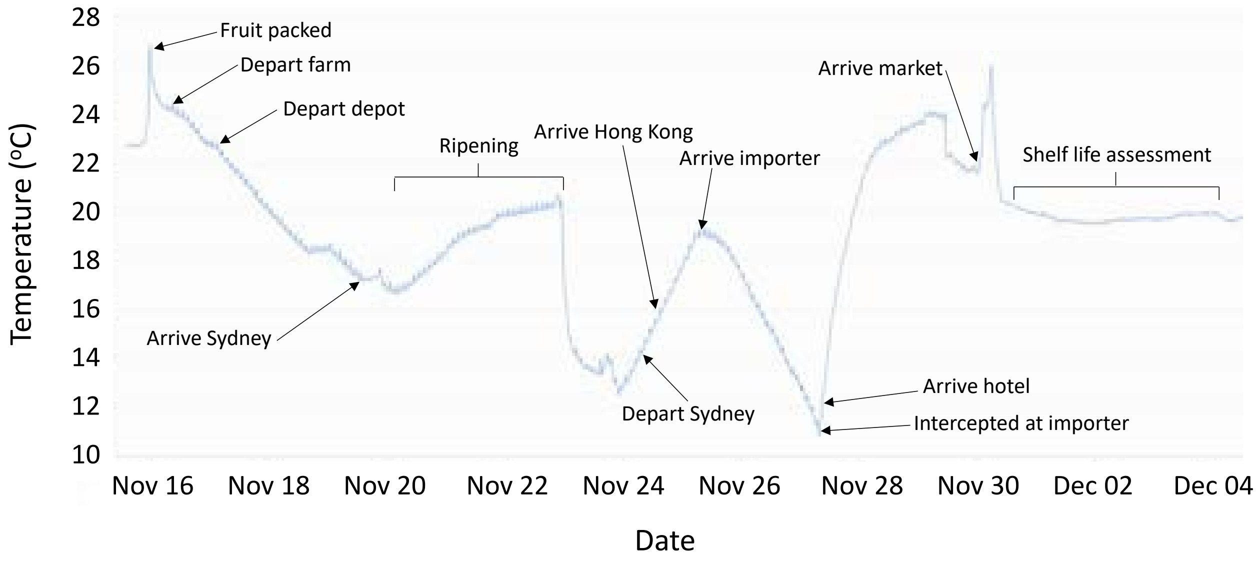


Figure 13. Changes in air temperatures within a box of Ecoganic® bananas from packing at a north Queensland farm, road freight to Sydney, ripening, air freight to Hong Kong through to display at a wholesale market. Data are representative of a box packed at layer 1 (base) in an AKE air freight container.

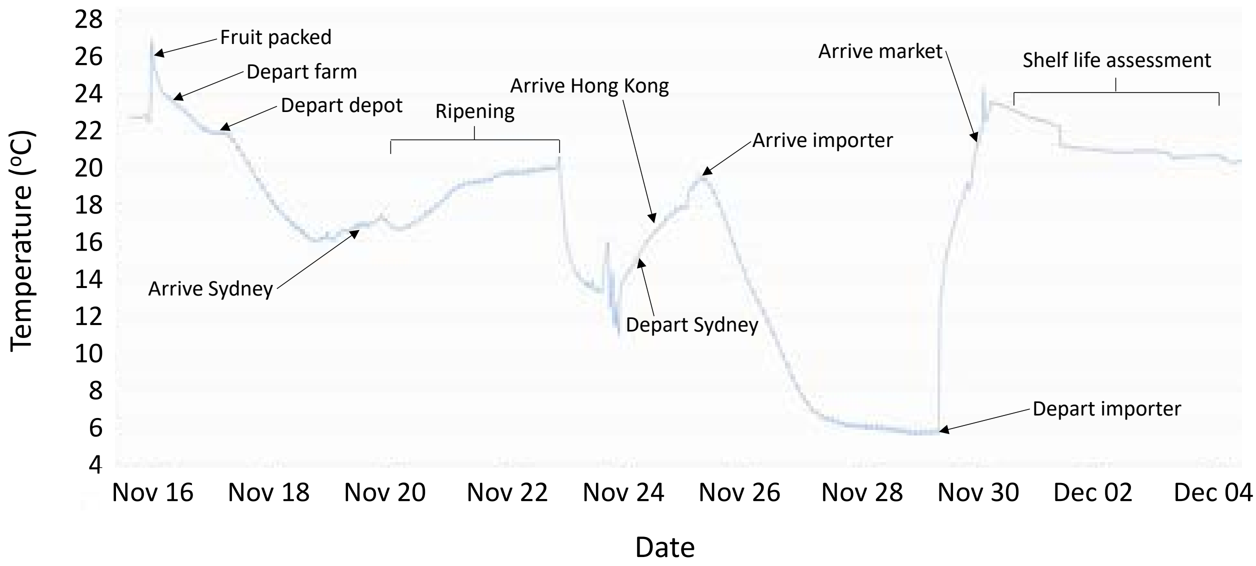


Figure 14. Changes in air temperatures within a box of Ecoganic® bananas from packing at a north Queensland farm, road freight to Sydney, ripening, air freight to Hong Kong through to display at a wholesale market. Data are representative of a box packed at layer 3 (centre) in an AKE air freight container.

Table 6. Time and temperature statistics for each stage of an Ecoganic® banana export supply chain from a north Queensland farm to a Hong Kong wholesale market. Data represent conditions experienced by sample boxes at two locations within an AKE air freight container. Coloured cells provide an indication of the relative temperature with respect to recommended handling conditions.

	Edge layer 1 of AKE				Centre layer 3 of AKE			
Supply chain stage	Time (hr)	Temperature (°C)			Time (hr)	Temperature (°C)		
		Avg	Min	Max		Avg	Min	Max
At pack shed	5	25.0	24.3	26.9	5	24.9	24.0	26.9
At depot	27	23.3	21.9	24.5	27	22.6	21.7	24.0
Transport to Sydney	54	20.6	17.2	24.5	54	17.7	16.0	21.7
Ripening	72	18.9	16.6	20.7	72	18.8	16.6	20.7
Holding before export	30	13.9	12.5	19.5	30	14.2	11.0	18.6
Airfreight	9	14.6	13.6	15.6	9	15.9	14.9	16.7
Customs clearance	24	17.9	15.6	19.3	24	18.3	16.8	19.6
Storage at importer	42	15.3	10.9	19.0	90	8.7	5.6	18.2
Holding until ripe	65	21.3	10.9	24.2	16	17.7	11.3	21.8
Shelf life	96	21.5	19.5	23.0	96	21.5	20.5	23.7

Too warm
Warm
Optimal
Too cold

Table 7. Ecoganic® banana fruit quality upon arrival in Hong Kong following export from Australia in an air freight AKE container. Fruit were sampled from two boxes at different locations in the container.

Quality attribute	Box 1 (Layer 3)	Box 2 (Layer 1)
Peel colour score	3.1 ± 0.1	3.4 ± 0.1
Firmness score	2.2 ± 0.1	2.4 ± 0.1

Data are mean ± standard error (n=40)
Colour score: 3 = 50% yellow, 4 = 75% yellow
Firmness score: 2 = sprung, 3 = firm soft

Figure 15. Photograph of a box of Ecoganic® banana fruit upon arrival in Hong Kong following export from Australia in an air freight AKE container. Fruit are from sample box 2 at the base layer 1 of the AKE.

Table 8. Shelf life of Ecoganic® bananas at 20°C following export from Australia to Hong Kong in an air freight AKE container.

Sample	Shelf life (days)
Box 2 (Layer 1)	5.0 ± 0.0
Box 1 (Layer 3)	4.2 ± 0.2

Data are mean ± standard error (n=40)
Box 1 was stored for 4 days at an average of 9°C
Box 2 was stored for2 days at an average of 15°C

Figure 16. Photograph of representative Ecoganic® banana fruit following export from Australia to Hong Kong in an air freight AKE container showing peel rub (left), ripe fruit quality (centre) and under-peel chilling injury (right). Fruit were sampled from a box at the base layer 1 (left, centre) and centre layer 3 (right) of the AKE.

Hong Kong mixed load

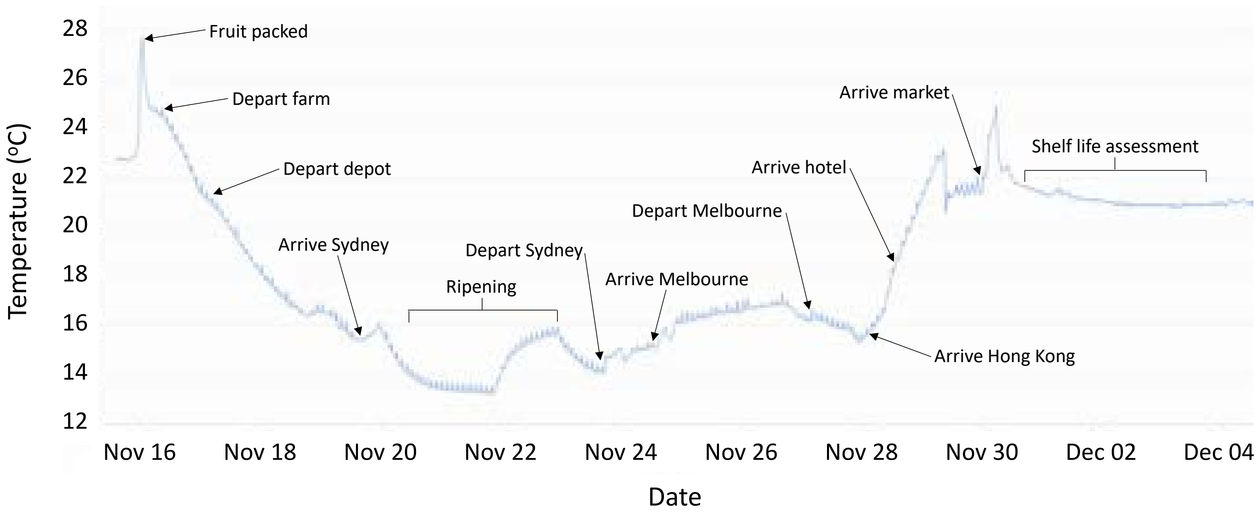


Figure 17. Changes in air temperatures within a box of Ecoganic® bananas from packing at a north Queensland farm, road freight to Sydney, ripening, road freight to Melbourne, air freight to Hong Kong through to display at a wholesale market. Data are representative of a box on the left side of layer 3 in a mixed commodity pallet.

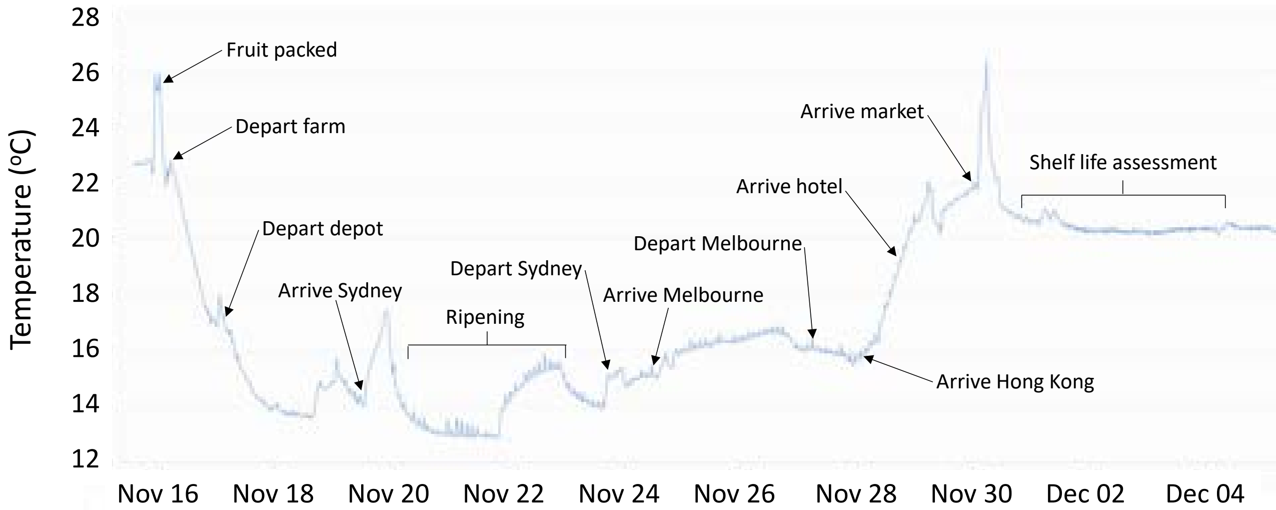


Figure 18. Changes in air temperatures within a box of Ecoganic® bananas from packing at a north Queensland farm, road freight to Sydney, ripening, road freight to Melbourne, air freight to Hong Kong through to display at a wholesale market. Data are representative of a box on the right side of layer 3 in a mixed commodity pallet.

Table 9. Time and temperature statistics for each stage of an Ecoganic® banana export supply chain from a north Queensland farm to a Hong Kong wholesale market. Data represent conditions experienced by sample boxes at two locations within an mixed commodity air freight pallet (PMC). Coloured cells provide an indication of the relative temperature with respect to recommended handling conditions.

	LHS Layer 3 of PMC				RHS Layer 3 of PMC			
Supply chain stage	Time (hr)	Temperature (°C)			Time (hr)	Temperature (°C)		
		Avg	Min	Max		Avg	Min	Max
At pack shed	5	25.8	24.8	27.7	5	24.0	21.9	25.9
At depot	27	22.8	20.7	24.9	27	18.9	16.3	22.8
Transport to Sydney	54	17.5	15.4	20.6	54	14.4	13.6	16.7
Ripening	72	14.3	13.2	16.1	72	14.0	12.9	17.3
Transport to Melbourne	12	14.9	14.5	15.3	12	15.2	14.7	15.9
Holding before export	60	16.4	15.1	17.3	60	16.3	15.4	16.9
Airfreight	9	16.1	15.8	16.4	9	16.0	15.8	16.2
Customs clearance	15	15.9	15.3	16.4	15	15.9	15.5	16.6
Storage at importer	2	16.8	16.5	17.3	2	16.6	16.3	17.0
Holding until ripe	42	21.0	17.4	23.1	42	20.3	16.3	22.2
Shelf life	96	21.2	20.8	24.9	96	20.6	20.1	26.3

Too warm
Warm
Optimal
Too cold

Table 10. Ecoganic® banana fruit quality upon arrival in Hong Kong following export from Australia in a mixed commodity air freight pallet. Fruit were sampled from two boxes at different locations in the pallet.

Quality attribute	Box 1 (left layer 3)	Box 2 (right layer 3)
Peel colour score	3.0 ± 0.1	3.2 ± 0.1
Firmness score	2.1 ± 0.1	2.3 ± 0.1

Data are mean ± standard error (n=40)
Colour score: 3 = 50% yellow, 4 = 75% yellow
Firmness score: 2 = sprung, 3 = firm soft

Figure 19. Photograph of a box of Ecoganic® banana fruit upon arrival in Hong Kong following export from Australia in a mixed commodity air freight pallet. Fruit are from sample box 2 on the right side of layer 3 in the pallet.

Table 11. Shelf life of Ecoganic® bananas at 20°C following export from Australia to Hong Kong in a mixed commodity air freight pallet. Fruit were sampled from boxes on the left and ride side of layer 3 in the pallet.

Sample	Shelf life (days)
Box 1 (Left side of layer 3)	5.4 ± 0.0
Box 2 (Right side of layer 3)	5.2 ± 0.2

Data are mean ± standard error (n=40)

Figure 20. Photograph of representative Ecoganic® banana fruit following export from Australia to Hong Kong in a mixed commodity air freight pallet showing minor peel rub (left) and ripe fruit quality (right). Fruit were sampled from a box at the left side of layer 3 of the pallet.

Competitor analysis

Table 12. Price and quality of Williams Cavendish banana fruit on sale in retail stores in Tokyo from 15 to 22 November 2023.

Store and location	Brand	Origin	Price (AUD)	Colour stage
Keikyu Store Takanawa,Minato City, Takanawa	Dole Sweetio	Ecuador	$2 per pack (500 g)	5
Maruetsu Kōnan World City, Minato City, Tokyo	The Velazquez family	Mexico	$2.50 per pack (500 g)	5
Maruetsu Kōnan World City, Minato City, Tokyo	Tanabe	Ecuador	$3.00 per cluster (500 g)	5
Maruetsu Petit Konan City Tower store, Minato City, Tokyo	Dole High Altitude	Philippines	$2.13 per pack (500 g)	4
Maruetsu Petit Konan City Tower store, Minato City, Tokyo	Life	Philippines	$1.50 per pack (500 g)	5
Keikyu StoreTakanawa, Minato City, Tokyo	Farmind	Ecuador	$2.14 per pack (500 g)	5
Keikyu StoreTakanawa, Minato City, Tokyo	Dole Sweetio	Philippines	$3.22 per pack (500 g)	5
atré Shinagawa, Minato City, Tokyo	Rin Banana	Vietnam	$2.14 per cluster (500 g)	5
atré Shinagawa, Minato City, Tokyo	Sumifru Organic	Mexico	$3.20 per pack (500 g)	5
atré Shinagawa, Minato City, Tokyo	Happy banana	Philippines	$2.79 per pack (500 g)	5
atré Shinagawa, Minato City, Tokyo	Sumifru Sweet	Philippines	$1.40 per pack (500 g)	5
atré Shinagawa, Minato City, Tokyo	Sumifru Sweet ripe king	Philippines	$3.20 per pack (500 g)	5

Table 13. Price and quality of conventional Williams Cavendish banana fruit on sale in retail stores in Hong Kong from 26 to 29 November 2023.

Store and location	Brand	Origin	Price (AUD)	Colour stage
Market Place (Wellcome), Mong Kok	Dole Sweetio	Philippines	$3.20 per pack (600 g)	3-4
Fusion by Parknshop, Admiralty	Dole Extra Sweet	Philippines	$3.80 per pack (500 g)	4
Parknshop, Mong Kok	Del Monte	Philippines	$1.00 per cluster (454 g)	3-4
Parknshop, Mong Kok	Dole Extra Sweet	Philippines	$3.80 per pack (500 g)	5-7
Marks & Spencer, Mong Kok	M&S Fairtrade	Dominican Republic	$5.00 per pack (500 g)	5-6
Marks & Spencer, Mong Kok	M&S Organic	Dominican Republic	$7.00 per pack (500 g)	3-6
Marks & Spencer, Mong Kok	Dole Sweetio	Philippines	$6.00 per pack (600 g)	3-4
Market Place, Victoria Dock	Lapanda Aloha	Ecuador	$1.30 per cluster (454 g)	3-5
Market Place, Victoria Dock	Dole Sweetio	Philippines	$3.20 per pack (600 g)	3-5

Fruit sensory testing

Pacific Coast Eco Bananas
Ecoganic®
Australia

Arco International
Organic
Mexico

Farmind
Organic
Philippines

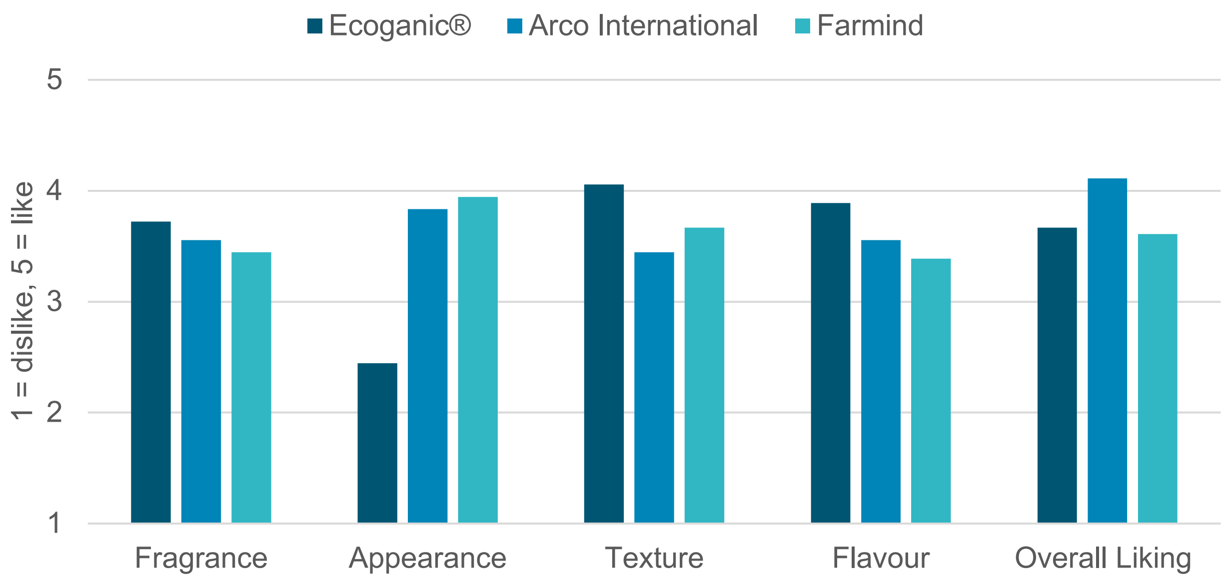


Figure 21. Scores for fragrance, appearance, texture, flavour, and overall liking of ripe Ecoganic®, Arco International, and Farmind banana fruit as assessed by 18 panellists in Ota City, Tokyo. Pacific Coast Eco Banana Ecoganic® fruit were sourced from an export consignment from Australia. Arco International and Farmind bananas, originating from Mexico and the Philippines, respectively, were purchased from retail stores in Japan.

Table 14. Fruit quality characteristics of ripe Australian Ecoganic®, Arco International Mexico and Philippine Farmind bananas assessed in Hong Kong.

Sample	Brix (°)	Acidity (% citric acid)
Ecoganic®	23.7 ± 1.0	0.15 ± 0.01
Arco International	20.8 ± 1.0	0.15 ± 0.01
Farmind	21.1 ± 1.2	0.16 ± 0.01

Data represent the mean ± standard deviation (Brix n=22, Acidity n=13)

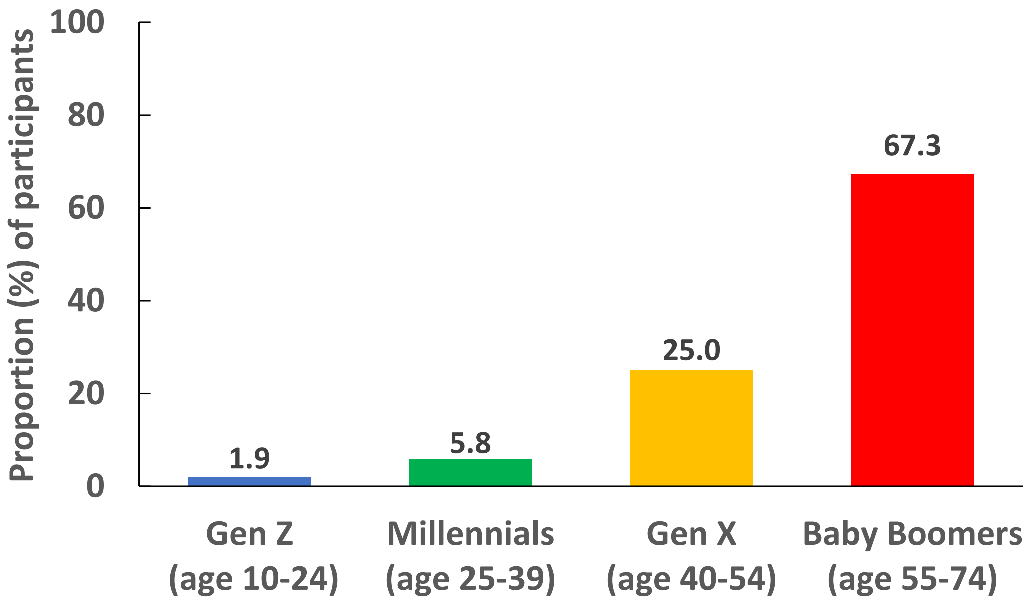


Figure 22. Age distribution of Hong Kong consumers (n=104) who participated in the banana sensory evaluation.

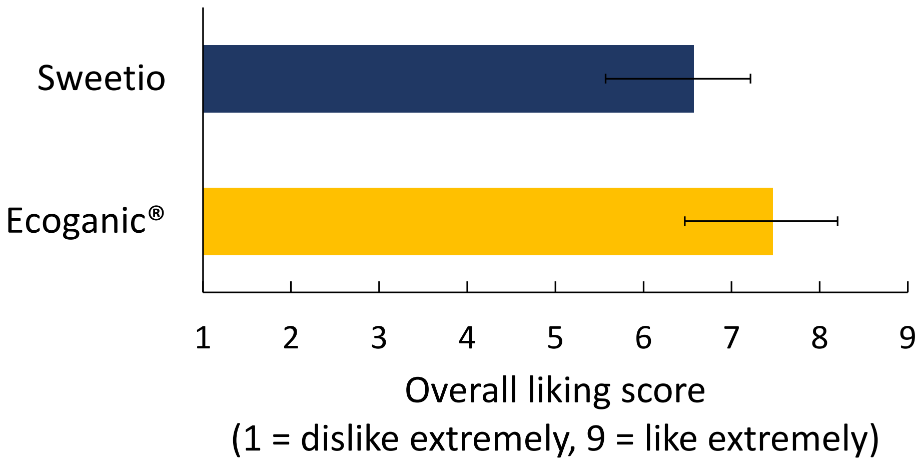


Figure 23. Overall liking score for the eating quality of ripe Ecoganic® and Sweetio banana fruit as assessed by 104 consumers in Hong Kong. Pacific Coast Eco Banana Ecoganic® fruit were sourced from an export consignment. Dole Sweetio fruit from the Philippines were purchased from retail stores in Hong Kong.

Table 15. Fruit quality characteristics of ripe Australian Ecoganic® and Philippine Sweetio bananas assessed in Hong Kong.

Sample	Fruit length (mm)	Fruit diameter (mm)	Brix (°)	Acidity (% citric acid)
Sweetio	241 ± 0.9	35.9 ± 0.8	18.7 ± 0.3	0.27 ± 0.01
Ecoganic®	285 ± 1.1	38.6 ± 0.4	20.6 ± 0.7	0.31 ± 0.02

Data represent the mean ± standard error (n=12)

Retail and wholesale promotion

Figure 24. Photographs of Ecoganic® banana fruit on display at a wholesale market in Hong Kong (left) and high-end retail stores in Hong Kong (centre) and Tokyo (right).

Conclusions and recommendations

This study highlighted the importance of maintaining bananas at optimal temperatures during export. Trial consignments were dispatched from the farm too warm and sometimes stored at the importer too cold, increasing the risk of quality loss and market rejection. Direct exports from North Queensland reduced the time to market, maintained fruit freshness and ensured the product met market access requirements. Consumers in Hong Kong and Japan were satisfied with Australian banana quality and were prepared to pay premium price. Retailers desired continuity of supply rather than irregular shipments. A decision support tool was used successfully to predict fruit quality based on different handling scenarios. The tool will be made available through the Better Bananas website.

Recommendations for delivering consistent premium quality bananas to export markets:

- Access on-the-ground resources in export markets to connect and build trusted relationships with potential customers
- Increase knowledge among supply chain partners about optimal (13°C) banana handling temperatures
- Regularly monitor consignment temperatures to improve practices and fruit quality outcomes
- Airfreight small mixed commodity loads that match demand to reduce the risk of excess fruit being stored
- Seafreight fruit at optimal temperatures if there is demand for larger volumes
- Roll out a promotional campaign to capitalise on consumer interest, targeting high-end retailers

Acknowledgements

We thank Angelo and Michael Russo from Marlin Blue for supplying fruit for trials. We acknowledge the support of Gary Kwan and Junko Akutsu from Trade Investment Queensland for coordination in Hong Kong and Japan, respectively. We greatly appreciate technical and professional assistance from Dianne and Frank Sciacca (Pacific Coast Eco Banana), Chaise Pensini and Tina Slattery (Perfection Fresh) and Minh Nguyen (Department of Agriculture and Fisheries).

APPENDIX B – Supporting Materials

A2. Summary of supply chain simulation trials

Contents

1. Introduction

The project team completed a series of 36 supply chain simulation trials between 2020 and 2023. The trials replicated observed postharvest handling conditions from commercial export and domestic banana consignments. The objectives were to:

1. Characterise Ecoganic®, organic and conventional 'Williams' Cavendish fruit quality and shelf life responses to different export and domestic supply chain handling scenarios (e.g. time x temperature);
2. Analyse and summarise the fruit response data to support development of best practice guidelines to enable growers and supply chain partners to adjust handling conditions to ensure optimum quality for consumers; and
3. Develop, verify and validate mathematical models, where applicable, that predict remaining shelf life and/or risk of food waste from quality defects such as chilling injury under commercial harvest, handling and supply chain conditions.

The trials were completed at the Department of Primary Industries laboratory in Cairns. Fruit bunches were harvested at commercial maturity from Pacific Coast Eco Banana farms and packed into boxes as per commercial practice. The fruit were transported to the laboratory and exposed to different temperatures and ethylene treatments in controlled environment rooms for varying durations that simulated the range of road, air and seafreight handling scenarios encountered in the monitoring program. The experiments were conducted with the summer and winter crop given their potential differences in postharvest response to different handling conditions.

While a range of fruit quality parameters were measured, the focus was quantifying risk of chilling injury and the end of shelf life. Model development involved determining the best fit for postharvest time temperature units (degree hours > 0°C) and shelf life data. The modelling relied on time x temperature matrices and a supply chain module approach. The storage experiments were refined and repeated based on results from the monitoring program over the life of the project to build more accurate models. Model robustness was verified by conducting comparative storage time x temperature experiments with organic and conventional 'Williams' fruit. Model accuracy was validated in the final year of the project by tracking and assessing several export consignments to Hong Kong and Japan.

This appendix provides a summary of the key trials that were undertaken and informed the decision support tool.

2. Export Simulation Trials

2.1 Cavendish green banana fruit responses to temperature by time storage for seafreight export to Korea and Japan

2.1.1 Introduction

The Pacific Coast Eco Banana cooperative has exported bananas to Hong Kong and Singapore via airfreight since 2009. While effective, airfreight is costly and limits the quantity of bananas that can be shipped. Moreover, bananas are often shipped with other fruit and vegetables that have lower storage temperature requirements, complicating the optimisation of storage conditions and increasing the risk of banana chilling injury and waste.

To enhance market reach and competitiveness, it was proposed to explore seafreight as an alternative mode of transport to high value markets such as Korea and Japan. Relative to airfreight, exporting bananas in refrigerated shipping containers represents a lower cost, higher volume option that minimises breaks in the cool-chain. Seafreight is widely practiced by other banana exporting countries. Given that it typically takes 3 weeks to reach Korea and Japan by sea from Australia, extending the banana storage life is crucial to ensure the fruit reaches consumers in optimal condition.

The study comprised a series of time x temperature trials, reflecting the diverse conditions bananas might encounter during seafreight. Nine treatment groups were established, each subjected to a specific combination of temperature and storage time, to assess the quality and residual shelf life of the bananas.

2.1.2 Methods

2.1.2.1 Fruit material

Williams Cavendish bananas (*Musa acuminata*) were cultivated using an Ecoganic® production system and harvested from a commercial orchard near Innisfail in north Queensland. Twelve banana bunches of commercial maturity (degree 2 or 3) were randomly selected. Hands consisting of 10-12 individual fruit from the top and bottom layers of the bunches were selected. The fruit underwent standard commercial processing and were packed into cartons with plastic liners. The fruit was transported to Cairns in an air conditioned van at 20-25°C with 1.5 hours, stored overnight, and then sorted. Unacceptable fruits were removed, and the remaining were assessed and placed into 17 treatment groups.

Table 1 Treatment Temperatures and duration

Treatment (°C)	Domestic Transport at 14°C (Days)	Export transport duration (days)			Ripening (days)
13	4	14	21	28	3
14	4	14	21	28	3
15	4	14	21	28	3

2.1.2.2 Timeline

Fruit were stored at 13, 14 or 15°C for 2, 3 or 4 weeks followed by treatment with ethylene gas for 2 days to coordinate ripening for retail display, as per commercial practice (see Figure 1).

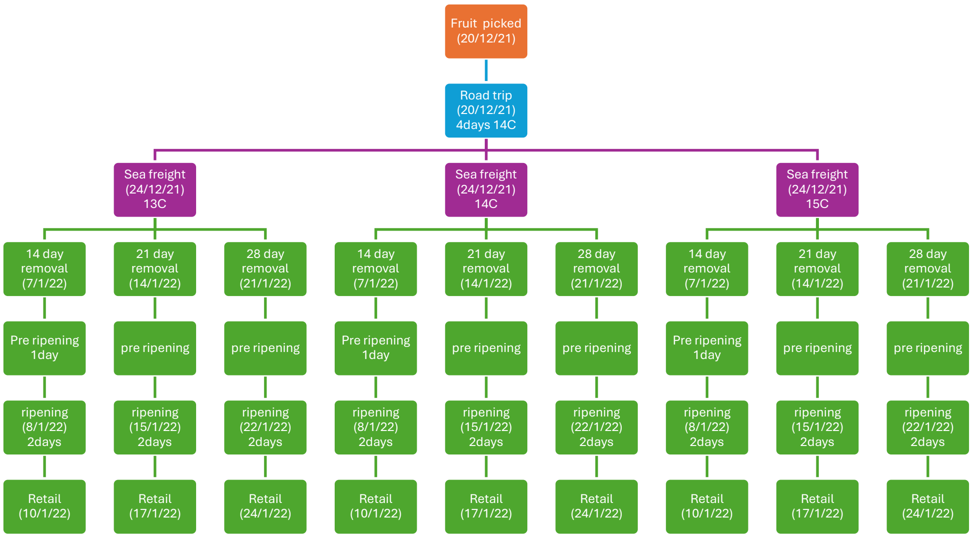


Figure 1. Timeline of banana storage and ripening treatments.

2.1.2.3 Fruit Quality Assessments

- Skin Colour: The percentage of yellow in the background skin colour was measured using a 1-7 scale as adopted by the industry (Loesecke, 1949). Colour of skin was rated for individual fruit with the score from 1 – 7; 1: completely green; 2: less than 30% yellow; 3: 30-50% yellow; 4: 50-80% yellow; 5: more than 80% of yellow; 6: completely yellow but no black dots; 7: black dots obviously on the skin. Visual guide for banana ripeness chart as following:

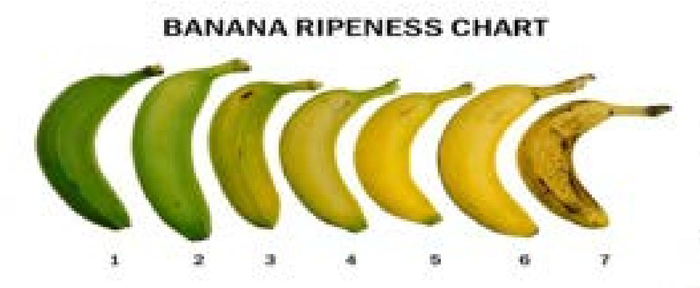


Figure 2. Banana colour chart from green to over ripe stage with score rating from 1 – 7.

- Mass Measurement: The mass (weight) of each hands was recorded to two decimal points (0.00) using a digital mass scale (FX-30001 WP, A&D Company Limited).
- Hand Firmness: Individual fingers' firmness was rated using a 1-5 scale from hard to soft.

- Overall Skin Defects: Defects were rated according to a 1-3 scale, adapted from Kader et al. (1973), for marks, spots, rots, and chilling injury (CI). The fruit was assessed for stem rots at colour stage 6 and the end of shelf life at colour stage 7.
- The total soluble solids (TSS) of the combined juice of 5 fruit was determined using a portable digital refractometer (Atago, Saitama, Tokyo, JP) and expressed as °Brix.
- Titratable acidity (TA) was measured by titrating 5 g of combined juice of 5 fruits with 0.1 N NaOH to pH 8.2 by an automatic titrator (Mettler Toledo, Greifensee, CH) and was expressed as percentage acid.

2.1.3 Results and Discussion

Fruit held at 13°C for 2, 3 and 4 weeks retained a mostly green (>90%) skin during storage, while those maintained at 14 and 15°C showed minor yellow colour development (Figure 3). All fruit developed uniform full yellow skin colour within 4 days of removal and ethylene treatment.

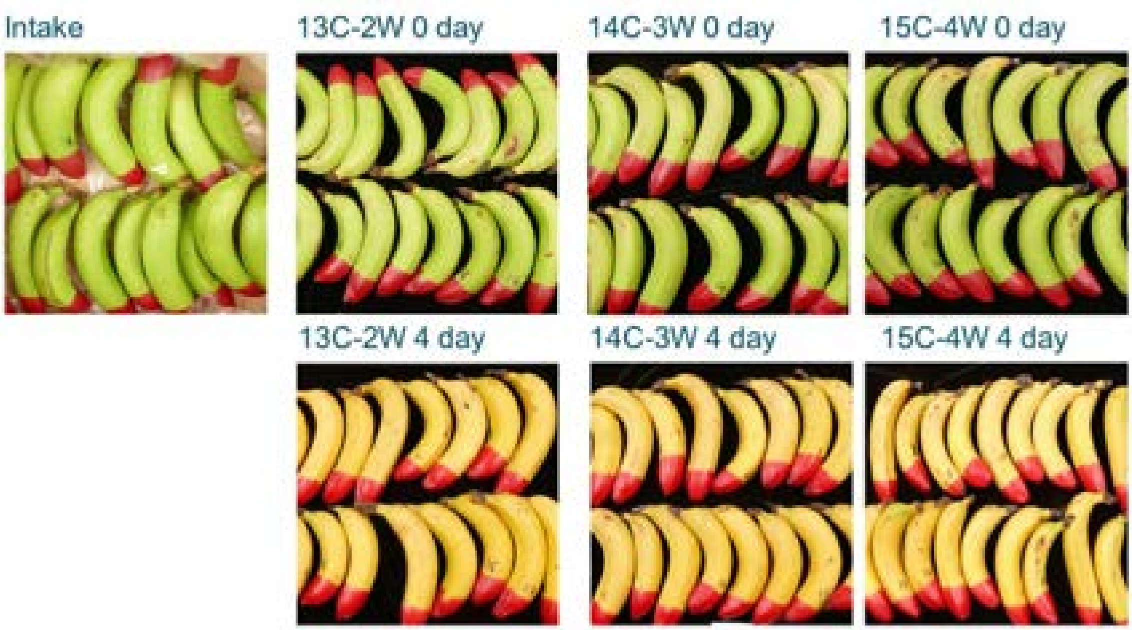


Figure 3. Photographs of Ecoganic® banana fruit at intake (beginning of trial) or after 2, 3 and 4 weeks of storage at 13, 14 and 15°C followed by 4 days of ripening.

Mould development on the fruit stem became evident in bananas stored for 4 weeks at 13, 14 or 15°C, particularly once they were ripened with ethylene (Table 2). The Ecoganic® fruit were not-treated with a synthetic fungicide after harvest, so the mould development represents a potential limitation for seafreight over 3 weeks in duration.

Table 2. Cavendish Green Banana Fruit Responses to Time by Temperature Storage for Sea Freight Export to Korea and Japan Results

Assessment Day # After Ripening	Treatment (°C-weeks)	Colour (1-7)	Firmness (1-4)	Defect (1-3)	Mass (g)	Mouldy (0-4)
0	13-2w	2.3	1.0	1.0	146.9	0.6
	13-3w	2.3	1.0	1.1	145.6	0.8
	13-4W	2.1	1.0	1.4	144.3	0.6
	14-2w	2.5	1.0	1.0	145.8	0.7
	14-3w	2.2	1.0	1.3	144.7	1.2
	14-4w	2.4	1.0	1.6	144.4	1.5
	15-2w	2.5	1.0	1.0	144.0	0.9
	15-3w	2.3	1.0	1.4	150.0	1.3
	15-4w	2.7	1.0	1.7	143.8	1.5
1	13-2w	3.8	1.9	2.0	146.2	0.9
	13-3w	4.2	2.1	1.3	145.1	0.8
	13-4W	4.1	2.0	1.7	143.7	0.7
	14-2w	3.9	2.0	2.0	145.1	0.4
	14-3w	3.9	2.0	1.4	144.4	1.4
	14-4w	4.3	2.3	1.4	143.8	1.3
	15-2w	4.0	2.0	1.9	143.3	1.1
	15-3w	4.3	2.1	1.6	149.6	1.4
	15-4w	4.4	2.4	1.8	143.2	1.5
2	13-2w	4.8	2.9	1.8	145.7	0.9
	13-3w	4.9	2.6	1.3	144.5	0.8
	14-2w	4.6	2.9	1.4	144.5	0.7
	14-3w	4.6	2.4	1.6	143.6	1.2
	15-2w	4.4	2.2	1.3	142.8	1.4
	15-3w	4.6	2.3	1.4	148.7	1.1
3	13-2w	5.4	3.0	1.4	145.1	0.9
	13-3w	5.5	3.0	1.4	143.6	0.9
	13-4W	5.1	3.0	1.7	142.5	0.8
	14-2w	5.2	3.0	1.3	144.0	0.7
	14-3w	5.2	2.8	1.6	143.0	1.2
	14-4w	5.5	3.0	1.5	142.9	1.6
	15-2w	4.9	3.0	1.5	142.3	1.3
	15-3w	5.1	2.9	1.6	148.0	1.0
	15-4w	5.3	2.9	1.8	142.2	1.6
4	13-2w	5.8	4.0	1.8	144.5	1.3
	13-3w	5.6	3.6	1.5	142.8	1.2
	13-4W	5.4	3.1	1.7	142.0	0.8
	14-2w	5.7	3.9	1.6	143.3	1.1
	14-3w	5.6	3.5	1.8	142.2	1.3
	14-4w	5.6	3.4	1.5	142.4	1.6
	15-2w	5.5	3.3	1.9	141.6	1.8
	15-3w	5.3	3.3	1.7	147.2	1.1
	15-4w	5.5	3.1	1.8	141.7	1.6

Table 3 continued

Assessment Day # After Ripening	Treatment (°C-weeks)	Colour (1-7)	Firmness (1-4)	Defect (1-3)	Mass (g)	Mouldy (0-4)
5	13-2w	6.4	4.0			
	13-4W	7.0	4.0	1.7		0.8
	14-2w	6.5	4.0			
	14-4w	7.0	4.0	1.5		1.6
	15-2w	6.5	4.0			
	15-4w	7.0	4.0	1.8		1.6
6	13-2w	7.0	4.0			
	13-3w	7.0	4.0			
	14-2w	7.0	4.0			
	14-3w	7.0	4.0			
	15-2w	7.0	4.0			
	15-3w	7.0	4.0			

Note: Results represent the average from 18 individual pieces of fruit. Three temperatures (13°C, 14°C, and 15°C) and three durations (2, 3, and 4 weeks) were tested.

2.1.4 Conclusions

Our findings highlight that Ecoganic® Cavendish bananas could be exported by sea in a mostly hard-green condition for up to 3 weeks at 13-15°C. Once the fruit were removed from storage and exposed to ethylene gas, it took approximately 5 to 6 days for the bananas to advance to a colour stage 7, marking the end of their shelf life. This indicates that the selected storage temperatures and durations were effective in preserving the fruit quality.

However, a common issue observed across all tested storage durations and temperatures was the development of mould on the stem. This occurrence was undesirable as it could potentially affect the aesthetic appeal, marketability and waste levels of bananas, despite not impacting the edible quality directly. The presence of mould suggests a need for further refinement in storage conditions or the introduction of preventive measures to mitigate mould growth without adversely affecting the fruit overall quality and shelf life.

These conclusions underscore the delicate balance required in managing storage conditions to extend storage life while also addressing issues like mould development. They highlight the importance of ongoing research and innovation in postharvest handling techniques to enhance the export viability of Australian bananas to Asia by sustainable seafreight.

2.2 Cavendish green banana fruit response to temperature by time: Impact of modified atmosphere packaging (MAP)

2.2.1 Introduction

Previous trials have shown that Ecoganic® Cavendish bananas stored for 3-4 weeks under simulated seafreight export conditions maintained acceptable quality levels, although they were prone to developing stem mould. Modified Atmosphere Packaging (MAP) is widely used technique for extending the shelf life of selected lines of fresh produce through the regulation of the surrounding atmospheric (O_2, CO_2) gases. MAP can also delay development of fungal pathogens on fresh produce. Currently, Australian banana growers rely on a perforated plastic liner or commercial plastic bag (CPB) that is included inside standard one or two-piece cardboard banana boxes.

With advancements in supply chain management and storage technologies, exporting Ecoganic® bananas via seafreight appeals to Australian producers. The typical duration for such exports is estimated at 21 days for reaching nearby markets and 28 days for more distant, yet likely, markets.

This study aimed to explore the viability of MAP in preserving fruit quality over these extended periods, potentially making seafreight a more sustainable and cost-effective option for the export of Australian bananas. The study compared two MAP bag types to a commercial plastic bag (CPB), all designed to accommodate a 15-kg banana export box (Figure 1).

2.2.2 Methods

2.2.2.1 Fruit material

Williams Cavendish bananas (*Musa acuminata*) were cultivated using Ecoganic® methods and harvested from a commercial orchard near Innisfail. The fruit was transported to Cairns in an air conditioned van at 20-25°C within 1.5 hours, stored overnight, and then sorted. Unacceptable fruits were removed, and the remaining were assessed and placed in treatment groups.

2.2.2.2 Fruit Quality Assessments

- Skin Colour: The percentage of yellow in the background skin colour was measured using a 1-7 scale as adopted by the industry (Loesecke, 1949).
- Mass Measurement: The mass (weight) of each bunch was recorded to two decimal points (0.00) using a digital mass scale (FX-30001 WP, A&D Company Limited).
- Hand Firmness: Individual fingers' firmness was rated using a 1-5 scale.
- Overall Skin Defects: Defects were rated according to a 1-3 scale, adapted from Kader et al. (1973), for marks, spots, rots, and chilling injury (CI). The fruit was assessed for stem rots at colour stage 6 and the end of shelf life at colour stage 7.
- The TSS of the combined juice of 5 fruit was determined using a portable digital refractometer (Atago, Saitama, Tokyo, JP) and expressed as °Brix.
- Titratable acidity (TA) was measured by titrating 5 g of combined juice of 5 fruits with 0.1 N NaOH to pH 8.2 by an automatic titrator (Mettler Toledo, Greifensee, CH) and was expressed as percentage acid.

2.2.2.3 Fruit bags

The experiment utilised two types of commercially available MAP bags and one type of CPB with perforation. The fruit was packed inside these bags in 15-kg banana export boxes, and while the MAP bags were sealed using a cable tie, the CPB was folded over.

Figure 1. Ecoganic® banana fruit in different treatment bags and export 15 kg capacity boxes (left to right MAP 1, MAP 2 and CPB).

2.2.2.4 Storage Treatments

The following Table 3 illustrates the storage treatments and temperatures for the three bag types:

2.2.2.5 Time line

Table 3. Treatment Temperatures and duration.

Bag type	Treatment Temperature	Treatment Durations	Ripening	Shelf Life
Commercial plastic bag	14°C	21 days, 28 days	24h at 16°C, then 48h at 16°C with 100ppm ethylene	20°C, 60 to 85 %RH
MAP 1	14°C	21 days, 28 days		
MAP 2	14°C	21 days, 28 days		

Export boxes were placed in a Latin square configuration on a commercial pallet (Figure 2).

Figure 2. Treatment boxes in Latin square configuration.

2.2.3 Results and Discussion

We observed that during the trial the O_2 levels reduced, and the CO_2 concentration increased inside both MAP bags (Figure 4). In contrast, CPB maintained ambient atmospheric concentrations throughout the trial. This modified atmosphere was maintained after the first 7 days for the duration of the trial. MAP bag 1 maintained a steady state of O_2 level at 14% while MAP bag 2 had an O_2 level of 12%. Additionally, CO_2 levels increased inside the MAP bags compared to the CPB. MAP 1 had a CO_2 level of 3%, and MAP 2 had a level of 4.5%. The commercial plastic bag had large perforations of ~8mm diameter throughout the bag therefore O_2 and CO_2 levels maintained at atmospheric levels throughout the experiment (Figure 4).

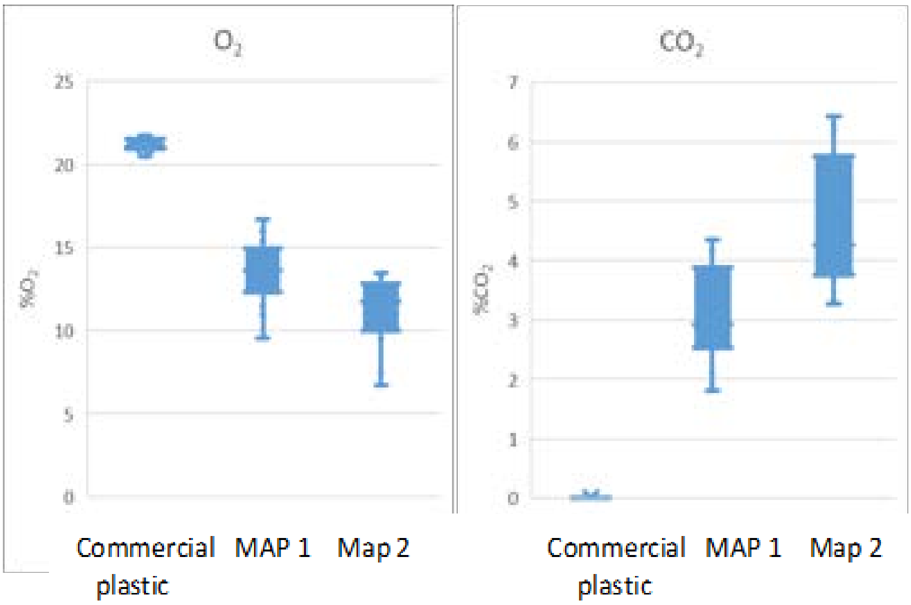


Figure 3. O_2 and CO_2 concentrations inside the three treatment bags (Commercial plastic bag, MAP 1 and MAP 2) for one treatment duration of 28 days at 14°C. The values are the mean of 3 replicates boxes of 15 kg of bananas.

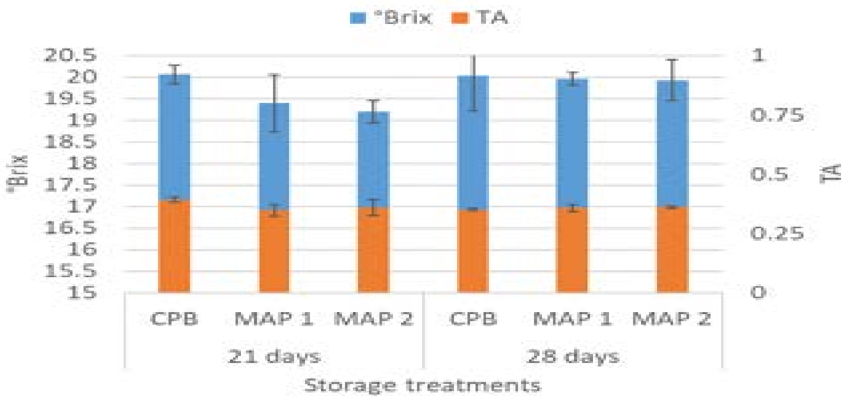


Figure 4. Brix and TA of fruit at colour stage 7 in the three treatments (Commercial plastic bag, MAP 1 and MAP 2) for two treatment duration (21 and 28 days). The values are the mean of 3 replicates 15 bananas. error bars are stranded deviation.

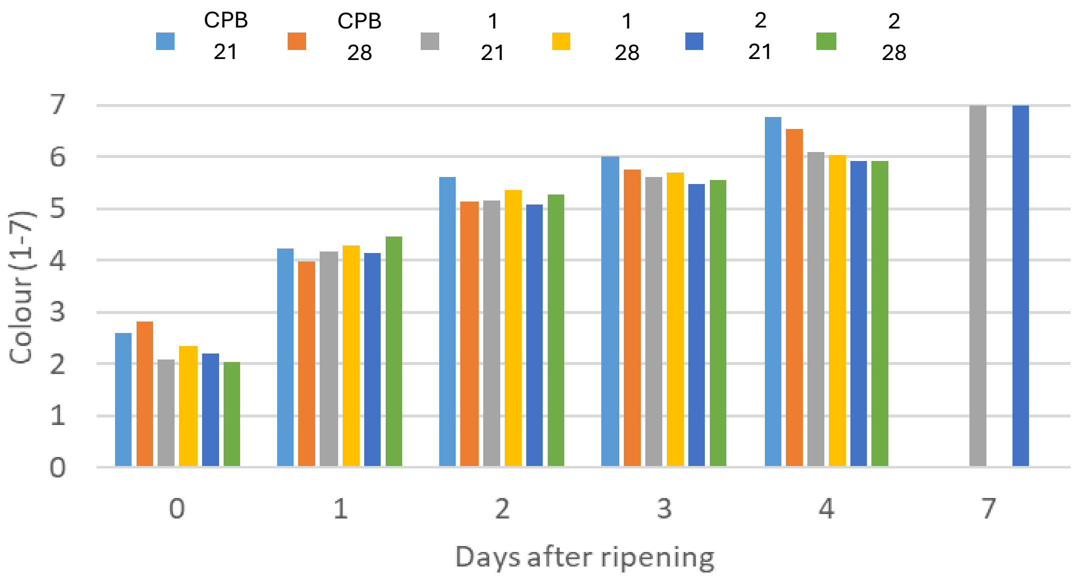


Figure 5. Fruit colour stage (1-7) for each day after ripening in the three treatments (Commercial plastic bag, MAP 1 and MAP 2) for two treatment durations (21 and 28 days). The values are the mean of 3 replicates 15 bananas.

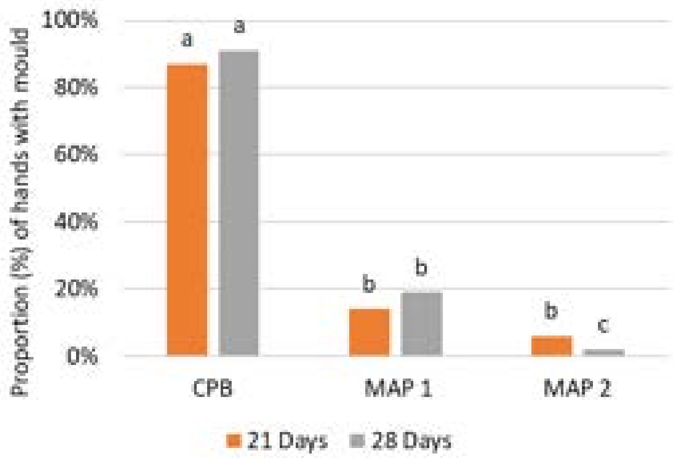


Figure 6. Percentage of hands with mould 7 in the three treatments (Commercial plastic bag, MAP 1 and MAP 2) for two treatment duration (21 and 28 days) The values are the mean of 3 replicates 15kg bananas boxes. 21 days LSD of 0.1558, 28 days LSD 0.1382.

The different storge environments had no significant impact on TA with no statistical differences detected (Figure 5). The packaging treatment also had no effect on °Brix (Figure 5). Starch was also evaluated and found not to differ between treatments. With TA, °Brix and starch being unaffected, it suggest the MAP treatment had minimal impact on taste.

The use of MAP bags had an impact on other fruit quality characteristics with colour being less advanced in every assessment after ripening in the MAP bags compared to the CPB (Figure 6).

In this study, there was a large amount of fruit which showed crown end mould. This is of great importance as fruit with mould will be unacceptable to the consumer. For example, ALDI rejects shipments if more than 10% of fruit within a consignment are impacted. Long-distance seafreight shipments place great stress on the fruit and increase the chance of mould developing.

The fruit which was packed in the CPB for both the 21-day and the 28-day trips exhibited over 80% incidence of mould growth, as compared to MAP 1 treatments which had less than 20% mould and MAP 2 having less than 10% (Figure 7). In Figure 8, the bananas on the fourth day after ripening are shown for the 28-day treatment duration for all 3 treatments with a magnification on the stems. CPB showed stem mould growth while MAP 1 and 2 showed no mould growth.

The fruit from all treatments were tasted and no off flavours were detected, and the fruit was shown to producers and despite the long storage duration and the low O_2 and high CO_2 conditions the fruit was assessed as being superior to that of the CPB. The fruit from all treatment had no detectable off flavours and the taste was determined to be “just like a banana” which would to be acceptable to the consumer.

In conclusion when considering all fruit quality characteristics (taste, colour, firmness, defects Chilling TSS, TA mould CI), bananas stored in MAP 1 and 2 bags for 28 days were superior to fruit stored in CPB and acceptable to the consumer.

Figure 7. Photos of fruit on the 4th day after ripening with a treatment duration 28 days photos a of the 3 different treatments A Commercial plastic bag, B MAP 1 and C MAP 2. Each photo has a zoom in on the stem showing mould development.

2.2.4 Conclusions

In conclusion, extending the seafreight duration up to 4 weeks was feasible when Ecoganic® bananas were stored at 14°C within a MAP. The fruit exhibited satisfactory shelf life and maintained quality aspects after the storage duration. Significantly, the introduction of MAP bags not only enhanced the overall quality of the fruit but also addressed and the issue of mould development on the stem. This underscores the importance of MAP technology in preserving fruit integrity during storage, offering a practical solution to mould challenges previously observed.

2.3 Cavendish green banana response to airfreight simulation trial: Assessing the impact of consolidation and post-ripening temperatures

2.3.1 Introduction

A trial was conducted to determine the impact of deviations in handling conditions at different segments of the airfreight export supply chain on the quality of bananas. Typically, fruit destined for air export is harvested from north Queensland farms and then transported to Sydney over a period of 3-4 days at a temperature of about 14°C. Upon arrival in Sydney, the bananas are consolidated at the markets for an additional 1-4 days at 13°C. The process is followed by a ripening phase, consisting of 1 day of pre-ripening equilibration to 16°C and 2 days of ripening with 100 parts per million (ppm) ethylene gas, before the fruit is air freighted for 1 day to customers in Asia.

Our study focused on the impact of the consolidation stage and post-ripening airfreight temperatures of 13°C, 16°C, or 20°C on fruit quality.

2.3.2 Methods

2.3.2.1 Fruit material

Williams Cavendish bananas were cultivated using Ecoganic® methods and harvested from a commercial orchard near Innisfail in north Queensland. The fruit was transported to Cairns in an air conditioned van at 20-25°C with 1.5-2 hours, stored overnight, and then sorted. Unacceptable fruits were removed, and the remaining were assessed and placed in treatment groups (Figure 1).

2.3.2.2 Timeline

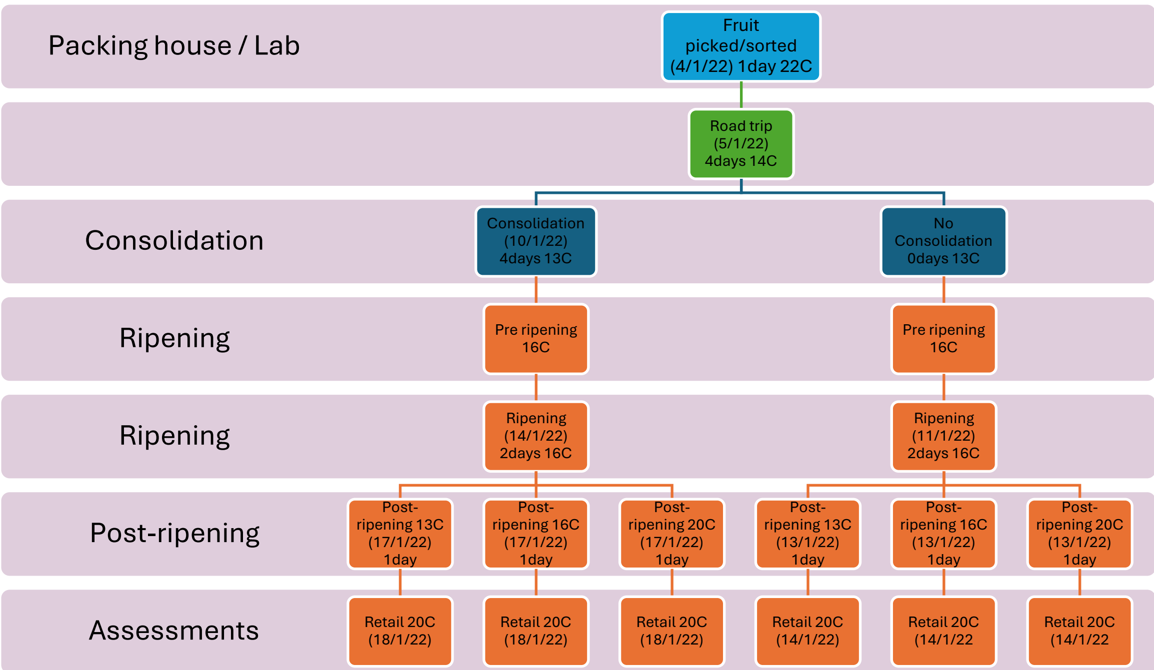


Figure 1. Schematic diagram of consolidation and ripening treatments applied to Ecoganic® banana fruit.

2.3.2.3 Fruit Quality Assessments

- Skin Colour: The percentage of yellow in the background skin colour was measured using a 1-7 scale as adopted by the industry (Loesecke, 1949). Colour of skin was rated for individual fruit with the score from 1 – 7; 1: completely green; 2: less than 30% yellow; 3: 30-50% yellow; 4: 50-80% yellow; 5: more than 80% of yellow; 6: completely yellow but no black dots; 7: black dots obviously on the skin.
- Mass Measurement: The mass (weight) of each bunch was recorded to two decimal points (0.00) using a digital mass scale (FX-30001 WP, A&D Company Limited).
- Hand Firmness: Individual fingers' firmness was rated using a 1-5 scale.
- Overall Skin Defects: Defects were rated according to a 1-3 scale, adapted from Kader et al. (1973), for marks, spots, rots, and chilling injury (CI). The fruit was assessed for stem rots at colour stage 6 and the end of shelf life at colour stage 7.
- The TSS of the combined juice of 5 fruit was determined using a portable digital refractometer (Atago, Saitama, Tokyo, JP) and expressed as °Brix.
- Titratable acidity (TA) was measured by titrating 5 g of combined juice of 5 fruits with 0.1 N NaOH to pH 8.2 by an automatic titrator (Mettler Toledo, Greifensee, CH) and was expressed as percentage acid.

2.3.3 Results and Discussion

Bananas that were not consolidated (0) and were post-ripened at 13°C, 16°C, or 20°C, showed an increase in colour and firmness over time, with minimal defects, chilling and mould. These parameters were generally consistent over time, indicating a relatively stable quality and condition of the fruit. These bananas also reached their end of shelf life by 21/01/22.

Table 1. Impact of consolidation and post-ripening temperatures on banana colour at 20°C.

Treatment		Days at 20°C colour stage	
Consolidation	**Post-ripening temperature**	**5**	**6**
Yes, 4 days at 13°C	**13°C**	0	57%
	16°C	0	61%
	20°C	4%	88%
No, 0 days at 13°C	**13°C**	0	7%
	16°C	0	30%
	20°C	0	22%

Figure 2. Photographs of Ecoganic® bananas following ripening with ethylene gas and storage at 13, 16 and 20°C.

Conversely, consolidated bananas (1), post-ripened at varying temperatures, demonstrated a more gradual increase in colour and firmness over time. These bananas also had minimal defects, chilling, and mould (Table 2), but interestingly, they did not reach their end of shelf life by the end of the monitoring period (23/01/22), indicating that the consolidation process might have extended the shelf life of these bananas.

Overall, the data shows that both consolidation and post-ripening temperatures influence the colour, firmness, occurrence of defects, chilling, mould, and ultimately, the end of shelf life of bananas. Particularly, the consolidation step seems to have contributed to a longer shelf life of the fruit. These findings are essential for informing best practices in banana storage and ripening processes to optimize quality and prolong shelf life.

Table 2. Impact of Consolidation and Post-Ripening Temperatures on Banana Fruit quality

Assessment Day # After Ripening	Consolidation	Post-ripening (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (0-3)
-6	0	13	1.0	0.0	0.5
		16	1.0	0.0	0.5
		20	1.0	0.0	0.6
3	0	13	3.5	1.2	0.8
		16	3.5	1.1	0.7
		20	4.2	1.8	0.7
4	1	13	2.9	1.1	0.8
		16	3.9	1.9	0.5
		20	4.1	2.1	0.8
5	1	13	3.3	2.1	1.6
		16	4.0	2.5	1.8
		20	4.3	2.6	1.9
6	0	13	5.4	2.8	1.4
		16	5.3	2.8	1.6
		20	5.8	3.0	1.9
	1	13	4.8	3.1	0.7
		16	5.5	3.5	0.7
		20	5.7	3.8	0.9
7	0	13	6.0	4.0	0.5
		16	5.9	4.0	0.7
		20	6.2	4.0	0.8
	1	13	5.4	3.9	0.6
		16	5.7	3.8	0.6
		20	5.8	3.9	1.2
8	0	13	6.1	4.0	0.0
		16	6.2	4.0	0.0
		20	6.8	4.0	0.0
	1	13	5.0	3.2	1.7
		16	5.5	3.9	2.2
		20	6.0	4.0	2.5
9	0	13	6.8	4.0	
		16	6.8	4.0	
		20	6.9	4.0	
	1	13	6.7	4.0	
		16	6.9	4.0	
		20	7.0	4.0	

The results presented are averaged from 3 replicate of 15 pieces of fruit, from 5 different bunches. For the consolidation phase, fruits were categorized as either 'Consolidation 1' (consolidated for 4 days at 13°C) or 'Consolidation 0' (not consolidated). Ripening was initiated with a 24-hour period at 16°C, followed by an additional 48 hours at the same temperature with an ethylene concentration of 100ppm. The post-ripening phase involved treatments at temperatures of 13°C, 16°C, or 20°C, each for a duration of 24 hours.

2.3.4 Conclusions

This trial demonstrated that an increase in post-ripening temperatures from 13 to 20°C led to more rapid fruit colour development, indicating accelerated ripening. Additionally, firmness increased with higher post-ripening temperatures, suggesting that temperature plays a significant role in determining the textural qualities of the fruit post-ripening. The effect of consolidation of up to 4 days on fruit quality was found to be minimal, indicating that the post-ripening temperature is a more critical factor in influencing fruit quality outcomes. This suggests that while consolidation processes are integral to the supply chain, their impact on the final quality of fruit, particularly in terms of colour and firmness, is less significant compared to the conditions under which the fruit is ripened and stored post-ripening.

3. Domestic Simulation Trials

3.1 Impact of field heat and transport temperature on fruit quality and shelf life

3.1.1 Introduction

The domestic supply chain for bananas begins with their harvest in North Queensland, followed by transport to markets for ripening, and eventually distribution to retailers. Challenges arise when bananas are harvested at high field temperatures, potentially reaching up to 31°C. This can lead to the fruit being excessively warm at the time of packing. Without effective cool room cooling to 14°C, such fruit may be loaded onto transport trucks that lack the capacity to adequately cool it down. As a result, bananas may be transported at suboptimal temperatures.

Packing the fruit tightly at these elevated temperatures can inadvertently initiate the ripening process earlier than desired, affecting colour development and overall quality of the bananas. Bananas arriving in the domestic market with advanced peel colour risk being rejected by retailers due to challenges for the ripeners to deliver uniform quality for consumers. This trial investigated how different cooling rates after harvest affect the colour development and quality of the fruit. By examining the impact of cooling strategies post-harvest, the study seeks to identify methods to mitigate premature ripening and ensure the fruit maintains its quality throughout the supply chain, from harvest to the point of sale.

3.1.2 Methods

3.1.2.1 Timeline

Fruit were initially stored at 31°C, 26°C, 21°C, and 14°C. Following this, a simulated cooling process was implemented. Fruit stored at 31°C and 26°C underwent a cooling process over 96 hours to reach the ideal transport temperature of 14°C. Meanwhile, fruit initially held at 21°C were cooled over 72 hours to the same target temperature. The fruit initially stored at 14°C were maintained at this temperature throughout the simulated total transport duration of 6 days as a best practice scenario (Figure 1).

At the conclusion of the transport simulation, fruit were warmed to 16°C for ripening with ethylene gas for 48 hours. The quality and shelf life of the fruit were evaluated at 20°C to end of shelf life.

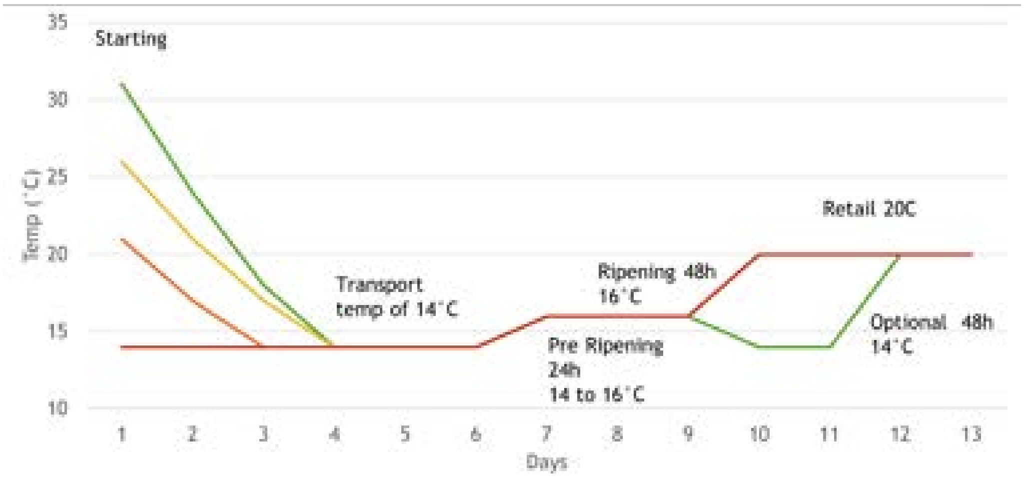


Figure 1. Storage Temperatures and Durations for Bananas in a simulated domestic supply chain.

3.1.2.2 Fruit Quality Assessments

- Skin Colour: The percentage of yellow in the background skin colour was measured using a 1-7 scale as adopted by the industry (Loesecke, 1949). Colour of skin was rated for individual fruit with the score from 1 – 7; 1: completely green; 2: less than 30% yellow; 3: 30-50% yellow; 4: 50-80% yellow; 5: more than 80% of yellow; 6: completely yellow but no black dots; 7: black dots obviously on the skin. Visual guide for banana ripeness chart as following:

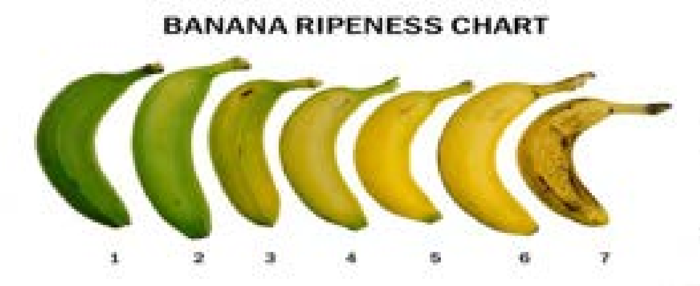


Figure 2. Banana colour chart from green to over ripe stage with score rating from 1 – 7.

- Mass Measurement: The mass of each bunch was recorded to two decimal points (0.00) using a digital mass scale (FX-30001 WP, A&D Company Limited).
- Hand Firmness: Individual fingers' firmness was rated using a 1-5 scale.
- Overall Skin Defects: Defects were rated according to a 1-3 scale, adapted from Kader et al. (1973), for marks, spots, rots, and chilling injury (CI). The fruit was assessed for stem rots at colour stage 6 and the end of shelf life at colour stage 7.
- The TSS of the combined juice of 5 fruit was determined using a portable digital refractometer (Atago, Saitama, Tokyo, JP) and expressed as °Brix.
- Titratable acidity (TA) was measured by titrating 5 g of combined juice of 5 fruits with 0.1 N NaOH to pH 8.2 by an automatic titrator (Mettler Toledo, Greifensee, CH) and was expressed as percentage acid.

3.1.2.3 Fruit

The Cavendish bananas (Musa acuminata) were cultivated using Ecoganic® methods and harvested from a commercial orchard near Innisfail. The fruit was transported to Cairns in an air conditioned van at 20-25°C, stored overnight, and then sorted. Unacceptable fruits were removed, and the remaining were assessed and placed in treatment groups.

3.1.3 Results and Discussion

Table 1. Post-Ripening Quality Assessment of Bananas.

Assessment Day # After Ripening	Initial Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)
-1	14°C	1.01	0.0	1.0
	21°C	1.03	0.0	1.1
	26°C	1.10	0.0	1.0
	31°C	1.23	0.0	1.0
4	14°C	5.4	3.3	1.0
	21°C	5.1	3.2	1.3
	26°C	5.2	3.9	1.0
	31°C	5.3	4.0	1.0
5	14°C	5.9	4.0	1.0
	21°C	5.7	4.0	1.3
	26°C	5.9	4.0	1.0
	31°C	5.7	4.0	1.0
6	14°C	6.4	4.1	1.0
	21°C	6.6	4.0	1.3
	26°C	6.9	4.0	1.0
	31°C	6.8	4.0	1.1
7	14°C	7.0	4.1	1.0
	21°C	7.0	4.0	1.3
	26°C	7.0	4.0	1.0
	31°C	7.0	4.0	1.1

The results are based on averages from three replicates, each consisting of 15 pieces of fruit sourced from five distinct bunches. Four initial treatment temperatures were tested: 14°C, 21°C, 26°C, and 31°C. Ripening was initiated with a 24-hour period at 16°C, followed by an additional 48 hours at the same temperature, with an ethylene concentration of 100ppm.

3.1.4 Conclusions

The findings indicated that while initial transport temperatures influenced fruit colour upon arrival, prior to ripening these differences were minimal. Once the fruit underwent exposure to ethylene during the ripening process, this became the primary factor affecting colour development. The variations in transport temperature tested in this study did not significantly impact the quality of the fruit. This suggests that the ripening process, facilitated by ethylene exposure, has the most influence in determining fruit colour, overshadowing the effects of any minor temperature differences experienced during transport. Nevertheless, fruit arriving at different colour stages creates challenges for ripeners and inefficiency in the handling process that can lead to significant food waste. Accordingly, best practice recommendations are always to pre-cool and transport bananas at 13-15°C.

4. Modelling Trials

4.1 Impact of Different Ripening Durations and Temperatures on Fruit Colour and Quality

4.1.1 Introduction

Upon reaching a minimum physiological maturity, banana fruit can produce and respond to ethylene gas to ripen by themselves. Ethylene is a naturally produced phyto-hormone. Banana fruit from different bunches and hand positions mature and ripen at variable rates. This can result in premature and uneven ripening and possible disease development during transport and storage. Therefore, on a commercial scale, bananas are ripened in a controlled environment room with an external source of ethylene gas using a precise methodology before the fruits are supplied to the retailers. The ethylene concentration, ripening room temperature and treatment duration are carefully managed to assure even fruit appearance quality on the market.

Banana can be treated with ethylene gas via pressurised cylinders, catalytic systems or sachet release products. Temperature management during ripening plays a significant role in fruit quality and shelf-life. Fruit ripening professionals typically treat banana fruit with ethylene at 15-16°C but may subsequently store them at low (i.e. 13°C) or high (i.e. 18°C) temperature to slow or speed up the final stages of ripening, respectively. Temperatures of >18°C can further accelerate ripening but increase disease development.

This experiment aimed to quantify the effect of the ethylene gas exposure duration (24, 48, 72 hours) at different temperatures (14, 16 and 18°C) on fruit quality.

4.1.2 Methods

The study tested the duration for ethylene gassing for 24, 48, 72 hours at the same concentration (100 ppm). The temperatures also tested for 14, 16 and 18°C. Because of the limit in ripening room facilities, three ripening temperatures were carried out separately.

4.1.2.1 Quality assessments

Colour

Colour of skin was rated for individual fruit with the score from 1 – 7; 1: completely green; 2: less than 30% yellow; 3: 30-50% yellow; 4: 50-80% yellow; 5: more than 80% of yellow; 6: completely yellow but no black dots; 7: black dots obviously on the skin. Visual guide for banana ripeness chart as following:

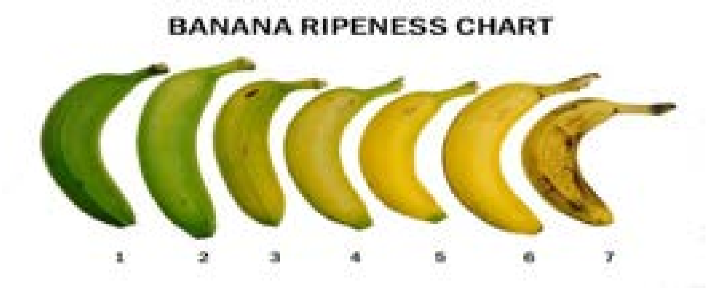


Figure 1. Banana colour chart from green to over ripe stage with score rating from 1 – 7.

Firmness

Firmness was rated for individual fruit with the score from 0 – 4; 0: hard; 1: rubbery with slight 'give'; 2: sprung, flesh deforms by 2 – 3 mm with extreme thumb pressure; 3: firm soft, whole fruit deforms with moderate hand pressure; 4: eating soft, whole fruit deforms with sight hand pressure.

Defect

Defect was rated for individual fruit using the following scale (0 – 4):

1: None, free from defect;
2: Slight, minor defect, not objectionable and affecting less than 5% of the surface area;
3: Moderate, slight to moderate objectionable defects, lower limit of attractions, less than 10% of the surface area;
4: Severe, excessive defect, limit of acceptability, less than 25% of the surface area;
5: Extreme; extremely poor, more than 25% of the surface area;

4.1.2.2 Chilling injury

Chilling injury was rated for individual fruit with the score from 0 – 3. Rating is based on the chilling symptom which include skin surface discoloration, dull or smoky colour, sub epidermal tissues reveal dark-brown streaks, failure to ripen. The rating score are following:
0: no chilling injury
1: light (light green colour or light pale yellow skin at ripe)
2. Medium (pale colour yellow at ripe)
3. Severe (poor appearance with light smoky colour, sub epidermal tissues reveal dark-brown streaks)
4. Complete severe (severe chilling symptoms: clear smoky colour, sub epidermal tissues reveal dark-brown streaks)
Other chilling symptom was noted for the failure to reach 100% yellow colour on skin:
Failure to yellow ripe was based on the proportion of fruits which could not reach 100% yellow colour at the optimum stage.

4.1.2.3 Data analysis

Data were statistically analysed as one way ANOVAs using the 'General Analysis of Variance' model of Genstatâ16 for WindowsÔ (VSN International Ltd., Hertfordshire, UK). The protected least significant difference (LSD) procedure at P = 0.05 was used to test for differences between treatment means for LD, lenticel water uptake index, wetting angle, proportion of lenticels taking up the solution and weight loss.

4.1.3 Results and Discussion

4.1.3.1 Gassing with ethylene at 14°C

The skin colour of fruit treated with ethylene at 14°C for 24 hours increased slowly during subsequent shelf life at 20°C and the fruit did not reach colour stage 6 (i.e. full yellow) on average after 9 days (Figure 2). Ethylene treatment at 14°C for 48 and 72 hours reached colour 6 after 5-6 days (Figure 2, left). Treatment 14°C for 24 hours only resulted in 60% of fruit reaching colour 6 and 40% of fruit remained unripened. Meanwhile, treatment for 48 and 72 hours had 100% of fruit reaching colour 6 (Figure 3).

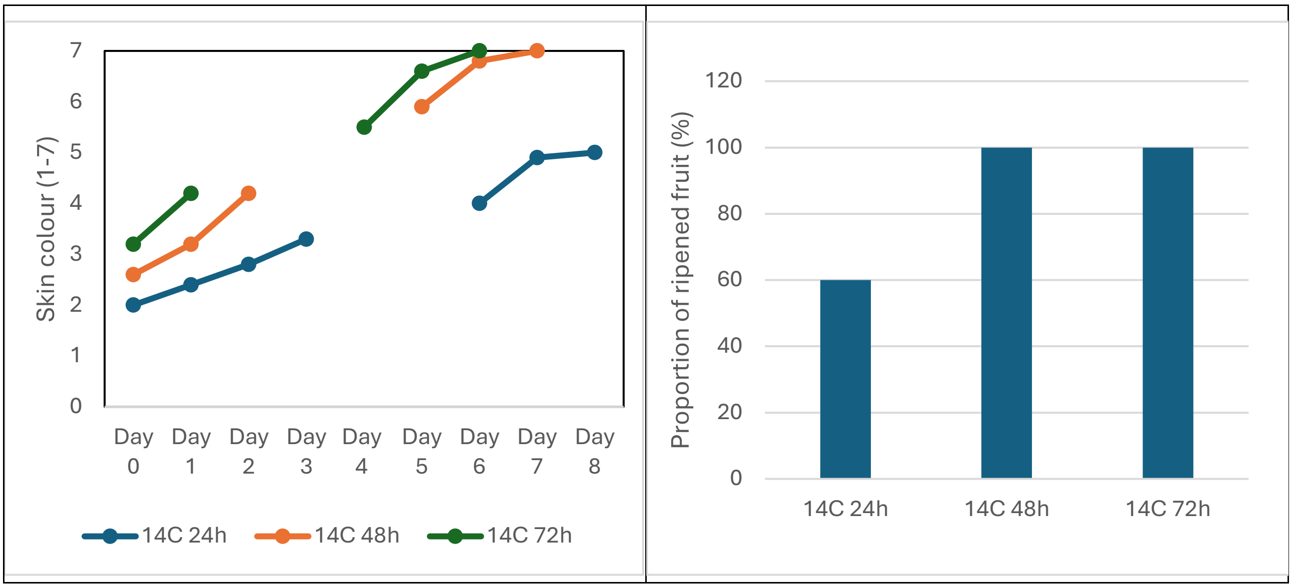


Figure 2. Fruit skin colour changes (left) and the proportion reaching colour stage 6 (right) during storage at 20°C after ethylene treatment at 14°C for 24, 48 and 72 hours.

14 °C 24h **14 °C 48h** **14 °C 72h**

Figure 3. Banana colour development at 14°C

4.1.3.2 Gassing with ethylene at 16°C

Fruit treated with ethylene at 16°C for 72 hours developed about 50% yellow skin colour (stage 3.5) when removed from the ripening room and reached full yellow (stage 6) within 2 days at 20°C (Figure 4). Fruit treated at 16°C for 48 hours developed to colour stage 2.5 after gassing with ethylene and then colour stage 6 after a further 3 days at 20°C. The fruit treated with ethylene for 24 hours had very low skin colour score and the fruit were firm during storage at 20°C (Figure 4).

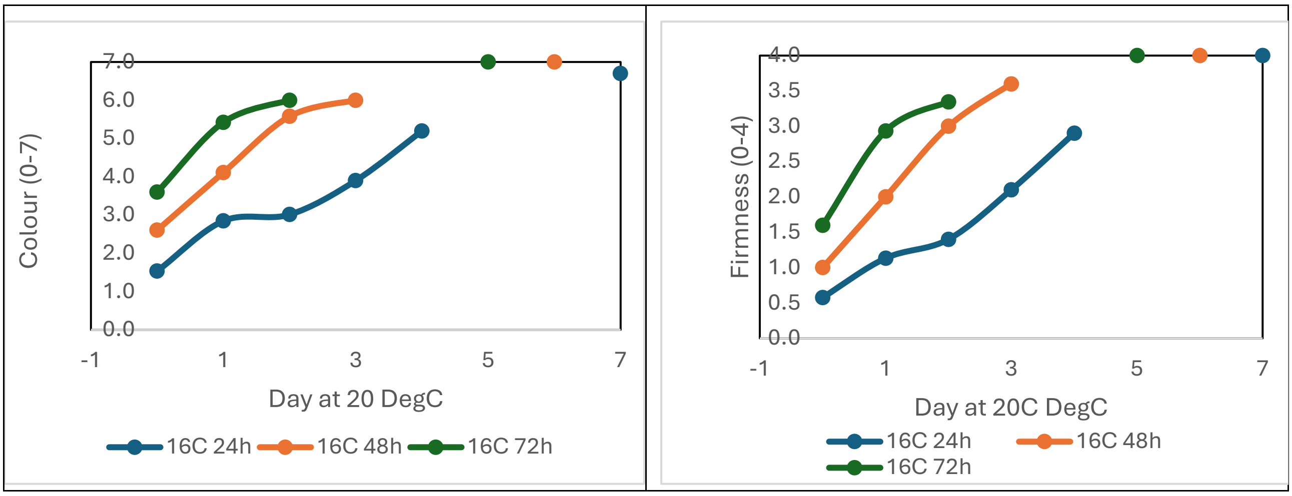


Figure 8. Colour changes (left) and firmness changes (right) during storage at 20C for treatments at 16C for 24h, 48h and 72h.

However, fruit treated for 24 hours had very high defects on the skin possibly because the ripening process was not triggered for long enough (Figure 5).

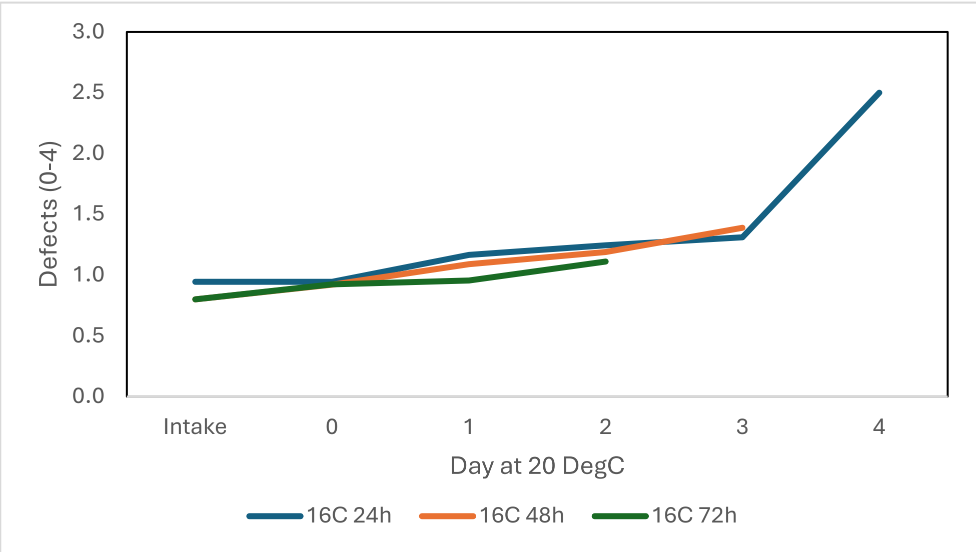


Figure 5. Defects changes during storage at 20C for treatments at 16C for 24h, 48h and 72h.

Thus, ripening with 100 ppm ethylene at 16°C for 24 hours did not enhance the quality, and fruit had brown skin development during storage at 20°C. Meanwhile, ripening with ethylene for 72 hours shortened the fruit shelf-life to only 2 days for retailing. Optimum ripening was 48 hours with ethylene at 100 ppm and could deliver the best quality, with fruit having 3-4 days for retailing before reaching colour 7 (end of shelf life).

16 °C 24h: Day 3 at 20C	16 °C 48h: Day 2 at 20C	16 °C 72h: Day 1 at 20C

Figure 6. Banana colour development at 16°C.

3.3. Gassing with ethylene at 18°C

Fruit treated with ethylene at 18°C for 24 hours could not reach full colour 6 after 11 days at 20°C, and fruit failed to ripen properly. While fruit that were gassed at 18°C for 48 or 72 hours reached colour 6 after 4 days and 3 days, respectively (Figure 7, left). Therefore, treatment at 18°C for 72 hours resulted in 1 day less shelf-life than treatment at 18°C for 48 hours. Fruits treated at18°C for 24 hours were firmer than fruit from two other treatments because of failure in ripening (Figure 7, right)

Table 1. Fruit Colour Stage (1-7) Development After Ripening at Temperatures of 14°C, 16°C, and 18°C for Durations of 24, 48, and 72 Hours

	14C			16C			18C		
Day	24	48	72	24	48	72	24	48	72
1	2			1.5			1.6	2	3.2
2	2.4	2.6		2.8	2.6		2.1	3.4	5
3	2.8	3.2	3.2	3	4.1	3.6		4.8	
4	3.2	4.2	4.1	3.8	5.5	5.4			
5				5.1	6	6	3.2		6.1
6					7	7	3.5	5.9	6.9
7	4	5.8	5.5				3.8	6.6	7
8	4.8	6.8	6.6	6.6			4	7	
9	5	7	7	7			4.4		

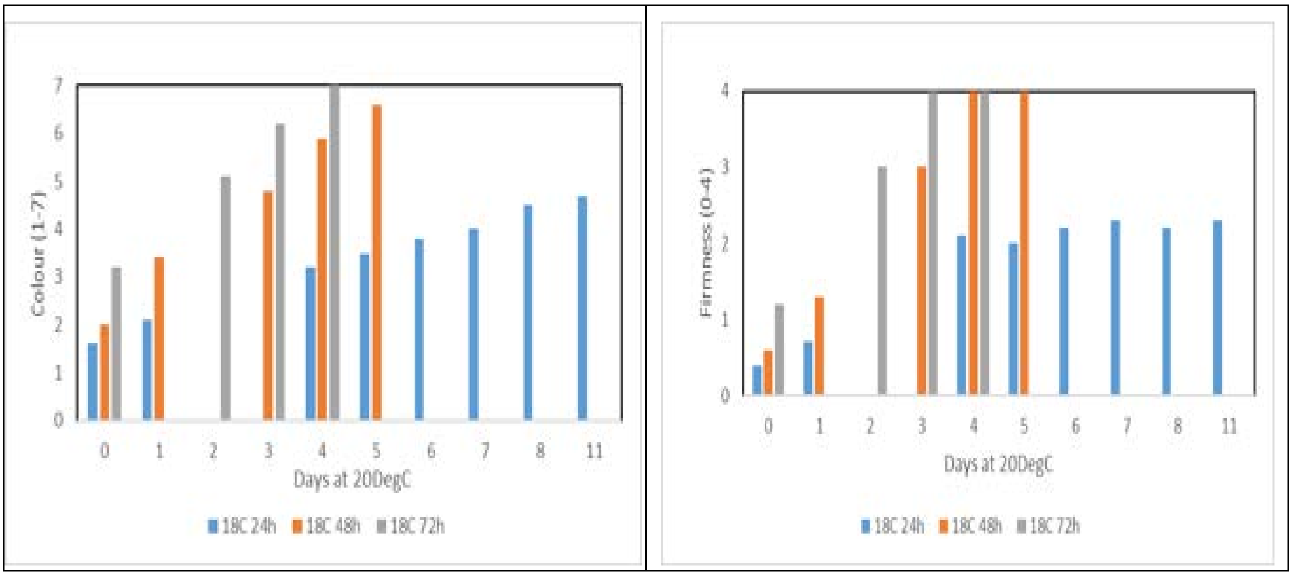


Figure 7. Colour and firmness changes during storage at 20C for treatments at 16C for 24h, 48h and 72h

In general, fruits from the three ripening temperatures had low defects (under 1 with scoring 0-4) while those at 18°C for 24 hours had a high degree of mouldy stem and rot after 10 days because of failure in ripening (data not shown).

18 °C 24h	18 °C 48h	18 °C 72h

Figure 8. Banana colour development at 18°C.

4.1.4 Conclusion

Ripening with 100 ppm ethylene for 24 hours at 14, 16 and 18°C did not meet the requirement for satisfactory ripe fruit quality and would be associated with significant food waste. Fruit from the 24 hour treatment had uneven poor and brown skin colour and partly failed to ripen.

Ethylene treatment for 72 hours at 14, 16 and 18°C accelerated uniform ripening and fruits had 1 day less shelf life than those treated for 48 hours at 14, 16 and 18°C, respectively. Therefore, 48 hour gassing with ethylene was the best option for ripening bananas.

Ripening at 14°C for 48 hours delayed ripening by nearly 1 day than at 18°C. The difference between treatment at 16°C and 18°C were not commercially significant.

4.2 Impact of Different Storage Temperatures on Pre-Ripened Fruit Colour and Quality

4.2.1 Introduction

Fruit colour development post-ripening is a critical quality indicator, essential for aligning with specific segments of the supply chain. Supermarkets enforce strict criteria regarding the colour stage of fruit they accept; any deviation can lead to rejection of the consignment. Consumers typically prefer purchasing fruit at colour stages 5-6, indicating a narrow window for offering fruit at the optimal colour stage. Ensuring accurate prediction and management of fruit colour post-ripening is thus vital for meeting both retailer standards and consumer expectations.

4.2.2 Methods

4.2.2.1 Fruit material

Williams Cavendish bananas (*Musa acuminata*) were cultivated using Ecoganic® methods and harvested from a commercial orchard near Innisfail. The fruit was transported to Cairns in an air conditioned van at 20-25°C, stored overnight, and then sorted. Unacceptable fruits were removed, and the remaining were assessed and placed in treatment groups.

4.2.2.2 Fruit

Fruit was stored for 6 days at 14°C to simulate domestic road freight supply chain conditions. Subsequently, the fruit underwent a pre-ripening equilibration period of 24 hours, followed by 48 hours of ethylene treatment at a concentration of 100 ppm. Post-ripening, the fruit were stored at 12, 13, 14, 15, 16, 18 and 20°C to observe colour development. Daily assessments were conducted to monitor the progression of the colour stage.

4.2.3 Results and Discussion

Post-ripening temperatures had a major impact on fruit shelf life (Table 1). Fruit held at 20°C (typical retail environment) after ripening with ethylene reached colour stage 7 (i.e. end of shelf life) in just 3 days. Dropping the storage temperature from 20°C to 18 and 16°C (typical of airfreight) added a further 2 to 5 days shelf life. Storing pre-ripened bananas at 13-15°C greatly slowed subsequent fruit ripening and skin colour development, extending the end of shelf life by 8-14 days over samples held at 20°C. Storage at 13-15°C would be optimal for handling bananas destined for airfreight into niche Asian markets. Remaining shelf life was related to the cumulative time x temperature following ethylene treatment (Figure 1), and highlights an opportunity to model fruit quality responses.

Table1. Fruit Colour Development After Ripening and Storage at Temperatures from 12°C to 20°C

Days	12C	13C	14C	15C	16C	18C	20C
0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
1	2.1	2.1	2.1	2.4	2.6	3.1	3.3
2							
3							
4	3.0	3.0	4.4	4.4	5.0	5.3	6.3
5	3.1	3.2	5.2	5.1	5.6	6.1	6.6
6	3.3	3.3	5.6	5.5	5.9	6.1	6.7
7	3.4	4.0	5.5	5.7	5.9	6.3	7.0
8	4.8	5.3	5.7	5.8	6.1	6.8	7.0
9	5.6	5.9	6.0	6.2	6.3	7.0	7.0
10	5.6	5.8	6.1	6.5	6.5	7.0	7.0
11	5.8	5.9	6.1	6.5	6.7	7.0	7.0
12	5.9	5.9	6.1	6.9	7.0	7.0	7.0
13	5.9	6.0	6.3	7.0	7.0	7.0	7.0
14	6.0	6.0	6.0	7.0	7.0	7.0	7.0
15	5.9	6.0	6.0	7.0	7.0	7.0	7.0
18	6.0	6.2	7.0	7.0	7.0	7.0	7.0
19	6.0	6.0	7.0	7.0	7.0	7.0	7.0
20	6.0	6.9	7.0	7.0	7.0	7.0	7.0
21	6.0	7.0	7.0	7.0	7.0	7.0	7.0
22	6.0	7.0	7.0	7.0	7.0	7.0	7.0
25	7.0	7.0	7.0	7.0	7.0	7.0	7.0

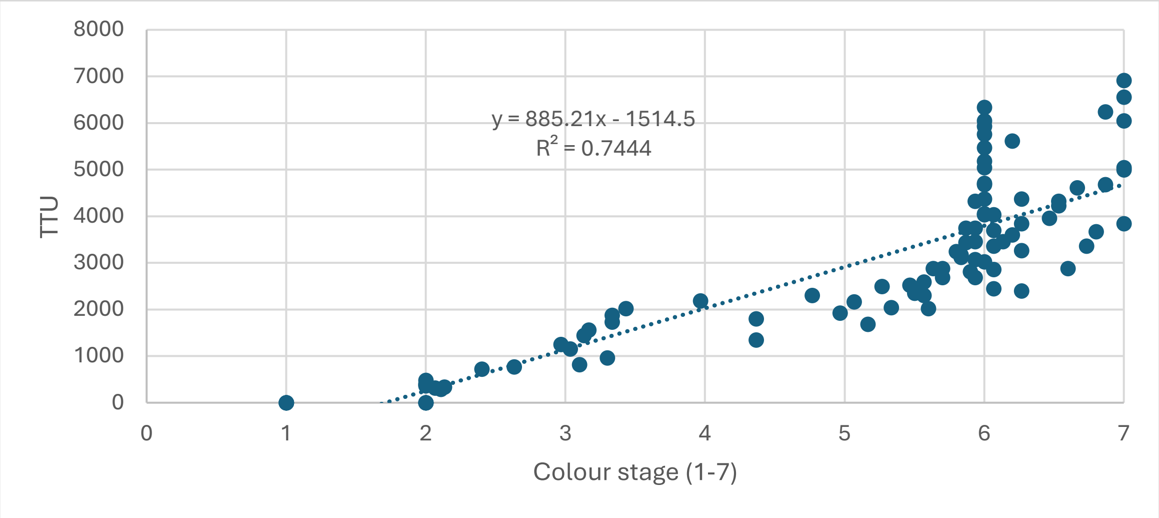


Figure 9. Pre-ripened Cavendish Ecoganic® banana fruit colour development vs cumulative time x temperature units (TTU).

4.3 Modelling Cavendish banana fruit shelf life and chilling responses

4.3.1 Introduction

The development of a banana time-temperature model is crucial for predicting chilling and other quality parameters that typically go untested due to their occurrence outside standard transport conditions. This model aims to enhance the understanding and prediction of how various temperatures and exposure durations affect fruit quality. Two trials were conducted to explore a range of temperatures—3, 5, 7, 10, 12, 14, 16 and 26°C—over durations of 1, 2, 4, 6, 7, 14, 21, 27, and 28 days, examining their impacts on banana quality. These temperature and exposure durations reflect the range of conditions observed during monitoring of Australian domestic and export (air and seafreight) banana supply chains. This approach seeks to provide insights into optimal storage and transport conditions, ensuring the preservation of banana quality across the supply chain.

4.3.2 Methods

Williams Cavendish bananas (*Musa acuminata*) were cultivated using Ecoganic® methods and harvested from a commercial orchard near Innisfail. The fruit was transported to Cairns in an air conditioned van at 20-25°C, stored overnight, and then sorted. Unacceptable fruits were removed, and the remaining were assessed and placed in treatment groups. The fruit were held at 14°C for 4 days and then treated with 100 ppm ethylene at 16°C for 48 hours to simulate commercial transport and ripening practice. They were then assigned to different storage temperature x time combinations as per Table 1.

Table 1. Tested Treatment Temperatures and Durations

Row Labels	0	1	2	4	6	7	14	21	27	28
3		X	X	X						
5		X	X	X						
7			X	X						
10			X	X	X					
12			X	X	X	X	X	X	X	X
13					X		X	X	X	
14		X	X	X	X	X	X	X	X	X
15					X		X	X	X	
16		X	X	X	X	X	X	X	X	X
20	X									
26		X	X	X	X	X				

4.3.3 Results and Discussion

Chilling injury was a function of temperature and exposure time. Exposure of banana fruit to 3, 5 and 7°C for 1 day, 10°C for 2 days triggered moderate to severe chilling injury (Table 2). Minor symptoms of chilling injury were occasionally detected on fruit held at 12°C for 6 days or more. Maintenance of fruit at 13°C for up to 27 days was seldom associated with even the slightest level of chilling injury.

Table 2. Impact of Storage Temperatures and Durations on Banana Fruit Quality Post-Ripening

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
-3	**0**	20	1.0	0.7	0.3	0.0
-3	**1**	3	1.5	0.0	0.4	0.0
		5	1.1	0.0	0.4	0.0
		7	1.2	0.0	0.4	0.0
		10	0.8	0.0	0.2	0.0
		12	0.8	0.0	0.3	0.0
		14	0.8	0.0	0.5	0.0
		16	0.8	0.0	0.3	0.0
		26	1.2	0.0	0.4	0.0
-3	**2**	3	1.7	0.0	0.5	0.2
		5	2.0	0.0	0.7	0.0
		7	1.1	0.3	0.4	0.0
		10	1.3	0.0	0.3	0.0
		12	1.3	0.0	0.5	0.0
		14	1.3	0.1	0.4	0.0
		16	1.3	0.0	0.5	0.0
		26	1.5	0.5	0.2	0.0
-3	**4**	7	1.5	0.5	0.0	0.0
		10	1.5	0.5	0.0	0.0
		12	1.5	0.5	0.0	0.0
		14	1.5	0.5	0.0	0.0
		16	1.5	0.5	0.0	0.0
		26	2.0	1.0	0.0	0.0
-3	**6**	10	1.6	1.0		0.0
-3	**7**	7	1.0	0.5	1.3	1.9
		10	1.4	0.3	0.7	1.0
		12	1.5	0.5	0.7	0.0
		14	1.5	1.0	0.6	0.0
		16	1.5	1.0	0.6	0.0
		26	2.0	0.9	0.9	0.0
-3	**14**	12	1.0	0.3	0.2	0.0
		13	1.0	0.0	0.2	0.0
		14	1.0	0.3	0.3	0.0
		15	1.0	0.0	0.0	0.0
		16	1.0	0.3	0.5	0.0
-3	**21**	12	1.8	1.0	0.5	0.0
		14	1.2	1.0	0.7	0.0
		16	2.0	1.0	0.5	0.0
-3	**27**	12	1.7	1.0	0.5	0.0
		13	1.9	1.0	0.6	0.0
		14	1.8	1.0	0.8	0.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
-3	**27**	15	1.6	1.0	0.8	0.0
		16	2.0	1.0	0.7	0.0
-3	**28**	12	1.7	0.4	0.7	0.0
		14	2.0	0.9	0.4	0.0
		16	2.4	1.0	1.0	0.0
-1	**21**	16	1.5	1.0	0.7	0.0
0	**0**	20	1.5	1.0	0.7	0.0
0	**1**	3	1.5	1.0	0.8	0.0
		5	1.5	1.0	0.5	0.0
		7	1.6	1.0	0.4	0.0
		10	1.6	1.0	0.4	0.0
		12	1.6	1.0	0.2	0.0
		14	1.5	1.0	0.3	0.0
		16	1.8	1.0	0.3	0.0
		26	1.8	1.0	0.7	0.0
0	**2**	3	2.0	0.0	0.9	0.2
		5	2.0	1.0	0.9	0.0
		7	2.0	0.5	0.3	0.0
		10	2.0	0.3	0.3	0.0
		12	2.0	0.3	0.5	0.0
		14	2.0	0.3	0.3	0.0
		16	2.0	1.0	0.9	0.0
		26	2.0	1.0	0.1	0.0
0	**4**	3	2.0	2.0		3.0
		5	2.0	1.0	3.0	3.0
		7	2.3	1.0	2.1	1.5
		10	1.9	1.5	1.3	0.5
		12	2.2	1.5	0.8	0.0
		14	2.0	1.5	0.9	0.0
		16	2.0	1.5	1.1	0.0
		26	2.0	1.4	1.1	0.0
0	**6**	10	2.2	0.8	1.3	1.0
		12	1.6	0.8	0.9	0.0
		13	2.0	0.4	1.1	0.0
		14	2.0	1.0	1.3	0.0
		15	2.0	1.0	1.5	0.0
		16	2.0	1.0	1.0	0.0
		26	2.2	1.1	1.3	0.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
0	**7**	7	1.5	0.5	1.4	1.9
		10	1.5	0.5	0.7	1.0
		12	1.5	0.5	0.7	0.0
		14	1.5	0.5	0.7	0.0
		16	1.5	0.5	0.6	0.0
		26	2.0	0.9	0.9	0.0
0	**14**	12	1.8	1.0	0.4	0.0
		13	2.0	1.0	0.5	0.0
		14	1.8	1.0	0.4	0.0
		15	1.4	1.0	0.6	0.0
		16	1.9	1.0	0.5	0.0
0	**21**	12	2.0	1.0	0.8	0.0
		13	1.6	1.0	0.8	0.0
		14	1.9	1.0	0.8	0.0
		15	1.7	1.0	0.6	0.0
		16	1.8	1.0	0.8	0.0
0	**27**	12	2.6	1.5	0.6	0.0
		13	2.3	1.7	1.0	0.0
		14	2.6	1.5	0.9	0.0
		15	2.6	1.6	1.0	0.0
		16	2.5	1.5	0.6	0.0
0	**28**	12	1.9	1.0	0.7	0.0
		14	2.2	1.1	0.5	0.0
		16	2.4	1.0	1.0	0.0
1	**2**	3	2.5	1.5	2.1	2.0
		5	2.6	1.5	1.4	1.5
		7	2.0	1.2	0.9	0.5
		10	2.1	1.3	0.6	0.6
		12	1.7	1.3	0.8	0.4
		14	2.3	1.3	0.8	0.0
		16	2.0	1.3	0.7	0.0
		26	2.0	1.0	0.5	0.0
1	**4**	3	2.0	2.0		3.0
		5	2.0	2.0		3.0
		7	2.3	1.7	2.1	1.4
		10	2.4	1.6	1.5	1.0
		12	2.8	1.6	0.9	0.0
		14	2.3	1.5	1.2	0.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
1	**4**	16	2.1	1.2	1.0	0.0
		26	2.3	1.2	1.2	0.0
1	**27**	12	3.7	2.0	0.6	0.1
		13	3.5	2.0	0.6	0.0
		14	3.8	2.0	0.4	0.0
		15	3.6	1.9	0.9	0.0
		16	3.8	2.0	0.5	0.0
2	**1**	3	3.5	2.0	1.6	1.0
		5	3.2	1.8	1.0	1.0
		7	2.4	1.5	0.9	0.7
		10	2.3	1.4	0.7	0.3
		12	2.2	1.4	0.6	0.1
		14	2.4	1.5	0.8	0.0
		16	2.5	1.5	1.0	0.0
		26	2.2	1.5	0.8	0.0
2	**2**	3	2.5	1.5	2.1	2.0
		5	2.7	1.5	1.4	1.5
		7	3.0	1.4	0.9	0.7
		10	3.0	1.7	0.6	0.8
		12	2.6	1.7	0.9	0.1
		14	3.2	1.7	0.8	0.0
		16	2.7	1.5	0.8	0.0
		26	2.4	1.3	0.5	0.0
2	**4**	3	2.0	2.0		3.0
		5	2.2	2.0		3.0
		7	3.0	2.2	2.1	2.0
		10	3.7	2.6	1.3	1.0
		12	3.9	2.6	0.9	0.0
		14	3.8	2.1	1.3	0.0
		16	3.3	1.9	1.2	0.0
		26	3.0	1.6	1.2	0.0
3	**0**	20	2.8	2.1	0.7	0.0
3	**1**	3	3.8	2.0	1.6	1.0
		5	3.2	1.8	1.0	1.0
		7	3.4	1.9	0.9	0.7
		10	3.3	2.0	0.7	0.3
		12	3.4	1.8	0.6	0.2
		14	3.3	1.9	0.8	0.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
3	**1**	16	3.2	1.9	1.0	0.0
		26	3.2	1.9	0.9	0.0
3	**2**	3	3.0	2.0	2.1	2.0
		5	3.4	2.0	1.9	1.5
		7	3.7	2.1	1.3	1.0
		10	3.6	1.8	0.9	0.9
		12	3.6	2.0	1.1	0.2
		14	3.4	2.2	1.0	0.0
		16	3.1	1.9	1.1	0.0
		26	2.7	1.8	0.8	0.0
3	**4**	7	4.3	3.2	1.3	2.0
		10	3.8	2.8	1.1	1.0
		12	4.3	3.1	0.7	0.0
		14	4.0	2.8	1.2	0.0
		16	4.0	2.8	1.3	0.0
		26	4.1	3.1	1.0	0.0
3	**7**	7	3.3	2.0	1.4	1.9
		10	4.4	2.6	0.7	0.7
		12	4.4	2.2	0.8	0.0
		14	4.6	2.0	0.8	0.0
		16	4.2	2.0	0.7	0.0
		26	4.6	2.2	0.9	0.0
3	**14**	12	4.4	2.5	0.6	0.0
		13	4.5	2.7	0.9	0.0
		14	4.0	2.5	0.4	0.0
		15	4.5	3.1	0.8	0.0
		16	3.8	2.2	0.8	0.0
3	**21**	12	3.7	2.4	0.8	0.2
		13	3.0	2.5	1.0	0.0
		14	3.2	2.6	1.0	0.0
		15	2.7	2.3	0.8	0.0
		16	4.1	3.2	1.2	0.0
3	**28**	12	4.1	2.5	0.7	0.0
		14	5.0	2.6	0.5	0.0
		16	5.0	3.0	1.3	0.0
4	**0**	20	4.2	3.0	0.7	0.0
	1	3	4.5	3.0	2.0	1.0
		5	4.0	2.4	1.4	1.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
4	1	7	4.1	2.5	1.4	1.0
		10	3.8	2.2	0.9	0.6
		12	3.8	2.4	1.2	0.1
		14	3.8	2.2	1.2	0.0
		16	3.8	2.8	1.3	0.0
		26	3.7	2.3	1.1	0.0
4	2	3	5.0	3.5	2.7	3.0
		5	4.6	3.5	2.2	2.0
		7	5.0	3.5	1.4	1.5
		10	4.9	3.1	1.0	0.8
		12	4.7	3.5	1.1	0.3
		14	4.8	3.6	1.2	0.0
		16	4.7	3.5	1.1	0.0
		26	4.4	3.4	1.0	0.0
4	6	10	3.0	4.0	1.8	1.4
		12	4.3	4.0	1.3	0.2
		13	4.8	4.0	1.6	0.2
		14	4.3	4.0	1.5	0.0
		15	3.8	4.0	1.6	0.0
		16	4.3	4.0	1.2	0.0
		26	4.3	3.9	1.5	0.0
4	7	7	4.1	2.5	1.7	1.9
		10	5.0	2.9	0.7	0.7
		12	5.1	3.0	0.8	0.0
		14	4.8	2.2	0.8	0.0
		16	4.6	2.4	0.8	0.0
		26	4.7	2.3	0.9	0.0
4	14	12	4.8	3.4	0.7	0.0
		13	5.3	4.0	0.9	0.0
		14	4.7	3.3	0.5	0.0
		15	4.9	4.0	0.8	0.0
		16	4.8	3.3	0.8	0.0
4	21	12	5.1	3.3	1.0	0.3
		13	4.6	3.0	1.3	0.0
		14	4.4	3.3	1.1	0.0
		15	3.8	3.5	1.0	0.0
		16	4.2	2.7	1.2	0.0
4	27	12	6.0	4.0	1.0	0.0
		13	5.8	4.0	1.0	0.0
		14	5.5	4.0	1.0	0.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
4	**27**	15	5.3	4.0	1.2	0.0
		16	5.4	4.0	1.1	0.0
	28	12	4.7	3.1	0.8	0.0
		14	5.6	3.6	0.5	0.0
		16	5.1	3.0	1.3	0.0
5	**0**	20	4.7	3.3	1.1	0.0
5	**1**	3	6.0	4.0	2.5	2.0
		5	5.2	3.5	2.1	1.5
		7	5.4	3.2	1.6	1.0
		10	5.3	3.5	1.2	0.8
		12	5.1	3.2	1.6	0.0
		14	5.2	3.3	1.4	0.0
		16	5.4	3.6	1.2	0.0
		26	4.8	3.4	1.3	0.0
5	**2**	3	5.1	4.0	2.9	2.6
		5	5.2	3.6	1.8	2.0
		7	5.2	3.7	1.7	1.5
		10	5.5	3.4	1.3	0.8
		12	5.1	3.8	1.3	0.3
		14	5.3	3.7	1.2	0.0
		16	5.3	3.7	1.1	0.0
		26	4.8	3.4	1.0	0.0
5	**6**	10	5.0	4.0	1.3	1.5
		12	3.1	2.5	0.9	0.1
		13	3.4	2.5	1.1	0.0
		14	3.1	3.0	1.3	0.0
		15	3.3	3.0	0.8	0.0
		16	3.4	3.0	1.0	0.0
		26	5.1	3.7	2.0	0.0
5	**7**	7	4.5	3.0	1.9	2.0
		10	5.6	3.6	0.9	0.7
		12	5.6	3.4	0.9	0.0
		14	5.7	3.7	0.8	0.0
		16	5.3	3.2	1.0	0.0
		26	5.6	3.1	0.9	0.0
5	**14**	12	5.4	3.8	1.0	0.1
		13	5.6	4.0	1.0	0.0
		14	5.4	3.6	1.1	0.0
		15	5.3	4.0	0.9	0.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
5	14	16	5.4	3.6	0.7	0.0
5	21	12	5.6	3.0	1.0	0.3
		13	4.9	3.0	1.7	0.0
		14	5.0	3.0	1.4	0.0
		15	4.0	3.0	1.6	0.0
		16	4.9	3.0	1.3	0.0
5	27	12	6.1	4.0	1.3	0.0
		13	6.1	4.0	1.1	0.0
		14	6.1	4.0	1.5	0.0
		15	5.9	4.0	1.5	0.0
		16	6.0	4.0	1.1	0.0
5	28	12	5.1	3.6	1.0	0.0
		14	5.7	3.8	0.5	0.0
		16	5.4	3.6	1.4	0.0
6	0	20	5.7	3.8	1.3	0.0
6	1	3	6.6	4.0	3.0	3.0
		5	5.6	3.5	3.0	2.0
		7	5.7	3.6	1.6	1.5
		10	5.5	3.7	1.3	0.8
		12	5.4	3.5	1.6	0.3
		14	5.6	3.6	1.2	0.0
		16	5.8	3.7	1.7	0.0
		26	5.3	3.7	1.4	0.0
6	4	3	7.0	4.0		3.0
		5	7.0	4.0		3.0
		7	5.6	4.0	2.4	1.5
		10	6.0	3.8	2.1	0.9
		12	6.0	4.0	1.8	0.0
		14	6.0	3.7	2.1	0.0
		16	5.4	3.8	1.5	0.0
		26	5.3	3.9	1.7	0.0
6	6	10	6.9	4.0	1.3	1.5
		12	7.0	4.0	0.9	0.6
		13	7.0	4.0	1.1	0.0
		14	7.0	4.0	1.3	0.0
		15	6.7	4.0	1.4	0.0
		16	6.5	4.0	1.0	0.0
		26	5.7	3.7	2.9	0.0
6	7	7	4.8	3.5	2.5	2.5
		10	6.2	4.0	1.4	0.6

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
6	7	12	6.0	4.0	0.9	0.0
		14	6.0	4.0	1.5	0.0
		16	5.7	4.0	1.5	0.0
		26	5.6	3.6	1.2	0.0
6	14	12	5.8	3.3	1.1	0.0
		14	5.7	3.6	1.3	0.0
		16	6.0	3.4	1.1	0.0
6	21	12	6.8	4.0	1.6	0.1
		13	6.4	4.0	1.6	0.0
		14	6.5	4.0	1.9	0.0
		15	6.2	4.0	1.5	0.0
		16	5.9	4.0	1.7	0.0
6	27	12	6.9	4.0		0.0
		13	6.7	4.0		0.0
		14	6.8	4.0		0.0
		15	6.9	4.0		0.0
		16	6.6	4.0		0.0
6	28	12	5.9	4.0	1.0	0.0
		14	6.7	4.0	0.5	0.0
		16	6.1	4.0	1.4	0.0
7	0	20	6.2	3.6	1.7	0.0
	4	3	7.0	4.0		3.0
		5	7.0	4.0		3.0
		7	6.8	4.0	1.8	1.5
		10	6.6	3.9	1.8	1.4
		12	6.7	4.0	1.7	0.0
		14	6.8	4.0	1.7	0.0
		16	6.7	4.0	1.7	0.0
		26	6.5	3.9	1.6	0.0
7	6	10	7.0	4.0	1.3	1.5
		12	7.0	4.0	0.9	0.6
		13	7.0	4.0	1.1	0.0
		14	7.0	4.0	1.3	0.0
		15	7.0	4.0	1.4	0.0
		16	7.0	4.0	1.0	0.0
		26	6.7	3.7	2.9	0.0
7	7	7	6.7	3.5	2.6	2.5
		10	6.8	4.0	1.4	0.6
		12	6.9	4.0	1.4	0.0

Table 2 continued

Assessment Day After Ripening	Treatment Duration (Day)	Treatment Temp (°C)	Colour Stage (1-7)	Firmness (0-4)	Defects (1-3)	Chilling (0-4)
7	7	14	7.0	4.0	1.6	0.0
		16	6.8	4.0	1.9	0.0
		26	6.3	3.9	1.2	0.0
7	**14**	12	6.8	3.9	1.1	0.1
		13	6.7	4.0	1.1	0.1
		14	6.8	4.0	1.1	0.0
		15	7.0	4.0	1.2	0.0
		16	6.9	4.0	1.2	0.0
7	**21**	12	6.8	4.0	1.2	0.3
		13	6.7	4.0	1.2	0.0
		14	6.7	4.0	0.9	0.0
		15	6.4	4.0	0.9	0.0
		16	6.9	4.0	1.1	0.0
7	**27**	12	7.0	4.0		0.0
		13	7.0	4.0		0.0
		14	7.0	4.0		0.0
		15	7.0	4.0		0.0
		16	7.0	4.0		0.0

[Table Notes]

4.4 Chilling sensitivity response of 'Cavendish' banana fruit

4.4.1 Introduction

Chilling injury in banana fruit is caused by prolonged exposure to temperatures less than 13°C. This can occur during bunch development in the field, transport, ripening, storage and marketing. The chilling damage may depend on cultivars, growing season, maturity, time exposure and low temperature. Symptoms include surface discolouration, dull or smokey colour, sub-epidermal tissue dark-brown streaks, failure to ripen, and, in severe cases, flesh browning. Chilled fruits are also more sensitive to mechanical injury.

According to the guidelines of the UC Davis Postharvest Centre, chilling injury results from exposing bananas to temperatures below 13°C for a few hours to a few days. Chilling injury is a function of temperature and exposure time. For example, moderate chilling injury will result from exposing mature-green bananas to 1 hour at 10°C, 5 hours at 11.7°C, 24 hours at 12.2°C, or 72 hours at 12.8°C.

During monitoring of Ecoganic® banana shipments from Innisfail to Brisbane, Sydney, Singapore and Hong Kong in 2022, we observed that banana fruit at a hard green (unripe) or partially ripened stage were kept below the 12°C (some cases under 5-6°C) during road transport, airfreight, at the wholesale markets and at supermarkets. Often, chilling symptoms were reported by assessors or customers. For example, chilling injury symptoms on Ecoganic® bananas were observed at a domestic supermarket in April 2022 (Figure 1).

Figure 1. Ecoganic® fruits displayed on the shelf at a supermarket in April 2022 showing possible chilling injury with grey discoloured skin.

The objective of this research was to quantify the sensitivity of Ecoganic® 'Cavendish' banana fruit to chilling temperatures. The minimum exposure time to low (e.g., <13°C) handling temperatures that resulted in injury was determined for fruit harvested at different times of the growing season.

The goal of this research was to establish industry guidelines and a decision aid tool for informing better commercial handling practice in the commercial supply chain that minimise the risk of chilling injury and associated food waste.

4.4.2 Methods

This research quantified chilling sensitivity across several trials at different growing seasons. Chilling was tested under the range of temperature from 10-13°C for 4-96 hours for green-mature fruit (before exposure to ethylene) and ripened fruits (after exposure to ethylene). This represented the risk of injury during consolidation in the market prior to ripening or during subsequent storage, retail distribution or export after ripening.

Preliminary post-gassing chilling trial

Ecoganic® banana fruit was supplied by the Pacific Coast Eco Banana farm near Innisfail. The preliminary trial for winter fruit was initiated on 22 September 2021. This fruit emerged in the middle of June 2021. Fruits were commercially packed in a plastic liner, then placed in a carton. Fruits were selected with similar size with no or minor defects. The trial had 6 treatments with 12 fruits per treatment. Fruits were held in a cold room 14°C for 5 days to simulated road freight to Brisbane or Sydney. After that, they were ripened with 100 ppm ethylene at 16°C for 2 days. After ripening with ethylene gas, a chilling challenge was applied by holding fruit at 11°C for 4, 8, 24, 48 and 96 hours. Fruit were then moved to 20°C. The control samples was stored at 20°C during the chilling test.

4.4.2.1 Winter-Spring post-gassing chilling trial and Spring-Summer post-gassing chilling trial

For the winter-spring post-gassing chilling trial, fruit emerged at the end of July 2021 and were harvested on 2nd November 2021. For spring-summer post-gassing chilling trial, fruit emerged in October 2021 and were harvested on 17th January 2022. Trial 1 took place from 3rd November 2021 and Trial 2 took place from 17 January 2022.

For each trial, twelve bunches were selected at a packing shed on Boogan Road near Innisfail. From each bunch, fruit at the 2nd hand position from the top were chosen. If the hand had less than 21 fruits, the hand at the 3rd position from the top of the bunch was also sampled. Fruits were selected without severe defects or no diseases. Fruit hands were marked with bunch number in order. All fruit hands were run through the packing line including detaching into fruit clusters of 3-5 fruit each, immersion in a water bath, drying, and wax marking at tip. Fruits were packed into carton boxes with a plastic liner and paper sheets between hands to reduce potential abrasion damage. They were then transported to the postharvest laboratory at Redden Street Research Facility (RRF), Cairns within 2 hours. Fruits were placed in the cold room at 20°C for the next day trial preparation and initial assessments. Fruit clusters were recorded and individual fruit were separated for 21 treatments in total. Each treatment had 12 fingers from 12 banana clusters.

All fruits were held in a cold room 14°C for 5 days to simulate road freight transport to Brisbane or Sydney. After that, they were ripened with 100 ppm ethylene at 16°C for 2 days. After ripening with ethylene gas for 2 days, chilling was tested as following:

Twenty chilling treatments were tested with 4 chilling temperatures: 10, 11, 12 and 13°C; and 5 chilling duration times: 4, 8, 24, 48 and 96 hours; and one control was kept at 20°C.

2.3. Summer-Autumn post-gassing chilling trial (Trial 3) and pre-gassing chilling trial (Trial 4)

These two chilling trials started at the same time on 28 March 2022 with fruit that had emerged at the beginning of January 2022. The two trials included modification of the chilling treatment duration (8, 16, 24, 48 and 96 hours). Similar to the two trials above, the summer-autumn post-gassing chilling trial (Trial 3) tested for fruits after ripening with ethylene. However, the summer-autumn pre-gassing chilling trial (trial 4) were different to the trial 1, 2 and 3 as fruits from trial 4 were chilled at the green mature stage, before ripening with ethylene gas. This simulated a potential chilling event before fruit reached the ethylene gassing stage.

For the post-ripening chilling trial (trial 3), fruits will be held in a cold room 14°C for 5 days. Next, they were moved to 16°C for 1 day and then ripened with 100 ppm ethylene at 16°C for 2 days. After that, chilling was tested at 4 low temperatures (10, 11, 12 and 13°C) and 4 duration time lengths (8, 16, 24, 48 and 96 hours). After chilling exposure, fruit were kept at 20°C for shelf life evaluation until they reached colour stage 7. Non-chilling control fruit were always stored at 20°C during the chilling exposure.

For the pre-ripening chilling trial (trial 4); fruit were placed at 14°C for 7 days, then chilling exposure were tested as above. After chilling exposure, fruit were stored at 14°C and the control was stored at 14°C as standard temperature for green banana storage. On 6 April 22, fruit were moved to the ripening room at 16°C for 1 day and then treated with100 ppm ethylene at 16°C. After ripening with ethylene, fruit were kept at 20°C until colour stage 7. Banana fruits were assessed at intake, and every day during storage at 20°C until end of shelf-life (ESL when dark spots appeared on fruit skin; colour stage 7).

2.4. **Autumn-Winter** p**ost-gassing chilling trial (trial 5) and pre-gassing chilling trial (trial 6)**

The two chilling trials started at the same time. Fruits were harvested on 11 July 2022 for bunches that emerged on 10 April 2022. Like the two trials above, the two trials had the same chilling duration (8, 16, 24, 48 and 96 hours). The autumn winter post-gassing chilling trial (Trial 5) tested for fruits after ripening with ethylene. For the post-ripening chilling trial (trial 5), fruits will be held in a cold room 14°C for 5 days. Next, they were moved to 16°C for 1 day and then ripened with 100 ppm ethylene at 16°C for 2 days. Chilling was tested at 4 low temperatures and 4 exposure duration as described above. After chilling exposure, fruit were kept at 20°C for shelf life evaluation. Non-chilling controls were stored at 20°C.

For the pre-ripening chilling trial (trial 4); fruit were placed at 14°C for 7 days, then chilling exposure were tested at 4 low temperatures and 4 exposure durations. After chilling exposure, fruit were stored at 14°C and control was stored at 14°C as standard temperature for green banana storage. On 6 April 2022, fruit were moved to the ripening room at 16°C for 1 day and then ripened with 100 ppm ethylene at 16°C. After ripening with ethylene, fruit were kept at 20°C as above. Banana fruits were assessed at intake, and every day during storage at 20°C until end of shelf-life (ESL when dark spots appeared on fruit skin).

4.4.2.2 Fruit Quality Assessments

Assessments were done for individual banana finger. Following assessments were:

- Fruit dimensions
- Photographs of samples
- Colour rating score

- Firmness rating score
- Defect rating score
- Chilling injury rating score
- Minolta L, C, H (objective colour coordinates)
- Weight loss

Colour

Colour of skin was rated for individual fruit with the score from 1 – 7; 1: completely green; 2: less than 30% yellow; 3: 30-50% yellow; 4: 50-80% yellow; 5: more than 80% of yellow; 6: completely yellow but no black dots; 7: black dots obviously on the skin. Visual guide for banana ripeness chart as following:

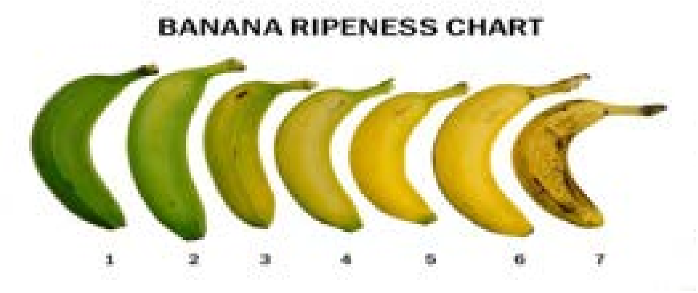


Figure 2. Banana colour chart from green to over ripe stage with score rating from 1 – 7.

Firmness

Firmness was rated for individual fruit with the score from 0 – 4; 0: hard; 1: rubbery with slight 'give'; 2: sprung, flesh deforms by 2 – 3 mm with extreme thumb pressure; 3: firm soft, whole fruit deforms with moderate hand pressure; 4: eating soft, whole fruit deforms with sight hand pressure.

Defect

Defect was rated for individual fruit using the following scale (0 – 4):

1: None, free from defect.
2: Slight, minor defect, not objectionable and affecting less than 5% of the surface area.
3: Moderate, slight to moderate objectionable defects, lower limit of attractions, less than 10% of the surface area.
4: Severe, excessive defect, limit of acceptability, less than 25% of the surface area.
5: Extreme; extremely poor, more than 25% of the surface area.

Chilling injury

Chilling injury was rated for individual fruit with the score from 0 – 3. Rating is based on the chilling symptom which include skin surface discolouration, dull or smoky colour, sub epidermal tissues reveal dark-brown streaks, failure to ripen. The rating score are following:

0: no chilling injury
1: light (less than 10 % surface with chilling symptoms or light green colour at ripe)
2. Medium (between 10 % -25% surface with chilling symptoms or green colour at ripe)
3. Severe (more than 25% surface with chilling symptoms or green colour at ripe)

Other chilling symptom was noted for the failure to reach 100% yellow colour on skin. Failure to ripen was based on the proportion of fruits which could not reach 100% yellow colour at the optimum stage.

Data analysis

Data were statistically analysed as one way ANOVAs using the 'General Analysis of Variance' model of Genstat®16 for Windows™ (VSN International Ltd., Hertfordshire, UK). The protected least significant difference (LSD) procedure at P = 0.05 was used to test for differences between treatment means.

3. Results

3.1. Preliminary trial

Shelf life

Days from harvest to end of shelf life (Figure 3) were significantly different. Fruit exposed to 11°C for 96 hours had the longest shelf life of 18 days, with almost 3-4 days longer than the 20°C control. Fruit held at 11°C for 48 hours had 2 days more shelf life longer than the control.

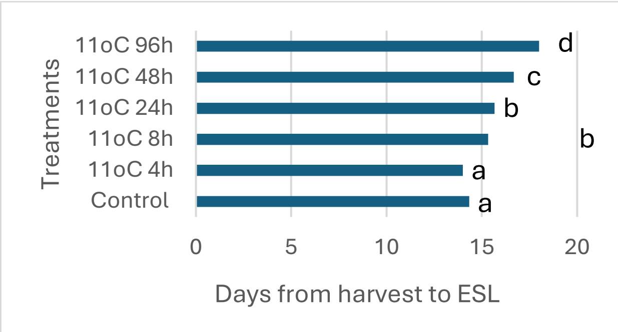


Figure 3. Days from harvest to ESL of 6 treatments at 11°C for 4, 8, 24, 48 and 96 hours; control at 20°C.

Chilling expression

Fruit from the treatment exposed to 11°C for 96h also did not always reach full yellow skin development at ripe. Exposure to 11°C for 48h resulted in some fruits having slight green colour appearance on the skin at the full ripe stage, as compared to control. Fruit from treatments that tested exposure to 11°C for 4 and 8 hours showed almost 100% yellow skin at ripe in line with the control. No dull skin or discolouration on skin or flesh were recorded.

3.2. Winter-Spring post-gassing chilling trial and Spring-Summer post-gassing chilling trial

Defects and dimensions

There were no significant (P > 0.05) differences in fruit dimension (circumference, length) at intake (Table 1). There were no effects of chilling temperatures or duration on fruit skin defects at intake or at during ripening at 20°C for winter-spring post-gassing fruits. In general, low temperature exposure from 10-13°C resulted in defect rating scores of less than 2, equating to slight defects.

Table 1. Ecoganic® banana fruit circumference, length and defect (0 = no defect to 4 = severe defect) at intake and at 5 days after ripening with ethylene gas (n=12). If followed by different letters, means within each column are significantly different (*P < 0.05*) by LSD (*P* = 0.05).

Treatment	Winter-Spring post-gassing chilling trial				Spring-Summer post-gassing chilling trial	
	Fruit circumference (cm)	Fruit length (cm)	Defect (0-4) at intake	Defect (0-4) at full yellow	Defect (0-4) at intake	Defect (0-4) at full yellow
Control	12.1	23.0	0.8	0.9	0.9 abc	1.2 bcde
10C 4h	11.9	22.7	0.8	0.8	0.8 ab	0.8 a
10C 8h	12.2	23.0	0.9	1.0	1.0 abcd	1.1 abcde
10C 24h	11.8	22.2	0.7	0.7	0.7 a	0.9 ab
10C 48h	11.9	22.2	0.6	0.9	0.7 a	1.0 abc
10C 96h	12.0	21.9	0.9	0.9	0.8 abc	1.0 abc
11C 4h	12.0	22.2	0.7	0.8	0.9 abc	1.0 abcd
11C 8h	12.0	22.5	0.8	1.0	1.0 abcd	1.0 abcd
11C 24h	12.1	21.9	0.7	0.7	1.0 abcd	1.2 bcde
11C 48h	11.9	22.7	0.8	0.8	1.2 cde	1.3 def
11C 96h	11.8	22.6	0.8	0.9	1.0 abcd	1.1 abcde
12C 4h	11.7	21.7	0.9	0.9	1.2 cde	1.3 cdef
12C 8h	11.6	22.2	0.8	0.8	1.1 bcde	1.3 cdef
12C 24h	11.9	21.6	0.9	0.9	1.1 bcde	1.4 def
12C 48h	11.7	22.6	0.7	0.7	1.0 abcd	1.2 bcde
12C 96h	11.8	21.8	0.9	0.9	0.7 a	0.9 ab
13C 4h	11.7	21.9	0.8	0.9	1.5 e	1.6 f
13C 8h	12.5	20.9	0.7	0.7	1.3 de	1.4 ef
13C 24h	11.6	22.2	0.8	0.9	1.0 abcd	1.3 cdef
13C 48h	11.7	22.7	0.7	0.9	0.9 abc	1.2 bcde
13C 96h	11.8	22.2	1.0	0.9	1.2 cde	1.3 cdef
LSD 0.05	n.s.	n.s.	n.s.	n.s.		

n.s. Not significant.

Fruit weight loss

There were significant treatment differences in fruit weight loss at 2, 5 and 6 days when ripening at 20°C (the letters not shown, Figure 4). However, the difference among treatments were minor, less than 1%.

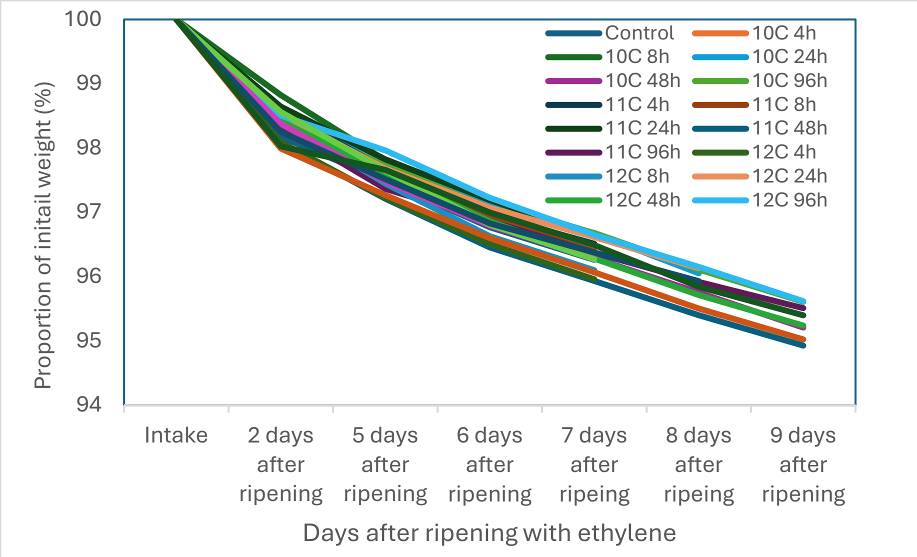


Figure 4. Effects of low temperature and exposure time length of banana on fruit weight loss (% of initial fresh weight) during storage.

Chilling expression

Almost no chilling symptoms were observed on fruit exposed to 13 or 12°C for less than 24 hours for both winter-spring and spring-summer trials. Treatments at 10°C for 96 hours had the highest severity of chilling score (1.4), following 10°C for 48 hours (0.5) and 11°C for 96 hours (0.6). Slight chilling symptoms were observed for fruit held at 11-13°C for 48 hours (Figure 5, left). The chilling symptoms were pale skin colour. Winter-spring fruit had fewer chilling injury scores but exhibited a higher proportion of partly green fruit than samples taken from the spring-summer crop.

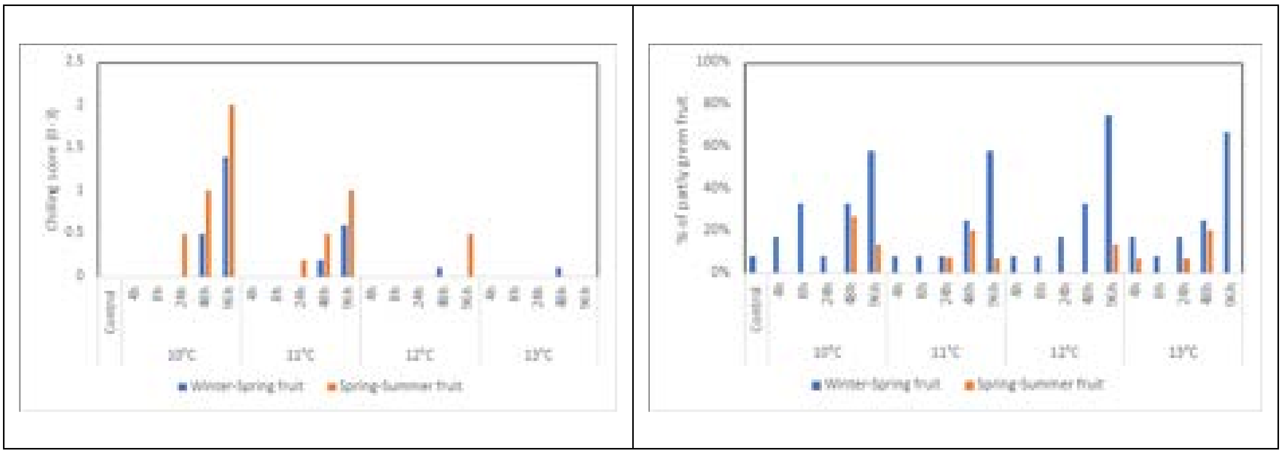


Figure 5. Chilling scores with pale skin colour (left) and proportion of partly green fruit for 2 fruit development time (right); Winter-Spring fruit banana with blue bar and Spring Summer- red bars.

Fruit from treatments held at 10 -13°C with exposure time of 96 hours had low proportion of replicates (25 – 42%) that reached full yellow colour at the ripening stage (Figure 5, left). That means a high proportion of fruits did not develop complete yellow skin colour before turning into an over-ripen stage.

Skin colour

There was a treament effect on skin colour at full ripe stage (Table 2). At that stage, treatment at 10°C and 11°C for 96 hours had the lowest objective colour, expressed as lightness or L*(67.0 and 65.7, respectively). Those two treatments had darker skin colour than other treatments and the control. It was consistent with the findings for chilling scores of fruit held at 10°C and 11°C for 96 hours which had highest severity of chilling (pale skin colour).

While there was no overall significant difference in skin chroma (C*) value for all treatments, one difference was noted. Treatment 10°C for 96 hours had the lowest in C* (40.4). Fruit from that treatment were slightly greener in colour than those from other treatments. In general, fruits from all treatments at full ripe stage developed 100% yellow colour. Only some fruits had not developed yellow colour at the skin near the stem end, that was recorded by skin colour rating in Table 2.

Table 2. Effects of low temperature and exposure time length on Ecoagnic® banana skin colour, as measured objectively (L*, C* andhvalue) at full ripe stage (n=12). If followed by different letters, means within each column are significantly different (P < 0.05) by LSD (P = 0.05).

	Winter-Spring fruit					Spring-Summer fruit		
	L*		C*		h	L	C	h
Control	71.6	ef	43.9	bcd	93.4	73.6	42.8	91.2
10C 4h	70.1	cdef	43.7	bc	92.5	72.5	44.0	90.8
10C 8h	70.7	cdef	44.5	bcde	92.9	72.9	41.5	90.7
10C 24h	68.5	abcd	43.1	abc	91.6	70.1	38.4	88.9
10C 48h	69.0	bcde	42.5	ab	91.2	70.0	39.1	88.8
10C 96h	67.0	ab	40.4	a	93.4	66.9	35.6	87.0
11C 4h	69.9	cdef	47.1	efg	93.5	73.8	42.1	91.0
11C 8h	70.0	cdef	44.1	bcde	93.6	73.7	42.7	91.0
11C 24h	69.0	bcde	47.7	fg	92.3	72.6	40.1	90.4
11C 48h	68.2	abc	46.0	cdefg	92.6	70.8	39.3	89.8
11C 96h	65.7	a	43.7	bc	93.5	70.2	39.1	87.9
12C 4h	72.1	f	43.5	abc	93.0	73.9	42.8	91.5
12C 8h	72.0	f	45.4	cdefg	92.4	74.6	43.5	91.4
12C 24h	71.1	def	44.5	bcde	93.1	70.8	42.8	90.6
12C 48h	69.8	cdef	45.9	cdefg	94.5	74.4	43.0	90.7
12C 96h	68.9	bcde	45.1	bcdef	93.5	69.9	40.3	88.3
13C 4h	68.9	bcde	48.3	g	92.6	71.1	43.4	91.1
13C 8h	68.9	bcde	46.9	defg	93.6	71.4	45.0	91.2
13C 24h	68.0	abc	47.9	fg	93.5	72.0	44.1	91.2
13C 48h	69.8	bcdef	44.9	bcdef	93.4	70.3	43.2	91.4
13C 96h	71.7	ef	46.2	cdefg	92.3	72.0	40.8	89.5

Fruit shelf life

The day fruits developed dark black spots on skin were noted as end of shelf life. The shelf life of fruits were affected by the exposure time at low temperature (Figure 6). Fruit from treatments at 10 - 13°C for 96 hours had the longest in shelf life; 18 days from harvest or about 10 days from end of ethylene gassing stage, while control fruit and those held at 10-13°C for 4-8 hours had 15 days of shelf life from harvest or 7 days after gassing with ethylene. Storage at 10°C for 96 hours increased the shelf-life to 4 days compared to the control.

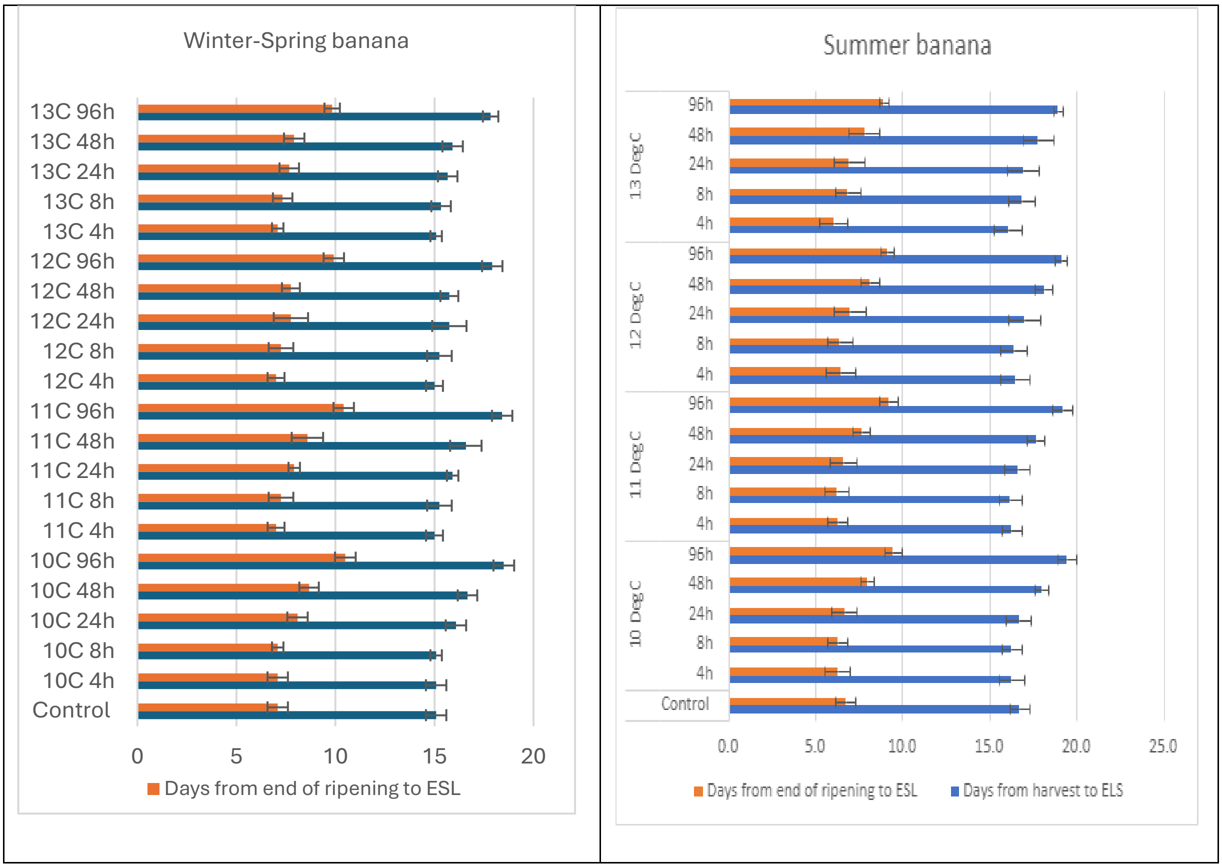


Figure 6. Effects of low temperature and exposure time length of Ecoganic® banana on shelf life (days from harvest or from end of gassing with ethylene to the day fruit developing black spots on skins). The vertical bars with the symbols represent the standard deviation.

Figure 7 shows Winter-Spring bananas that had high proportion of partly green fruits at ripe. There were some fruits with pale colour on skin for the treatment at 10°C for 96 hours.

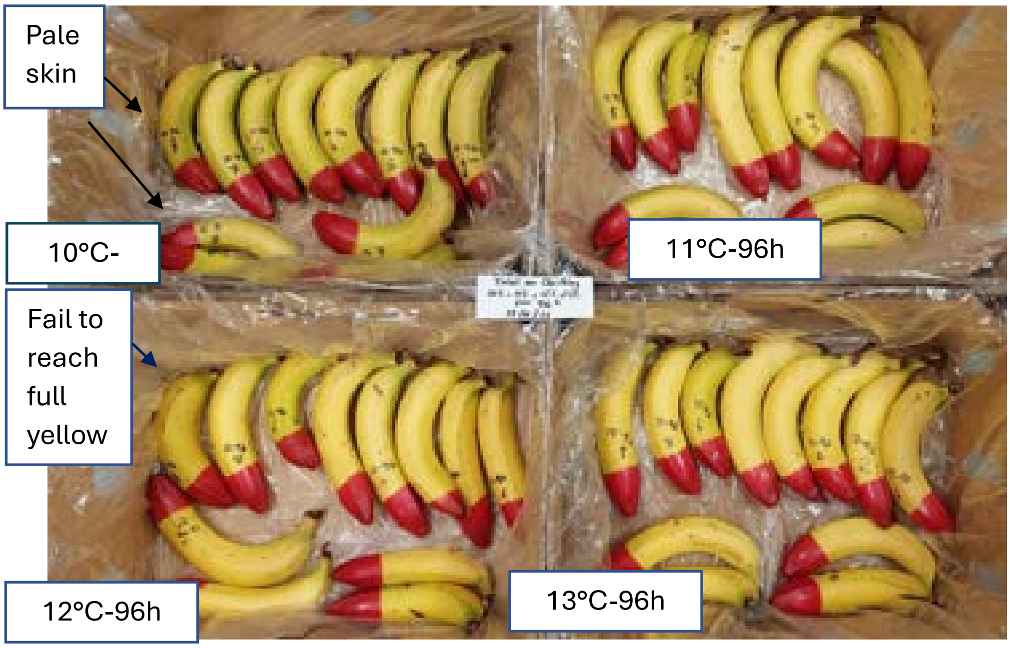


Figure 7. Photos of ripe Ecoganic® bananas from 4 chilling treatments at 10, 11, 12 and 13°C for 96 hours for Winter-Spring fruit. Chilling was carried after fruits were exposed with ethylene. After chilling, fruits were kept at 20°C until over ripe. The picture is showing chilling-induced failure to ripen symptoms.

Figure 8 shows that the skin of fruit exposed to 10°C for 96 hours had the highest pale skin colour at ripe. The degree of pale colour decreased when chilling temperatures increased. For example, treatment at 13°C for 96 hours showed almost no pale colour on ripe fruit skin.

Figure 8. Photos of ripe Ecoganic® bananas from 4 chilling treatments at 10, 11, 12 and 13°C for 96 hours. Chilling was carried after fruits were exposed with ethylene and then kept at 20°C. The picture shows varying degrees of chilling damage manifested in pale colour skin.

3.3. Summer-Autumn post-gassing chilling trial and Summer-Autumn pre-gassing chilling trial

Fruit dimensions (circumference, length) and defects at intake for all 21 treatments were similar (Table 11). There were no effects of chilling temperatures or duration on fruit skin defects at full colour stage of the Summer-Autumn pre-gassing chilling trial. However, a slight defect difference was recorded for the Summer-Autumn post-gassing chilling trial, but all defect average scores were under 2; that means acceptable for commercial trade and within retailer specifications.

Chilling injury

Figure 9 shows almost no chilling symptoms developed on fruit at 13 or 12°C when exposed for less than 24 hours. However, when held at 12°C for 48 to 96 hours, fruits started to develop chilling symptoms (pale colour on fruit skin). The highest in chilling rating score were recorded for treatments at 10°C for 96 hours for both trials. This is a clear threshold for fruit damage. The chilling score decreased when the duration exposure decreased. Treatments at 11°C for 8 and 16 hours of the pre-gassing trial caused limited injury on fruit.

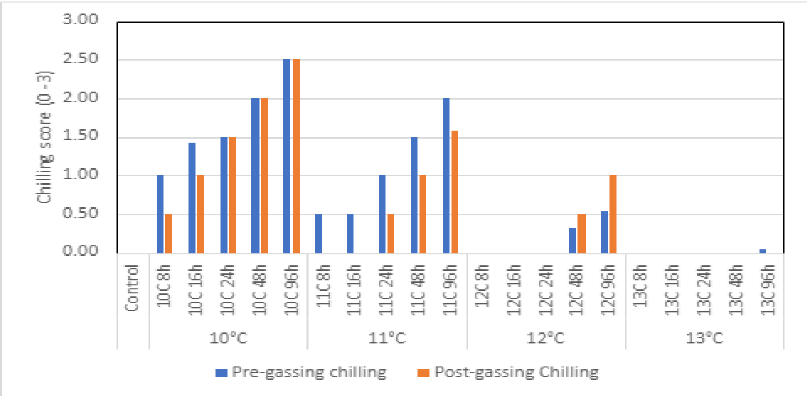


Figure 9. Chilling scores for Ecoganic® bananas with pale skin colour (0-4) of Summer-Autumn post-gassing chilling trial (red bars) and Summer-Autumn pre-gassing chilling trial (with blue bars).

Table 4. Ecoganic® banana circumference, fruit length and defect (0 = no defect to 4 = severe defect) at intake and at full colour stage of Summer-Autumn post-gassing chilling trial and Summer-Autumn pre-gassing chilling trial. If followed by different letters, means within each column are significantly different (P < 0.05) by LSD (P = 0.05).

	Post-gassing chilling					Pre-gassing chilling	
	Circle (mm)	Length (mm)	Defect (0-4) at intake	Defect (0-4) at full colour stage		Defect (0-4) at intake	Defect (0-4) at full colour stage
Control	11.8	20.9	0.9	1.2	abc	0.9	1.4
10C 8h	11.4	20.7	0.9	1.4	abcde	1.0	1.5
10C 16h	11.5	20.5	0.8	1.0	a	0.9	1.4
10C 24h	11.4	20.5	1.1	1.4	bcde	0.8	1.4
10C 48h	11.5	20.1	1.3	1.8	f	0.8	1.7
10C 96h			1.0	1.8	ef	0.7	1.5
11C 8h	11.4	20.6	0.8	1.3	abc	0.7	1.3
11C 16h	11.4	20.7	1.0	1.3	abc	0.8	1.1
11C 24h	11.4	20.5	1.0	1.2	abc	0.7	1.0
11C 48h	11.5	20.9	0.8	1.4	abcde	1.1	1.6
11C 96h			0.7	1.7	def	0.9	1.0
12C 8h	11.7	20.1	0.9	1.2	abc	0.9	1.5
12C 16h	11.6	20.8	0.7	1.1	ab	0.8	1.2
12C 24h	11.5	20.6	1.0	1.1	ab	1.2	1.5
12C 48h	11.6	20.5	1.0	1.5	bcdef	1.0	1.3
12C 96h			1.0	1.8	ef	0.8	1.2
13C 8h	11.6	20.6	1.0	1.0	a	0.9	1.1
13C 16h	11.6	20.4	1.2	1.3	abc	0.8	1.3
13C 24h	11.6	20.7	1.0	1.3	abcd	0.8	1.3
13C 48h	11.3	20.0	1.0	1.5	cdef	0.7	1.1
13C 96h			1.1	1.8	ef	0.8	1.0
			n.s.			ns.	n.s

Minolta (objective colour)

The chilling symptoms were compared by using the objective Minolta measurements (Table 11). There were significant differences in Lightness (L*), chroma (C*) and huge angle (H°). The control fruit from both treatments had a C* value above 47, while other treatments marked with red in Table 11 showed lower C* values, such as fruit held at 10°C for 8, 16, 24, 48 and 96 hours . That indicates those treatments had less yellow skin than the control. That was consistent with the findings of chilling scores in Figure 9.

Table 5 Lightness (L*), chroma (C*) and huge angle (H°) at full colour stage of Ecoganic® bananas from the Summer-Autumn post-gassing chilling trial and Summer-Autumn pre-gassing chilling trial. If followed by different letters, means within each column are significantly different (P < 0.05) by LSD (P = 0.05).

Treatment	Summer-Autumn pre-gassing chilling trial						Summer-Autumn post-gassing chilling trial					
	L		C		H		L		C		H	
Control	66.1	defg	47.8	i	91.9	k	72.1	hijkl	47.2	efgh	90.9	fghi
10C 8h	64.8	bcde	38.9	ab	87.4	ab	67.0	bc	41.3	bc	88.3	b
10C 16h	63.2	abcd	37.8	a	86.9	a	70.1	defghi	41.2	bc	89.2	cd
10C 24h	62.5	abc	38.0	a	87.6	abc	69.0	cdefg	42.5	cd	88.8	bc
10C 48h	62.1	ab	37.9	a	87.8	abcd	60.3	a	39.3	ab	87.4	a
10C 96h	65.8	cdefg	38.6	ab	91.1	ghijk	67.7	cde	37.9	a	88.2	b
11C 8h	67.7	efgh	44.1	efg	90.3	fghi	73.4	l	49.9	i	90.4	efg
11C 16h	63.0	abcd	42.5	def	89.3	ef	73.0	kl	49.3	hi	90.4	efg
11C 24h	60.1	a	42.0	cde	88.8	de	72.9	jkl	50.0	i	90.3	efg
11C 48h	65.2	bcdef	39.4	abc	88.6	cde	70.8	ghijkl	46.2	ef	90.1	ef
11C 96h	69.2	ghi	40.8	bcd	88.4	bcde	65.0	b	42.6	cd	90.7	fghi
12C 8h	68.2	efghi	46.9	hi	91.2	hijk	69.5	cdefgh	47.7	fghi	90.6	fgh
12C 16h	70.9	hij	47.7	i	91.6	jk	68.0	cdef	46.3	efg	90.3	efg
12C 24h	71.5	ij	46.1	ghi	90.5	ghij	70.2	efghij	45.7	ef	90.7	fgh
12C 48h	66.4	defg	44.7	fgh	90.0	fg	67.4	bcd	44.8	de	90.1	ef
12C 96h	67.5	efgh	41.9	cde	89.4	ef	71.6	ghijkl	44.5	de	89.7	de
13C 8h	70.1	hij	47.3	i	90.8	ghijk	70.5	fghijk	48.9	ghi	90.9	ghi
13C 16h	68.1	efghi	47.7	i	91.3	ijk	72.2	ijkl	47.8	fghi	91.3	hi
13C 24h	68.5	fghi	45.7	ghi	90.1	fgh	72.3	ijkl	46.9	efgh	91.5	i
13C 48h	70.8	hij	45.8	ghi	91.1	ghijk	69.3	cdefg	48.1	fghi	90.8	fghi
13C 96h	66.1	defg	47.9	i	90.8	ghij	70.7	fghijkl	46.5	efg	90.5	efg

End of shelf life

Similar to the result in trial 2 and trial 3 on post-ripening chilling banana, Ecoganic® banana kept longer time at low temperature from 10-13°C after gassing with ethylene increased the shelf life of fruit (Figure 10, left). When fruit ripened with gas and kept at 20°C at the same time, all treatments had about 6-7 days to reach the end of shelf life (Figure 10, right).

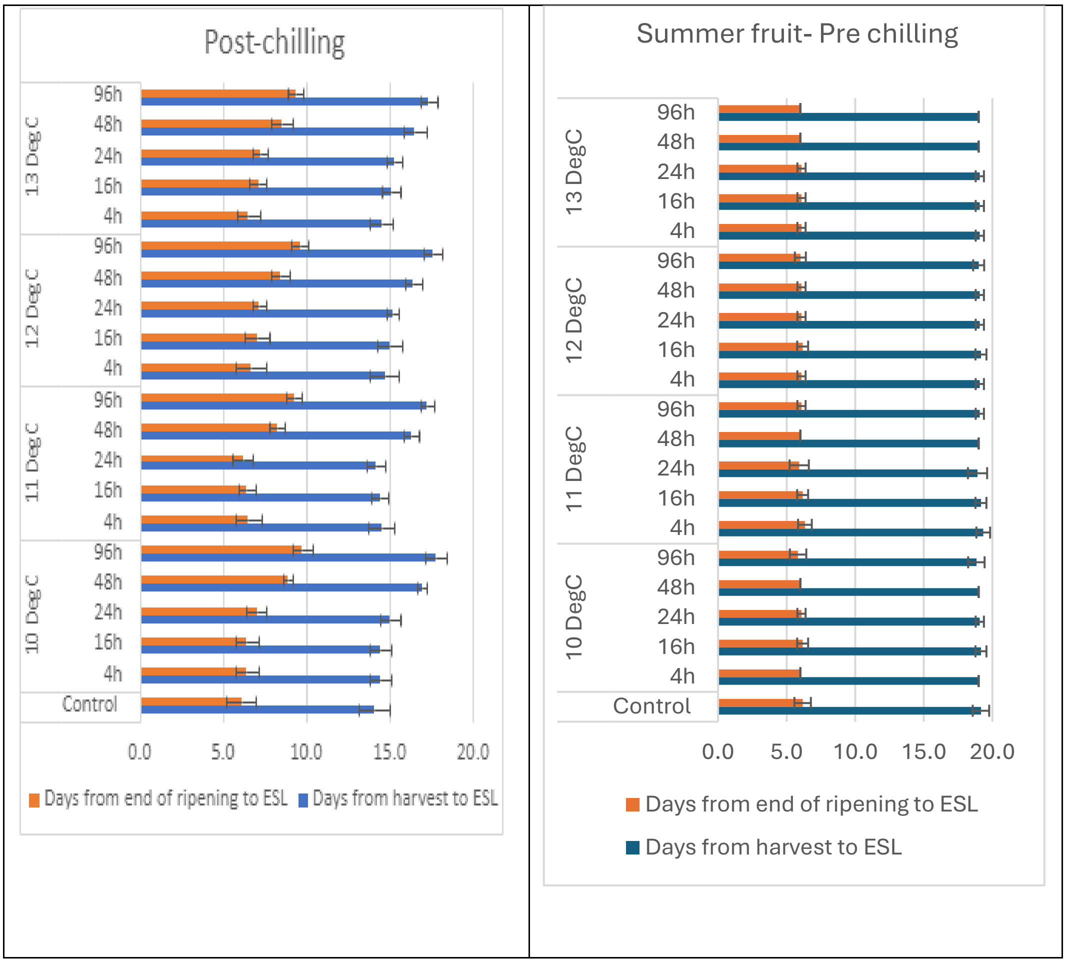


Figure 10. Effects of low temperature and exposure time length of Ecoganic® banana on shelf life (days from harvest or from end of gassing with ethylene to the day fruit developing black spots on skins). The vertical bars with the symbols represent the standard deviation.

Figure 11. Photo of ripe Ecoganic® bananas from chilling treatments at 10, 11, 12 and 13°C for 96 hours at full ripe stage of Summer-Autumn post-gassing chilling trial. Chilling was carried before fruits were exposed with ethylene. The picture shows chilling symptoms with pale colour on skin of the chilling treatments compared to control.

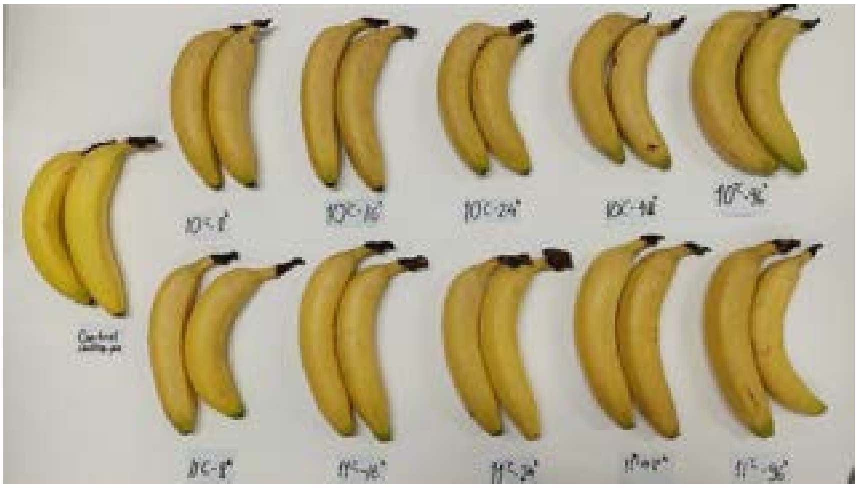


Figure 12. Photo of ripe Ecoganic® bananas from the control and chilling treatments of Summer-Autumn pre-gassing chilling trial at 10 and 11°C for 8, 16, 24, 48 and 96h at full ripe stage. Chilling was carried before fruits were exposed with ethylene. After ripening with ethylene, fruits were kept at 20°C until overripe. The picture was taken at ripe stage of summer fruit emerged in Dec 2021 and harvested in 28th March 2022. The picture shows chilling symptoms with pale colour on skin of the chilling treatments compared to control.

3.4. Autumn-Winter post-gassing chilling trial (trial 5) and pre-gassing chilling trial (trial 6)

Chilling injury

There were almost no chilling symptoms on fruit held at 12 or 13°C for both post-ripening and pre-ripening chilling trials for Autumn-Winter fruits. Low temperature exposure to 10 or 11°C for 48 to 96 hours showed the highest chilling injuries with pale colour on fruit skin.

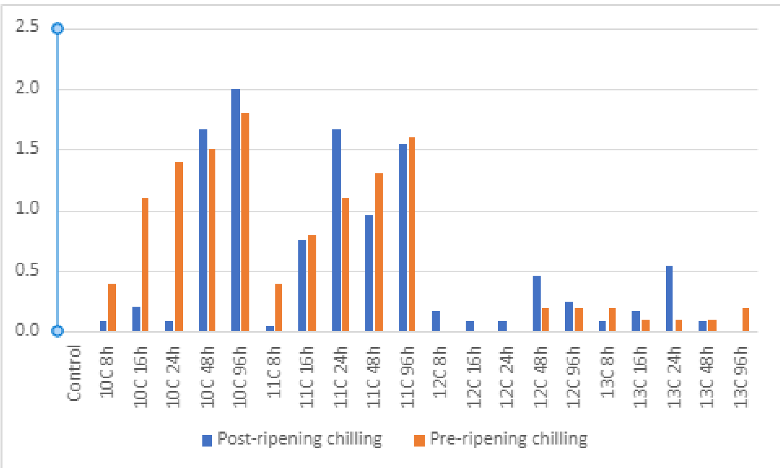


Figure 13.. Chilling scores for ripe Ecoagnic® bananas with pale skin colour (0-4) of Autumn-Winter post-gassing chilling trial (red bars) and Autumn-Winter pre-gassing chilling trial (with blue bars).

Fruit defects

In general, chilling injury was more severe on bananas that were exposed to 10-11°C before ethylene treatment, relative to those treated after ripening (Table 13).

Table 13. Defect (0 = no defect; 4 = severe defect) at intake and at full colour stage for Ecoagnic® bananas sampled from Autumn-Winter post-gassing and pre-gassing chilling trial. If followed by different letters, means within each column are significantly different (P < 0.05) by LSD (P = 0.05).

	Post-gassing chilling							
				Pre-gassing chilling				
	Defect (0-4) at intake	Defect (0-4) at full colour stage		Defect (0-4) at intake		Defect (0-4) at full colour stage		
Control	1.3	1.3	abc	1.1	ab	1.0	abc	
10C 8h	1.3	1.3	ab	1.4	abcde	1.3	abcde	
10C 16h	1.3	2.3	de	1.3	abcde	1.0	abcd	
10C 24h	1.3	2.3	de	1.2	abcd	1.0	abc	
10C 48h	1.3	2.2	de	2.0	g	1.3	abcde	
10C 96h	1.3	1.3	ab	1.7	efg	1.6	e	
11C 8h	1.2	1.3	abc	1.8	fg	1.2	abcde	
11C 16h	1.2	2.0	de	1.6	defg	1.5	cde	
11C 24h	1.3	1.4	abc	1.5	cdef	1.5	cde	
11C 48h	1.3	2.1	de	1.1	abc	1.2	abcde	
11C 96h	0.9	0.9	a	1.0	a	0.8	a	
12C 8h	1.0	1.2	ab	1.3	abcde	0.9	ab	
12C 16h	1.6	2.6	e	1.3	abcde	0.8	a	
12C 24h	1.5	2.6	e	1.3	abcde	1.3	abcde	
12C 48h	1.3	2.2	de	1.3	abcde	1.5	de	
12C 96h	1.3	1.1	a	1.5	bcdef	1.4	bcde	
13C 8h	1.2	1.2	ab	1.4	abcdef	1.3	abcde	
13C 16h	1.0	1.9	cd	1.7	efg	1.6	e	
13C 24h	1.2	1.8	bcd	1.2	abcd	1.2	abcde	
13C 48h	0.9	1.9	cd	1.5	bcdef	1.6	e	
13C 96h	1.3	1.3	ab	1.4	abcdef	1.4	bcde	

Minolta

The chilling symptoms were also assessed by using the objective Minolta skin colour measurements (Table 4). There were significant differences in Lightness (L*), chroma (C*) and huge angle (H°). The control of both treatments had C* value above 47, while other treatments marked with red in Table 4 showed low in C value, such as treatments at 10°C for 8, 16, 24, 48 and 96 hours . That indicates those treatments had less yellow skin than the control.

Table 4. Lightness (L*), chroma (C*) and huge angle (H°) at full yellow colour stage of Ecoagnic® bananas from the Autumn-Winter post-gassing pre-gassing chilling trial. If followed by different letters, means within each column are significantly different (P < 0.05) by LSD (P = 0.05).

Treatment	Post-gassing chilling trial						Pre-gassing chilling trial					
	L		C		H		L		C		H	
Control	64.1	efg	47.8	de	93.2	fg	59.7	a	35.8	a	85.2	a
10C 8h	61.4	bcdefg	44.3	bc	94.8	gh	62.1	ab	37.0	ab	85.7	ab
10C 16h	61.0	bcdef	41.9	ab	88.9	abc	62.1	ab	38.8	abc	86.2	abc
10C 24h	60.7	bcde	41.0	a	89.1	abc	62.5	abc	39.4	bc	86.2	abcd
10C 48h	58.3	abc	42.4	ab	93.7	fg	62.8	abc	39.7	bc	86.2	bcd
10C 96h	58.3	abc	41.8	ab	88.8	abc	64.0	bcd	39.9	bc	86.4	bcd
11C 8h	62.2	bcdefg	45.8	cd	97.3	i	64.3	bcd	40.6	c	86.6	bcd
11C 16h	58.2	ab	41.4	ab	90.2	cde	64.6	bcde	41.3	c	86.7	bcde
11C 24h	60.0	bcd	42.3	ab	89.5	abc	65.0	bcde	41.6	cd	86.8	cdef
11C 48h	55.3	a	40.5	a	92.1	ef	65.3	bcdef	41.7	cd	86.9	cdefg
11C 96h	59.0	abc	42.2	ab	89.5	abc	65.6	bcdef	44.7	de	87.2	defgh
12C 8h	63.3	defg	47.9	de	96.1	hi	65.8	bcdef	44.7	de	87.7	efghi
12C 16h	63.2	defg	49.1	e	90.5	cde	66.0	cdef	45.0	e	87.7	efghij
12C 24h	61.8	bcdefg	47.7	de	89.9	bcd	66.5	def	45.1	e	87.8	efghij
12C 48h	64.8	fg	46.2	cde	92.1	ef	66.5	def	45.1	e	87.8	fghij
12C 96h	63.5	defg	45.4	cd	87.8	ab	66.5	def	45.6	e	87.9	ghij
13C 8h	64.9	fg	47.4	de	95.3	ghi	66.55	def	46.49	e	88.0	ghij
13C 16h	63.3	defg	47.2	cde	90.3	cde	67.13	def	46.84	e		
13C 24h	62.1	bcdefg	47.3	de	90.7	cde	68.27	efg				
13C 48h	62.3	cdefg	47.6	de	91.7	def	68.75	fg				
13C 96h	65.2	g	47.3	de	87.7	a						

End of shelf life

Similar to the result in trial 2 and trial 3 on post-ripening chilling banana, banana kept longer time at low temperature from 10-13°C after gassing with ethylene increased the shelf life of fruit (Figure 10, left). When fruit ripened with gas and kept at 20°C at the same time, all treatments had about 6-7 days to reach the end of shelf life (Figure 10, right).

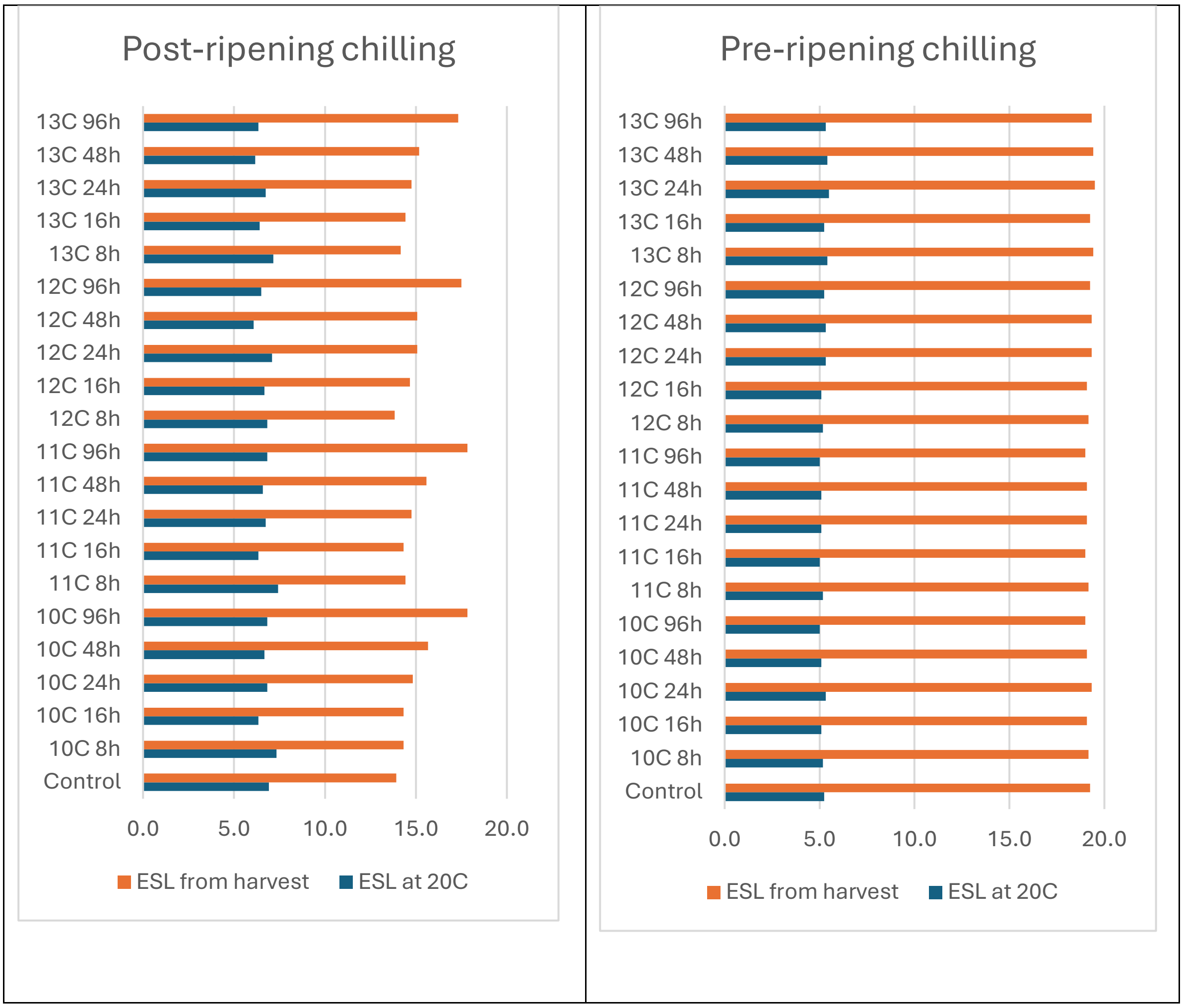


Figure 10. Effects of low temperature and exposure time length of Ecoganic® banana on shelf life (days from harvest or from end of gassing with ethylene to the day fruit developing black spots on skins). The vertical bars with the symbols represent the standard deviation.

Conclusion

- Winter Ecoganic® Cavendish banana fruits (fruits developed from July-October 2021) exposed to 10-11°C for 48-96 hours displayed chilling injury as evidenced by pale skin colour.
- Spring summer season fruits (which developed from middle of September 2021 to middle of January 2022) exposed to 10-11°C for 24-96 hours displayed chilling injury as evidenced by pale skin colour.
- Summer season fruits (which developed from middle of January to end of March 2022) exposed to 10°C for 8-96 hours or 11°C for 24-96h displayed chilling injury as evidenced by pale skin colour.
- Winter fruits had slightly less chilling severity than summer fruits. Longer exposure duration to chilling temperatures was associated with higher chilling severity.
- The green mature fruits (un-gassed fruits) had slightly higher chilling severity than ethylene-gassed fruits.

- Most attention should be paid to fruit from the summer crop as they are of greatest risk to chilling temperatures during transport, consolidation and distribution to market.

The results showed that low temperature at 13°C caused almost no chilling effect and could extend the shelf life equal to the days fruits stay at that low temperature (e.g. low temperature at 13°C for 96 hours prolonged fruit shelf-life up to 3-4 days). Therefore, the shelf life of banana can be prolonged by keeping the fruit at 13°C before they were moved to 20°C for marketing, which help retailers significantly improve marketing potential, especially for airfreight export which requires ripening process before shipments.

4.5 Chilling alleviation for banana fruit using Styrofoam and air-cell insulation

Introduction

In 2022, two airfreight consignments of Ecoganic® bananas from Sydney to Singapore showed that fruits were kept at about 5°C, much under optimal temperatures for banana at 14°C. This was associated with severe chilling injury and the fruit was unmarketable, representing significant food waste and economic loss. When queried, the exporter and importer indicated the banana fruit were kept at low temperature because they were part of a mixed commodity load. The other products in the load (e.g. cherry, blueberry, dairy products) needed to be maintained at low temperature to prolong shelf-life.

Figure 1. Photograph of severe chilled bananas which arrived in Singapore in June 2022 and were unmarketable.

Banana fruit have an optimal temperature for storage and transport at 13-14°C. Our current trials showed that fruit could stand at 12°C for 1-2 days without chilling symptoms. Exposing at 10-11°C for less than 24 hours lead to only brightness loss on skin colour, depending on growing seasons. Banana could not stand at 5-7°C as fruits showed severe chilling symptom and become unmarketable.

This trial aimed to test products to alleviate chilling injuries for banana fruit when stored temporarily at 5°C-cold transport as part of mixed commodity loads for domestic and export supply chains.

Methods

Test 1: Styrofoam box used to alleviate chilling injury for banana

Green-mature Ecoganic® bananas were collected from Pacific Coast Eco Banana near Innisfail. Fruits were harvested and packed in commercial boxes on 13 September 2023. Fruits were transported to the laboratory in Cairns on the same day in standard industry cardboard banana boxes and stored for 2 weeks at 14°C.

After long cold storage, banana fruits were repacked into a Styrofoam box (size HxLxW: 360x570x380 mm; wall thickness: 27mm, net weight 22.5kg. After that, the fruits were stored at 5°C for 48 hours, then the box was moved to 14°C for 72 hours without opening the lid to simulate exporter, airfreight and importer handling. An industry standard cardboard banana box lined with a perforated plastic liner acted as the control at 14°C.

Figure 2. Ecoganic® Banana fruits were repacked into Styrofoam boxes after cold storage

The Styrofoam box was then opened and all fruits were kept at 16°C for 24 hours. The fruit were then ripened with 100 ppm ethylene gas at 16°C for 2 days. Fruits were stored at 20°C for quality assessments.

Test 2: Air-cell insulation used to alleviate chilling injury for bananas

Ecoganic® banana fruits were harvested and packed on 16 November 2023 from the Marlin Blue farm near Innisfail. Fruits were stored overnight at 14°C at the laboratory in Cairns. On the following day, 2 standard industry cardboard banana boxes lined with perforated plastic film were used for the chilling test 2. One box was wrapped with Kingspan® Air-cell insulated liner (see the picture below) and the second box for control (no insulation). Both boxes were kept at the same temperature.

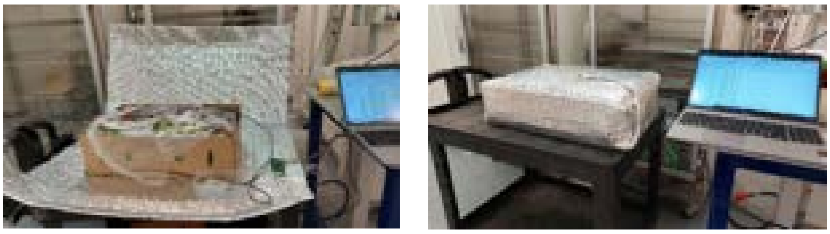


Figure 3. Air-cell insulation used to wrap the whole box of Ecoagnic® bananas

The temperatures at the centre and edge of the boxes and of the core fruit were monitored. Two boxes were placed at 10°C for 65 hours, then the boxes were moved to 14°C for 51 hours. After that, the two boxes were placed into 5°C for 50 hours. Finally, the boxes were placed at 14°C for 72 hours. The insulation was removed after the chilling period and both boxes were ripened with 100 ppm ethylene for 2 days at 16°C, and then moved to 20°C for assessments.

Test 3. Chilling alleviation using Styrofoam boxes and insulation liners.

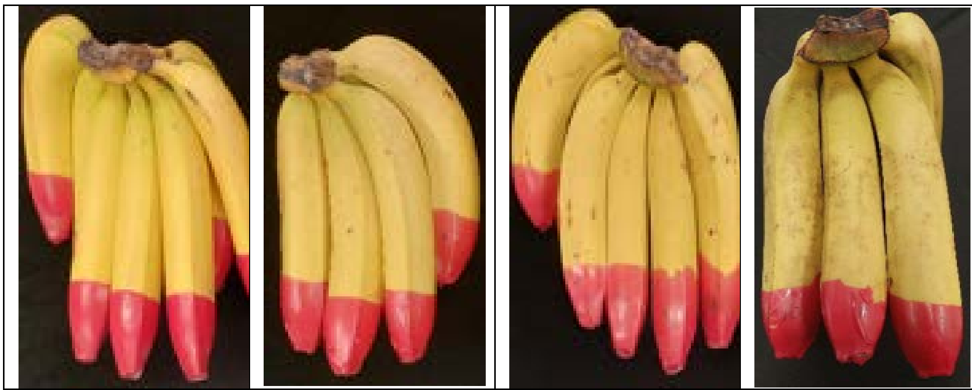
Ecoganic® banana fruits were collected on 20th Dec 2023 from Pacific Coast Eco Banana near Innisfail. The fruits were assessed and then stored at commercial boxes at 14°C for 2 weeks. For the chilling test, fruits were randomly divided into 4 treatments as following:

- Styrofoam boxes: fruits were repacked into Styrofoam boxes with foam layer underlay (Figure 2 above).
- Air-cell insulation (Kingspan): the insulation completely covered the full commercial carton box and tape was applied at the edge to keep the insulation box firmly (Figure 3 above).
- Control 1: Commercial boxes were chilled at the same temperature (5°C).
- Control 2: Commercial boxes at optimum temperature storage (14°C).

The chilling durations for the 4 treatments were 24, 32 and 48 hours at 5°C, based on previous monitoring of commercial consignments. Each treatment had 3 replications. After exposure to a chilling period at 5°C, all boxes were moved to 14°C for 1 day without opening the lids or unwrapping the insulation sheets. After that, all Styrofoam lids were opened and insulation sheets were removed. The fruits stayed at 14°C for 1 day. The fruits were ripened with 100 ppm ethylene for 2 days at 16°C. After that, they were kept at 20°C for assessments. The temperatures at fruit core, at the edge and core of the box for all replications and storage room were recorded.

2.3 Assessments

The color values L* (lightness* (hue angle in degrees), a* (redness/greenness) and b* (yellowness/blueness) were determined by using a chromatometer (model CR-400, Minolta, Tokyo, Japan), which had been calibrated with a white plate. Measurements were taken at the surfaces of the banana skin near the crown.



Score 0	Score 1	Score 2	Score 3
Bright, natual yellow colour.	Pale skin colour,	Dull skin colour	Brown areas on skin

Chilling rating score (0-3)

The measurements of total soluble solids (TSS) were conducted with a digital refractometer. The samples of the banana flesh were homogenized in a blender and the produced pureed samples were placed on the opening of a refractometer. The TSS were obtained as °Brix, as provided by a direct reading of the refractometer. Acidity of the blended samples (5g) were determined using a Metrohm titrator with 0.1N NaOH.

An iodine test was used to determine the presence of starch in the banana flesh during ripening. The surfaces of the banana flesh slices, with 1 cm thickness, were immersed in a starch–iodine staining solution for 20s. A blue–black colour resulted if starch amylose was present. The starch distribution in the slices was then estimated by image analysis. Each measurement was carried out for eight replicates (after Sinanoglou et al. 2023 with modification).

Results

Test 1: Styrofoam box used to alleviate chilling injury

The temperature at side box dropped faster than fruit core and central box temperature (Figure 4). During the first 24 hours of storage at 5°C, fruit core and central box temperatures decreased to about 12°C. In our previous study, banana fruits had no chilling effect above 12°C. The temperature at box wall reduced about 1-2°C compared to the central box temperature. A slight chilling effect started occurring on fruit at near the box wall.

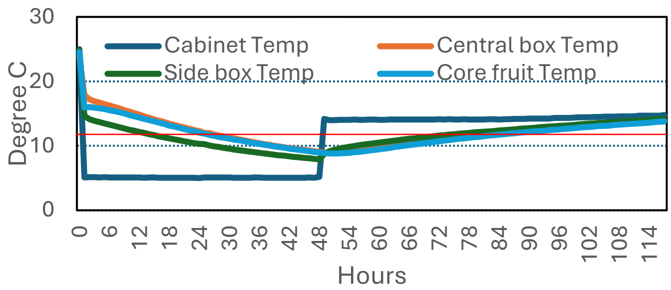


Figure 4. Temperature changes inside a Styrofoam box at 5°C storage.

If the Styrofoam box was stored for 48 hours at 5°C, the internal box and fruit temperature dropped to 8-9°C, but still above the room temperature (5°C). The low temperature period of 8-9°C caused chilling injury in fruit. When the room temperature was increased to 14°C (to represent arrival in the market) and the Styrofoam box was kept closed, the temperature inside the box only increased slightly and the chilling effect was prolonged for a further 24 hours.

The fruit chilling symptoms were rated 1.5, consistent with pale dull yellow skin colour (Table 1). Starch dye scores were similar for chilled fruits and control at 14°C, and internal flesh had good texture and flavour.

Table 1. Chilling rating score for ripe Ecoganic® bananas stored at low temperature.

	Skin colour at ripe			Chilling score (0-3)	Note	Dye test
	L	C	h			
Styrofoam box, 5°C for 48h	53.2	37.1	111.6	1.5	Pale and dull colour, but good texture and flavour	8.25
Control, 14°C	55.2	40.9	114.6	0	Good quality as normal	8.25

Prolonging the very cold storage and/or transport (5°C) for 2 days could lead to chilling. Chilled fruits had had slight pale colour appearance (Figure 5) compared to the control fruit. However, the eating quality was still good. The level of chilling injury on fruits was similar to in-field symptoms sometimes seen on winter grown fruits in Innisfail.

Figure 5. Picture of Ecoganic® bananas following low temperature transport at 5°C

Some remarks:

Styrofoam boxes have potential to reduce the time that banana fruit are exposed to chilling temperatures (below 13°C) during a mixed commodity load simulation for 1 day at 5°C. If the cold storage extended to 2 days at 5°C, the core temperature in the Styrofoam box dipped and chilling injury occurred.

Test 2: Air-cell insulation to alleviate banana chilling injury

Chilling injury at 10°C

The temperature at the box edge, centre and fruit core of the commercial box wrapped with air-cell insulation decreased during chilling storage at 10°C and then 5°C (Figure 6). For the first cold storage at 10°C, fruit core temperature started at 15°C and dropped to 10°C. The temperatures of the insulation box dropped slightly more than commercial box control. The insulated box delayed chilling by about 8 hours compared to the unwrapped commercial box.

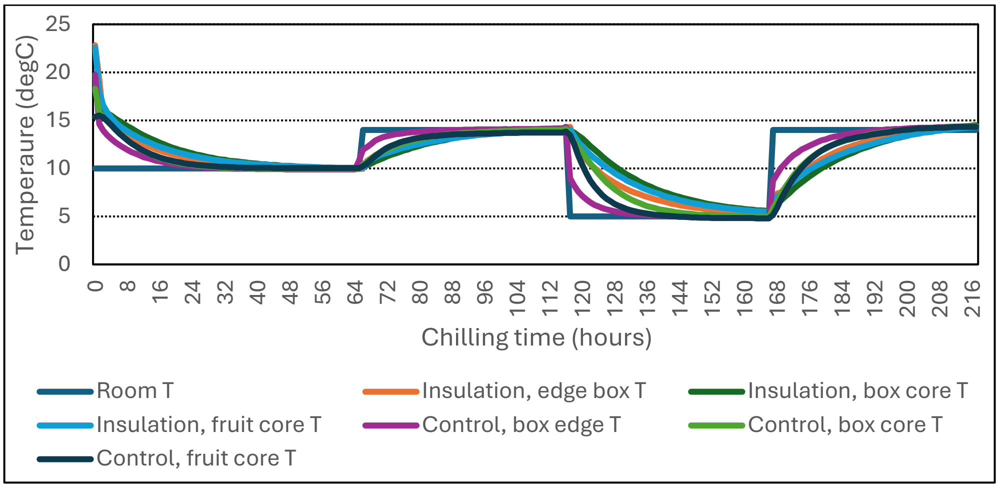


Figure 6. Temperature changes during chilling storage of insulated Ecoganic® banana box at 10°C, then 5°C.

When the room temperature changed to 14C, the insulation delayed the temperature increase about 10h compared to the unwrapped control when the temperature of the environment increased. For further details, the comparison of different positions between two treatments were assessed in Table 2.

Table 2. Time to reach certain temperatures during storage of bananas in insulated packaging at 10°C

Temp drop to	Air-cell insulation			Control (no insulation)			Delay
	Box edge	Box centre	Fruit core	Box edge	Box centre	Fruit core	
12°C	15 h	20 h	17 h	7 h	11 h	11 h	6-9 h
11°C	24 h	30 h	27 h	13 h	16 h	17 h	10-14 h
10°C	48 h	57 h	59 h	28 h	32 h	37 h	20-25 h

To reach 12°C, it took the air cell insulation box about 15 hours at the box edge, 20 hours at the box centre, and 17 hours at the fruit core (Table 2). Meanwhile, it took the commercial box (control) 7 hours to reach 12°C at box edge; 11 hours at box centre and 11 hours at the fruit core. The air cell insulation delayed cooling to 12°C by about 6-9 hours.

To reach 11°C, it took the air cell insulation box 24 hours at the box edge of, 30 hours at the box centre, and 27 hours at the fruit core. In contrast, it took the control industry standard box 13 hours to reach 11°C at box edge; 16 hours at box centre and 17 hours at the fruit core. This represented a delay of 10-14 hours.

To reach 10°C, it took the insulated box 48 hours at the box edge, 57 hours at the box centre, and 59 hours at the fruit core. It took the control box 28 hours to reach 10°C at box edge; 32 hours at box centre and 37 hours at fruit core. Thus, adding the air cell insulation delayed fruit reaching 10°C by 20-25 hours.

Chilling injury at 5°C

After the 10°C chilling period, the room temperature was increased to 14°C for more than 2 days to increase the fruit temperature back to 14°C, prior to a further chilling test at 5°C (Table 3).

Table 3. Time to reach certain temperatures during storage at 5°C

Temp drop to	Air-cell insulation			Control (no insulation)			Styrofoam box		
	Box edge	Box centre	Fruit core	Box edge	Box centre	Fruit core	Box edge	Box centre	Fruit core
12°C	3	7	5	0.1	3.5	2.5	13	25	24
11°C	5.5	9.5	7	0.2	5	3.5	19	32	31
10°C	7	13	10	0.3	7	4.5	26	39	38
7°C	20	28	25	4	7	9.5	>50	>50	>50

To reach 12°C, it took the insulated air cell box about 3 hours at the box edge, 7 hours at the box centre, and 5 hours for fruit core. It took the control industry standard only 7 minutes to reach 12°C at the box edge; 3.5 hours at the box centre and 2.5 hours at the fruit core. The air cell insulation delayed fruit reaching 12°C by about 3 hours. The Styrofoam box delayed fruit reaching 12°C by about 20°C.

To reach 11°C, it took the air cell insulated box 5.5 hours at the box edge, 9.5 hours at the box centre, and 7 hours at the fruit core. It took the control box just 12 minutes to reach 11°C at the box edge, 5 hours at box centre and 3.5 hours at the fruit core. This represented a delay of 4-5 hours. The Styrofoam box was more effective and delayed fruit reaching 11°C by 24 hours relative to the control.

To reach 10°C, it took the air cell insulation box 7 hours at the box edge, 13 hours at the box centre, and 10 hours at the fruit core. In contrast, it took the control box just 20 minutes to reach 10°C at the box edge; 7 hours at the box centre and 4.5 hours at the fruit core. This equated to a 6-7-hour delay to reach 10°C. The Styrofoam box was most effective and delayed fruit dropping to 10°C by 30 hours.

To reach 7°C, it took the air cell insulation box 20 hours at the box edge, 28 hours at the box centre, and 25 hours for the fruit core. It took the control 4 hours to reach 7°C at the box edge, 7 hours at the box centre and 9.5 hours at fruit core. The insulation delayed fruit reaching 7°C by 14-21 hours. The Styrofoam box delayed fruit reaching 7°C by about 40 hours.

In a 5°C storage environment, the Styrofoam packaging was superior to air-cell insulation, reducing the rate of temperature decrease around fruit and delaying the onset of chilling injury (Table 6). While the material was very effective, consideration of recycling or reusing Styrofoam will need to be investigated to ensure a sustainable outcome.

Table 6. The extent of chilling alleviation using Styrofoam boxes and Insulation liners.

Treatments	24h duration		32h duration		48h duration	
	Chilling (0-4)	L*	Chilling (0-4)	L*	Chilling (0-4)	L*
Styrofoam 5°C	0.3	64.7	0.6	65.2	1.5	61.9
Insulation 5°C	1.3	63.1	1.4	64.1	1.5	61.5
Control 1 5°C	1.6	62.8	1.6	64.3	1.5	61.6
Control 2 14°C	0.0	68.6	0.0	70.8	0.0	69.0

Figure 4. Styrofoam, insulation, chilled control and optimum storage control 2 during 5°C for 24 hours.

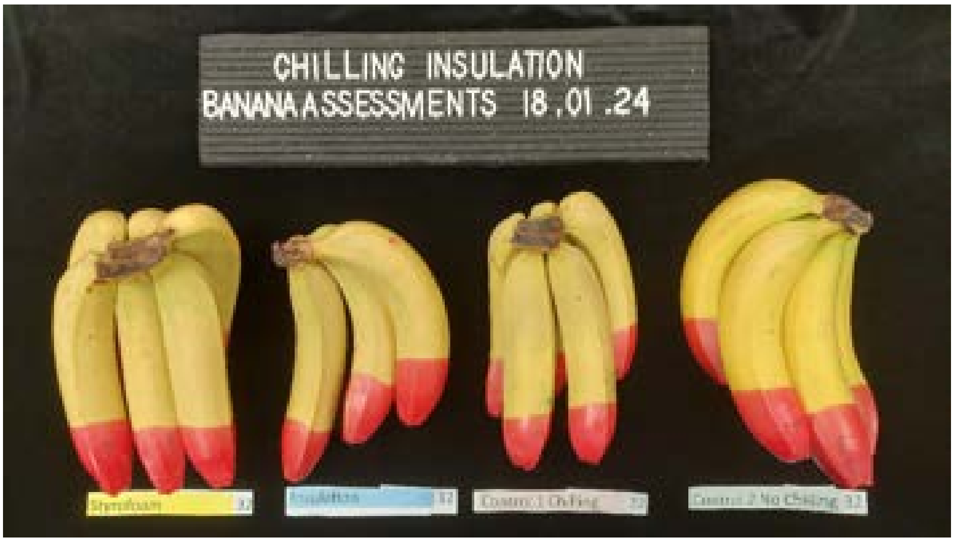


Figure 5. Styrofoam, insulation, chilled control and optimum storage control 2 during 5°C for 32 hours.

Figure 6. Styrofoam, insulation, chilled control and optimum storage control 2 during 5°C for 48 hours.

Conclusion

The preliminary data showed that repacking bananas into a Styrofoam box could maintain fruit inside the box above 12°C for 1 day when temperature for consignment kept at 5°C. Wrapping a standard cardboard banana box in sheets of air cell insulation could maintain fruit above 12°C for few hours in a 5°C storage room The control box temperature reached chilling temperature after less than 20 minutes at the same chilling condition.

Based on these results, Styrofoam boxes could be used to protect bananas against low airfreight temperatures by maintaining fruits above the chilling injury threshold for 1 day even in a 5°C storage environment. The air cell insulation could be a good alternative to use for transport at 10°C, which could prevent chilling injury for nearly 1 day during airfreight at 10°C. The chilling exposure can be reduced by further optimisation of handling practices by the exporter and importer. Moving bananas to 13°C immediately after cold storage can reduce the risk of chilling injury, consignment rejection and food waste.

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4.6 Decision Support Tool

The decision support tool uses data derived from the modelling trials presented in this appendix to forecast chilling injury and the development of peel colour.

4.6.1 Chilling Injury Decision Support Tool

The Chilling Injury Decision Support Tool incorporates data from temperature-by-time trials and simulation studies to predict the likelihood of chilling injury in fruit.

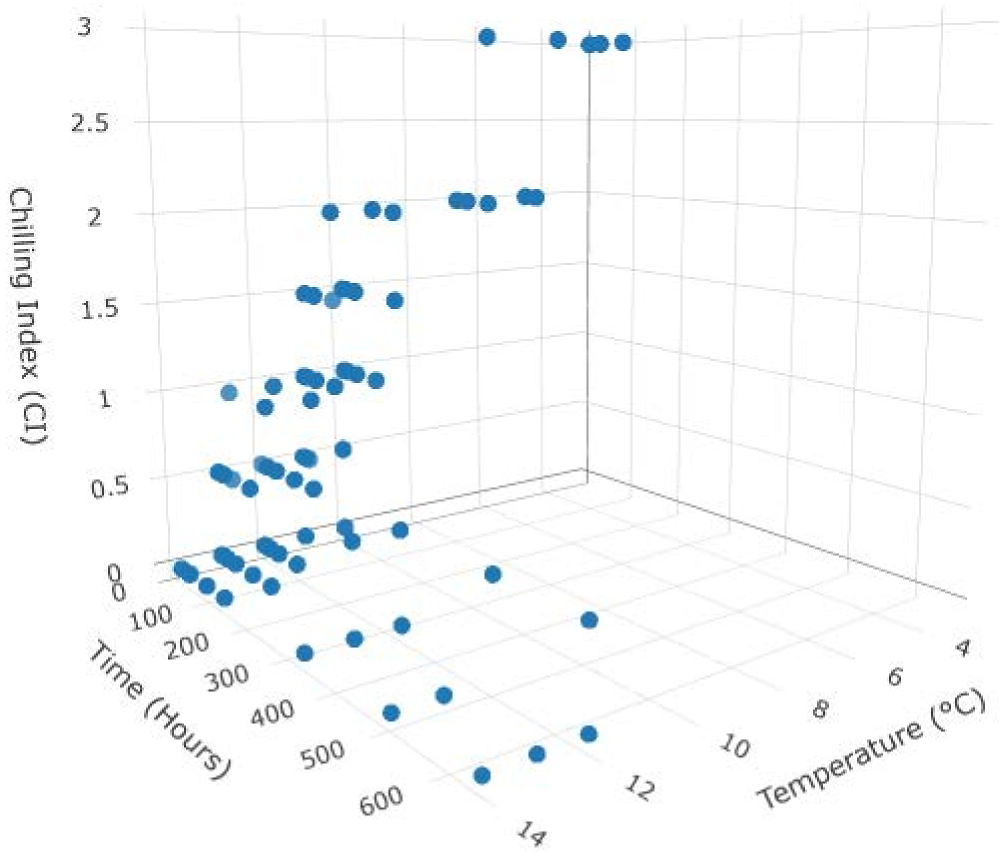

Figure 1. 3D scatter plot of the Chilling Index (CI) for banana shipments as a function of storage time (hours) and temperature (°C). The plot demonstrates the correlation between storage conditions and the potential for chilling injury.

Figure 2 below shows the Chilling Injury Decision Support Tool's output for a shipment where fruit was stored at 11.2°C for 64 hours. The tool predicts a chilling index of 0.6. This forecast suggests that approximately 15% of the fruit is at risk of not fulfilling Australian supermarket standards due to chilling injury.

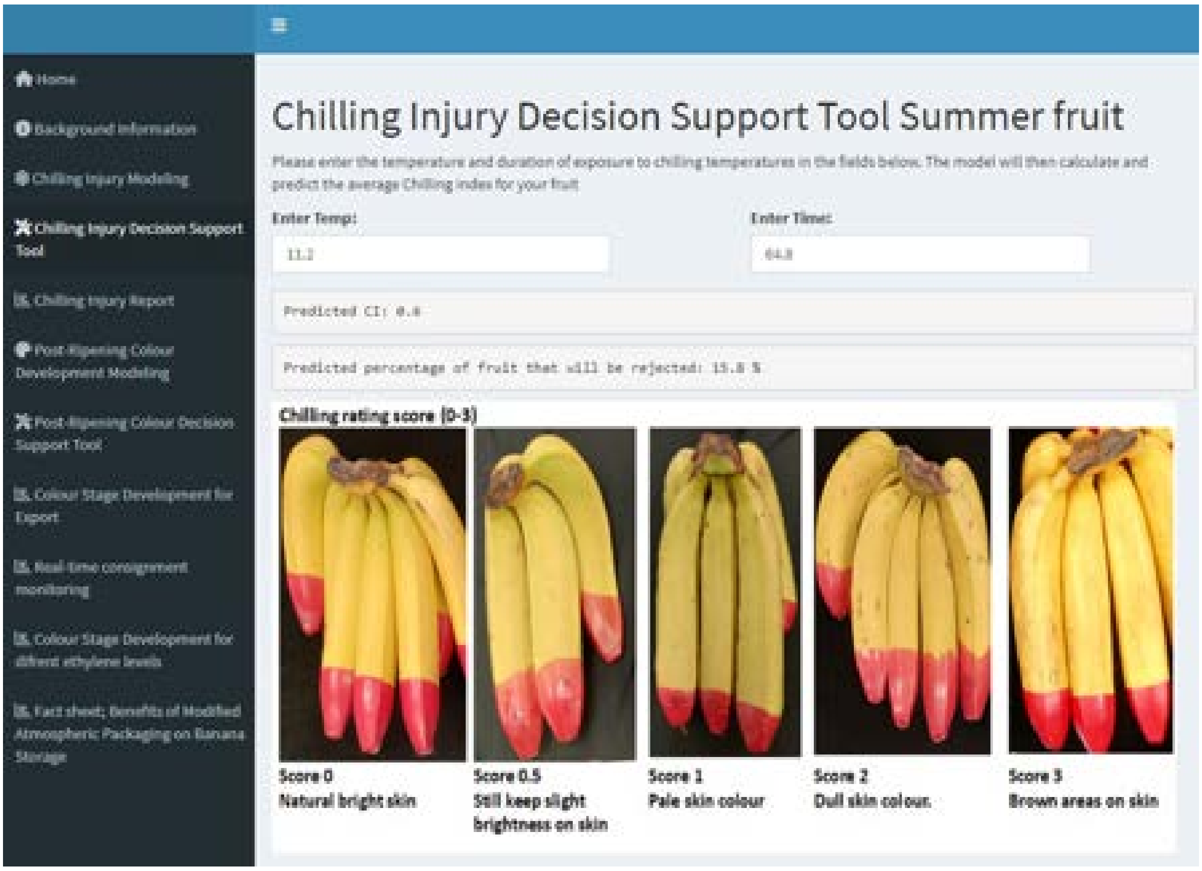

Figure 2. An Ecobanana domestic shipment was entered into the Chilling Injury Decision Support Tool, which predicts a chilling index of 0.6. Based on this index, it is anticipated that approximately 15% of the fruit may not meet the requirements set by Australian supermarkets.

4.6.2 Post-Ripening Colour Development Decision Support Tool

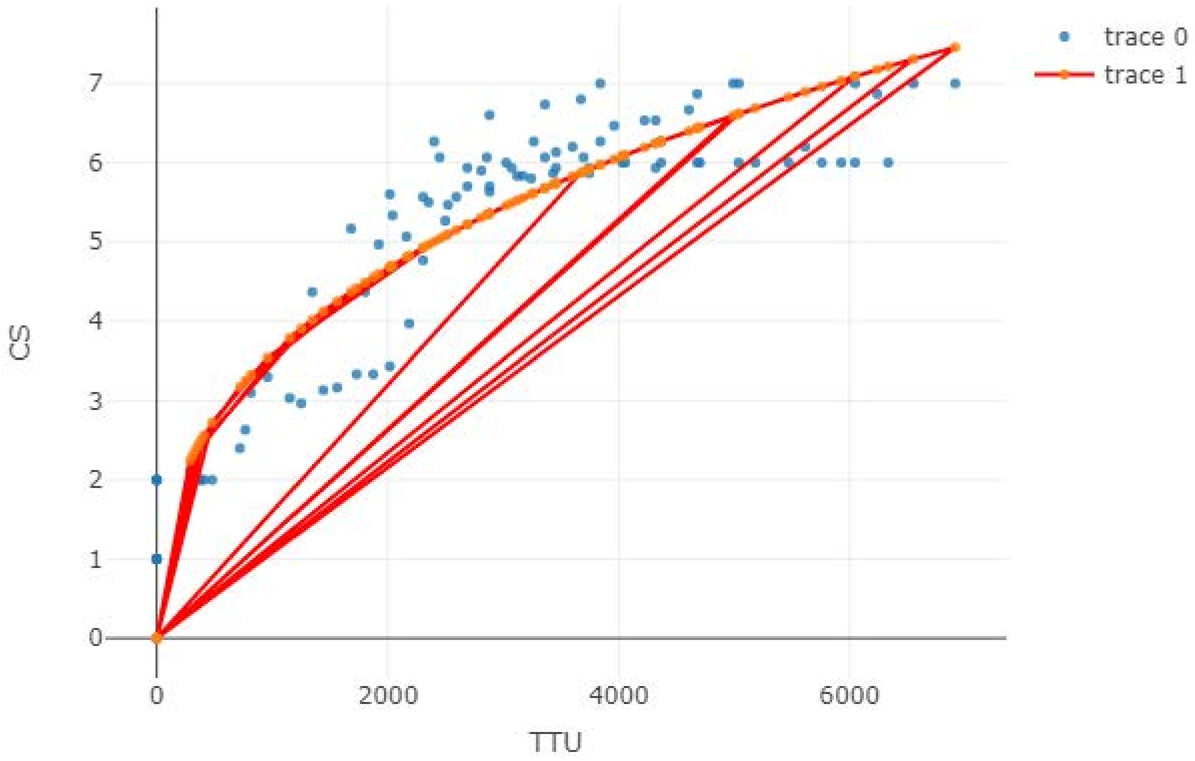

Figure 3. Scatter plot illustrating the relationship between Banana Colour Stage (CS) and Temperature Time Unit (TTU). This graph shows how storage conditions influence the Banana Colour Stage post ripening.

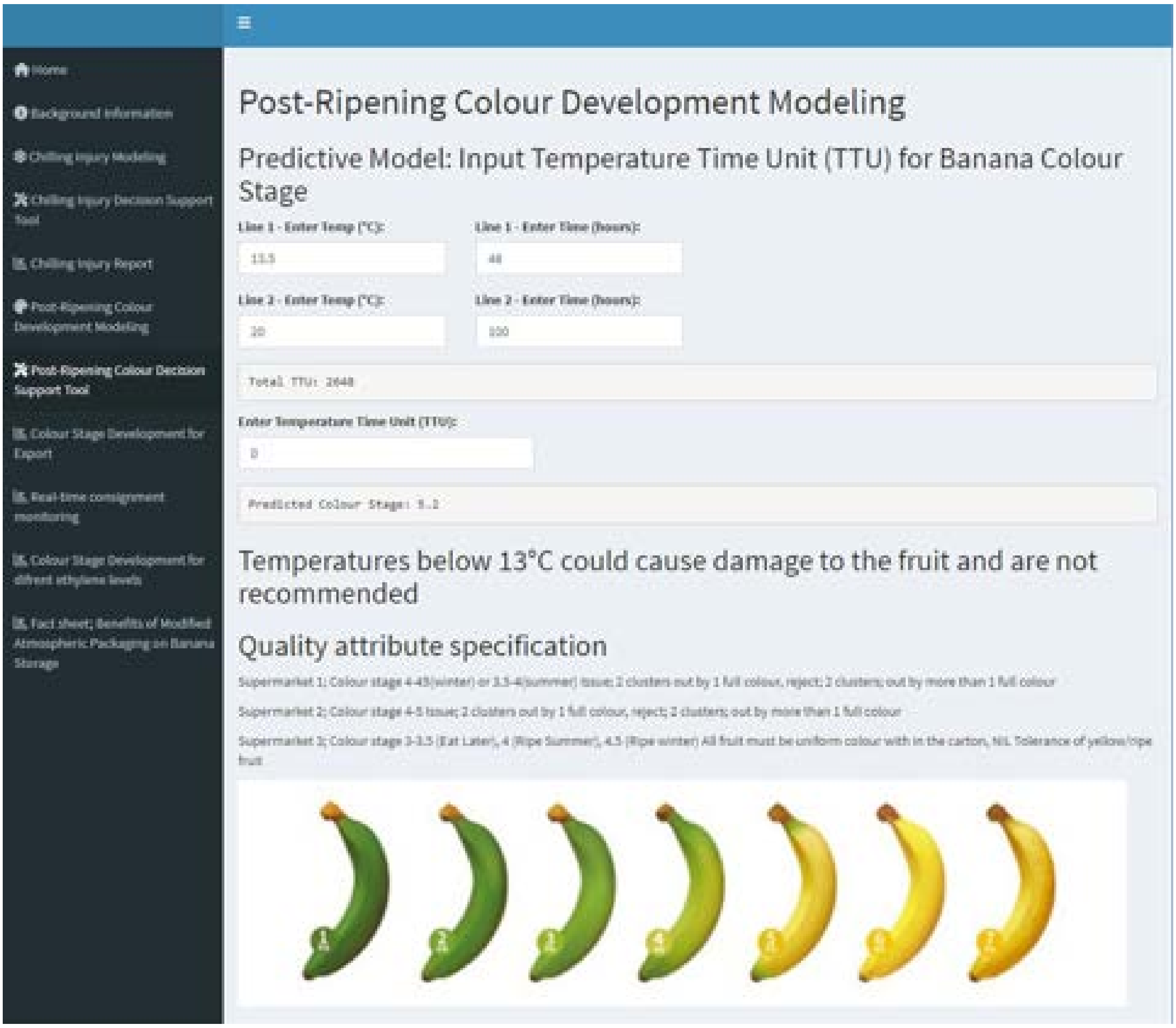

Figure 4. Post-Ripening Colour Development Modeling

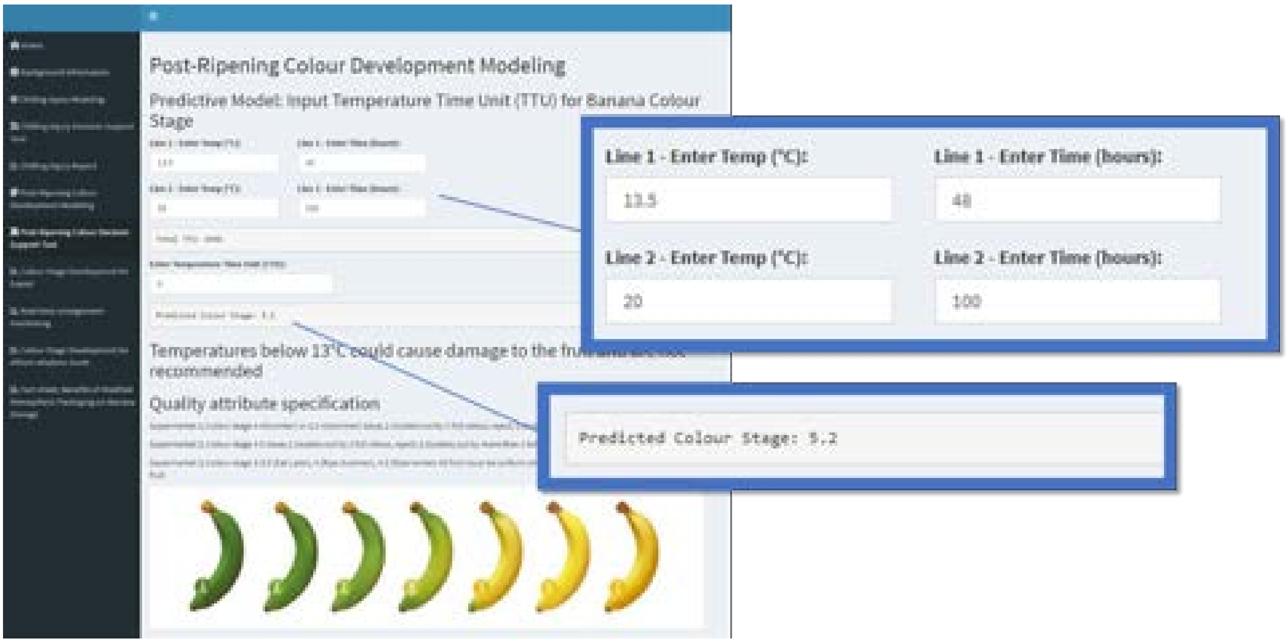

Figure 5. Post-Ripening Colour Development Modeling with call outs showing where temperature and time is added and the predicted fruit peel colour.

Figure 6. Post-Ripening Colour Development Modeling with call outs showing where temperature and time is added and the predicted fruit peel colour.

According to the Post-Ripening Colour Development Decision Support Tool, when fruit is stored at 13.5°C for 48 hours followed by storage at 20°C for 100 hours, the bananas are predicted to reach a colour stage of 5.2. This stage corresponds example banana photograph provided above.

5. Fruit rejection numbers

Below are data collected during the project showing Pacific Coast Eco Banana fruit rejection rates. Figure 1 provides an illustrative look at the rejection rates for annual domestic banana shipments over a four-year period, from 2019 through 2022. Initially, the rejection rate stood at 3% in 2019, which can be interpreted as a positive indicator of either stringent quality control measures being effective or favorable conditions in the supply chain. However, there is a noticeable uptick in rejection rates in the following years, climbing to 7% in 2020 and slightly higher to 8% in 2021. This trend culminates in a significant rise to 15% in 2022, suggesting a potential escalation in quality issues or changes in supply chain processes that need to be addressed. The graph prompts a deeper analysis of the factors contributing to this upward trajectory in rejections, be it changes in industry standards, logistical challenges, or other external factors affecting shipment quality.

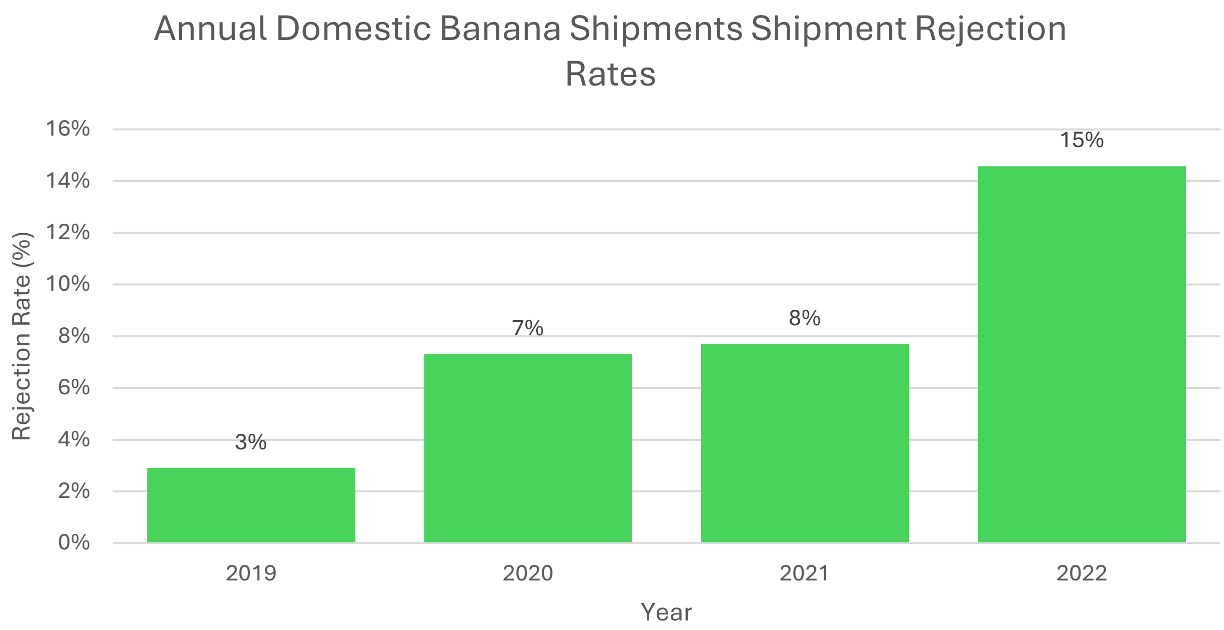

Figure 1.10 Annual Rejection Rates for Domestic Banana Shipments (2019-2022)

Figure 2 comprises four pie charts depicting the rejection rates of fruit shipments over three consecutive years – 2019, 2020, and 2021 – based on the responsible party, and a fourth chart showing rejection rates by location for a given year.

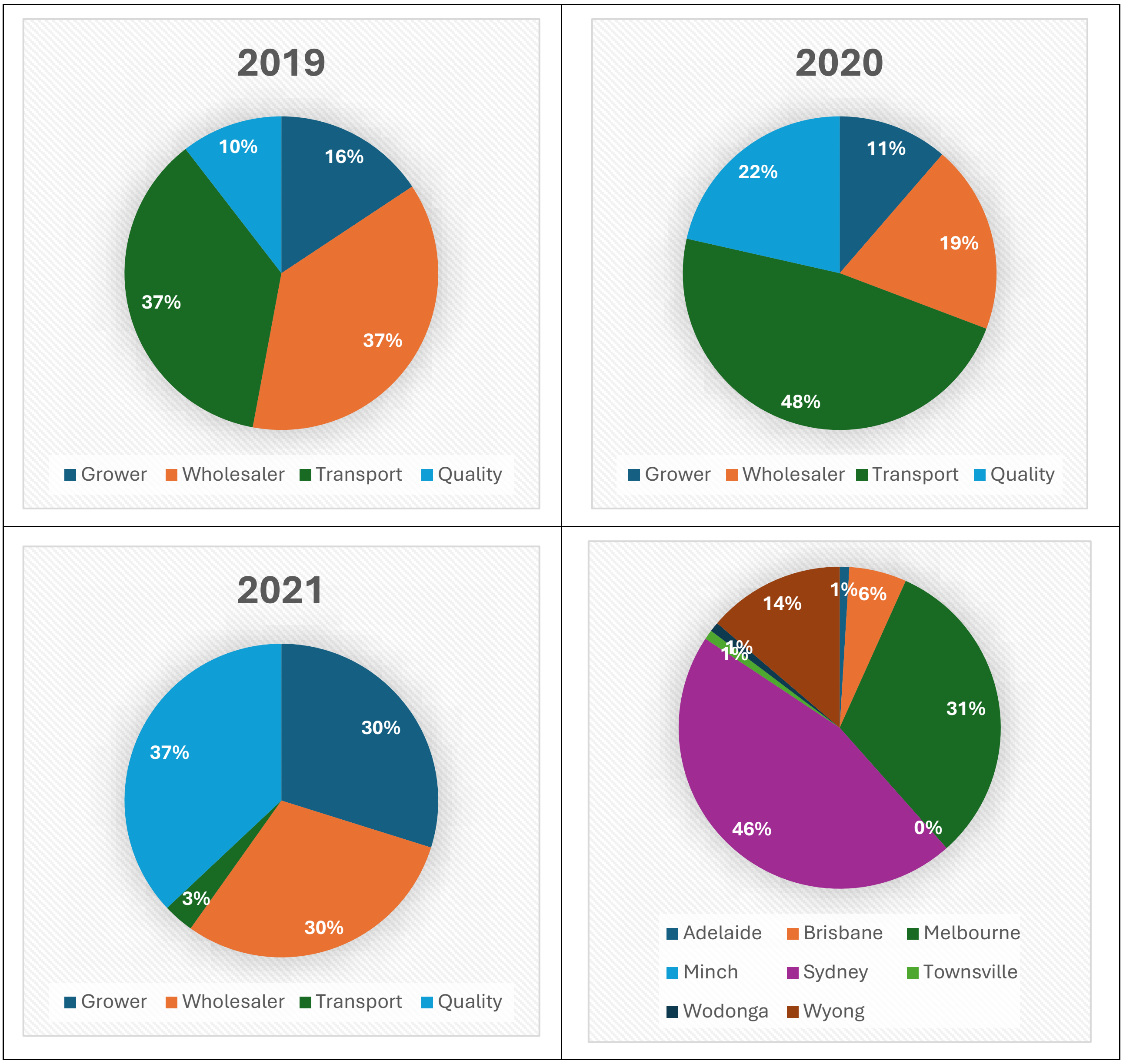

Figure 2. Pie Chart Quadrants of Fruit Rejection Data, Top Left: 2019 Fruit Rejection by Responsible Party, Top Right: 2020 Fruit Rejection by Responsible Party, Bottom Left: 2021 Fruit Rejection by Responsible Party, Bottom Right: Overall Rejection by Location

In 2019, rejections were evenly split between Grower and Quality issues, each accounting for 37%, with lesser contributions from Wholesalers and Transport issues. By 2020, the trend shifted, highlighting Transport as the leading cause of rejections at 48%, with Quality and Grower issues trailing. In 2021, there was a more balanced distribution among the causes, with Grower and Quality issues both accounting for 30% of rejections, and Transport issues notably reduced.

The fourth chart breaks down rejection by location, indicating that Sydney and Melbourne bear the most significant proportions of rejections. The concentration of rejections in these locations suggests a higher volume of shipments. This comprehensive visual data set allows for a nuanced analysis of the fruit shipment rejection rates, identifying critical areas for improvement in the supply chain to reduce losses.

APPENDIX B – Supporting Materials

A3. Supply chain best practice manual and development of a decision support tool

Banana Supply Chain Best Practice Manual

John Archer and Minh Nguyen

Department of Primary Industries

31 July 2023

Queensland Government

Contents

Introduction

The banana industry currently enjoys a stable position with near-universal consumption in the Australian domestic market. This widespread acceptance fuels the need to explore new international markets. However, these markets present challenges, including phytosanitary concerns and competition from more affordably produced fruit in countries like the Philippines and Ecuador.

Bananas have been grown in Australia for over a century. Today, they are a popular choice in 93% households (Neilsen, 2024). The banana industry's fresh supply wholesale value was $607.8 million in the year 2022 (AHSH, 2022). Bananas are cultivated commercially in Queensland, New South Wales, Western Australia, and the Northern Territory. Approximately 13,000 hectares of banana plantations are present in Australia where Queensland accounts for the lion’s share (94%) with almost all of that in North Queensland: Tully, Innisfail, Lakeland, and the Atherton Tablelands (AHSH, 2022). Bananas are cultivated throughout the year, with the Cavendish variety being the most prominent in Australia, accounting for 97% of all production and the other main variety is Lady Finger (3%).

Maintaining fruit quality from the farm through the supply chain to the consumer is a critical task, with temperature management being of utmost importance. The ideal temperature range for ‘Williams’ Cavendish banana transportation is between 13°C and 15°C. This controlled environment reduces the risk of under peel chilling injury, premature ripening and decay, ensuring the fruit reach their destination in optimal condition. In Australia's varied climate, the implementation of refrigerated transportation systems is a key factor in removing field heat soon after harvest and preserving the quality of bananas during long-haul journeys.

This supply chain best practice manual presents a summary of findings from a CRC End Food Waste project with Pacific Coast Eco Bananas. The manual recommendations are based on observations from domestic and export supply chain monitoring and simulation trials of ‘Williams’ Cavendish Ecoganic® bananas that were completed by the DPI. The manual is limited to a focus on temperature and ripening management and the prevention of under peel chilling injury. It aims to improve banana supply chain efficiency, minimise waste, and deliver consistent quality fruit to markets across Australia and internationally. The manual also forms the basis of an interactive decision support tool that will be made available to industry.

1. Supply Chain Banana Supply Chain Best Practices

1.1 Pre-Cooling on farm to 13-15°C

Bananas are a climacteric fruit. They generate heat, water vapour, ethylene and carbon dioxide during ripening. On a commercial scale, bananas are harvested green but physiologically mature. The fruit are capable of ripening on their own once harvested. Delaying this natural process until fruit consignments reach central markets for artificial controlled ripening is critical for facilitating orderly marketing.

Pre-cooling bananas soon after harvest is important for removing field heat and slowing fruit ripening and quality loss along the supply chain. This process involves lowering the temperature of fruit after quality grading and packing to extend green life. This is particularly important for bananas destined for long-distance transportation or export to protocol markets that demand fruit arrive in a hard-green condition.

For Cavendish bananas, pre-cooling to a pulp temperature of 13-15°C is required. Temperatures lower than this can cause chilling injury, while higher temperatures may not slow ripening sufficiently. Fruit harvested in summer in north Queensland can have core temperatures of 35°C. Removing this field heat before transportation to markets is critical as refrigerated trucks are designed to maintain product loading temperatures and cannot cool palletised climacteric fruit. Cavendish bananas, including those in the core of a pallet, should be cooled to 13-15°C before loading into trucks that are running at the same temperature.

Palletised boxes of bananas contain a significant thermal mass, which can take considerable time to adequately cool. In our laboratory trials, a pallet of fruit with a mass of 858 kg, initially at 21°C, took 50 hours to reach a pulp temperature of 14°C with regular room cooling (Figure 1). To achieve this temperature reduction, approximately 22,523 kJ of energy was removed. Leaving spaces between pallets and aligning individual box vent openings can increase cold air movement through the load. Forced-air cooling is an alternative approach that can be built into regular cold stores to achieve more rapid pre-cooling of palletised fruit. It is recommended to maintain relative humidity at 90-95% within the cold room during any cooling process. Maintaining accurate, calibrated temperature and relative humidity sensors in cold rooms is essential.

Figure 1. Photo of palletised boxes of bananas undergoing regular room cooling. Note spacing between pallets and alignment of box vent openings to aid cooling of fruit.

1.2 Road transport

Given Australia's diverse climate and long road transport distances, adhering to best practices is important for banana quality. Green banana fruit are transported up to 4,000-5,000 km from production regions to major metropolitan centres for controlled ripening.

Bananas are best transported in insulated, refrigerated truck trailers or shipping containers at temperatures between 13°C and 15°C to prevent premature ripening or chilling injury. Trucks equipped with reliable refrigeration systems are essential, and temperatures should be monitored throughout the journey. Pallets of bananas should not be stacked too high to impede cold air distribution through the load. Pallets should be positioned neatly against each other so that the box vent holes align to aid air movement. Humidity control is also another important factor, as bananas are susceptible to moisture loss, which can lead to quality loss. Maintaining a relative humidity level of 90-95% during transport is recommended to preserve the fruit's freshness and extend shelf life (Opara et al., 2013).

Proper packaging and packing techniques are important to prevent physical damage to the bananas. Packaging, including the industry standard one or two-piece cardboard boxes lined with perforated poly film, can reduce the risk of vibration and abrasion damage along the whole supply chain from farm to consumers. Bananas should be transported in trucks equipped with air-ride suspension to reduce vibration impacts from a rough road surface. Transit delays can expose the fruit to prolonged periods of suboptimal conditions, affecting its arrival quality. Fruit that arrive with advanced peel colour may be rejected by the market or require a different ripening regime.

1.3 Ripening fruit

When bananas arrive at the ripening facility, all fruit within a consignment are typically equilibrated to the ripening room temperature (e.g. 16^{o}C) overnight. Ethylene gas is then introduced to the room either as a trickle or a shot from ethylene generators or pressurised cylinders. Exogenous application of ethylene at a concentration of 100 µl/l or parts per million (ppm) is commonly used to induce ripening.

After the first 24 hours of ethylene introduction, the bananas start to produce their own ethylene at a rate of 2 to 4 µl/kg/hr. Ripening increases the respiration rate from 20 to 80 ml carbon dioxide/kg/hr and a corresponding 3 to 4-fold increase in heat production (Dairi et al., 2023). Throughout this process, bananas consume oxygen and emit carbon dioxide. For uniform ripening, it's essential to remove excess ethylene and carbon dioxide by venting the ripening room. The venting system should be capable of removing excess carbon dioxide to keep its concentration below 10,000 ppm to avoid injury of ripening fruits. Also, high carbon dioxide levels can negatively affect the fruit respiration rate and ripening quality by reducing the various enzymes of respiratory metabolism and changing the intracellular pH.

The refrigeration system must effectively remove the heat from respiration while maintaining desired temperature and relative humidity levels. Bananas are typically ripened to colour stages 3 or 4 before being dispatched to the market and the cycle can take 3 to 4 days.

2. Real-time consignment monitoring

A range of technologies are available for monitoring supply chain handling conditions. Hard-wired tracking systems in trucks can provide information on fruit temperature during transport. Portable temperature dataloggers can be included in boxes of fresh produce to record conditions from packing to retail. Manual download dataloggers cost as little as $12 each. The data they collect can help identify areas for improved handling practices in future shipments. However, retrieving these loggers from consignments can be challenging. Without the data, this can become a costly and futile exercise. Modern autonomous reporting dataloggers can be fitted with a SIM card retail for $50-90 each. These loggers capture consignment temperature and location plus other variables like vibration, in real-time. Whilst the unit cost is relatively higher, less time is required to pinpoint handling issues.

2.1 Some costs and benefits of real-time supply chain monitoring

Table 1: Cost and Benefit of real time monitoring

Cost items	Benefit
Datalogger hardware	Opportunities to intervene to avoid loss or divert product to other markets or use
Staff time and commitment to monitoring	Improved communication, collaboration and practices along the supply chain
Identification of improved infrastructure for future practices	Create opportunity to uncover the need for investment in better practices and infrastructure facility improvement in the next to get more consistent product quality in the market

2.2 A domestic supply chain scenario

Bananas with good quality throughout the supply chain in domestic market carry a potential value for the growers of far north Queensland. Economic losses occur due to downgrading of banana consignments for chilling injury and quality loses. Our research has shown that exposure to 10-12°C for 8 hours may not damage banana fruits but it risks fruit rejection and diversion to another customer at considerable economic loss. However, exposure to these low temperatures for 24-48 hours will result in significant injury and food waste. While chilled fruit may be diverted to a food processor, the total retail value of an average 20-pallet consignment would reduce from about $80,000 to as little as $13,000, which would not cover production and transportation costs. A $60-90 investment in a standard real-time temperature datalogger that provides notification of chilling events could potentially help avoid this loss and guide rapid decision-making if redirecting rejected fruit is required.

2.3 An export supply chain scenario

Two out of nine Pacific Coast Eco Banana export consignments were rejected due to chilling injury in 2022. Real-time dataloggers in the affected consignments indicated that fruit were held at 3 to 5°C for 4 to 8 days at the freight forwarder and importer. Sharing this information prompted improved handling to limit exposure to <13°C for no more than 8 hours in subsequent shipments. In addition, activating low temperature alerts on the dataloggers now provides a reminder to move the consignments to a warmer storage environment. Based on chilling injury risk models developed by the DPI, if fruit are moved within 24 hours of exposure to 3 to 5°C then damage could be reduced by up to 65%. If the fruit cannot be moved in time, the export shipment could potentially be cancelled, saving up to $4,620 per pallet in air freight alone. If the damaged fruit were redirected to a local cake processor, then up to $9,000 could be saved less the cost of loggers ($100) and time to monitor. This could also save 1,980 kg of fruit going to waste.

These scenarios highlight the potential economic benefits of real-time dataloggers and associated decision aid tools for monitoring and managing banana consignments. Recognising the cost, effort and cooperation required to realise the full benefits, we recommend monitoring is based on the risk profile of supply chains.

3. Supply Chain Decision support tool

The following supply chain decision support tool has been created for Cavendish bananas. It incorporates experimental supply chain data to forecast fruit quality parameters with different scenarios. The tool is designed to optimise fruit handling practices, retain fruit nutritional quality and reduce economic loss. Its functionality includes predicting and reducing quality damage, thereby minimising waste throughout the banana supply chain. Overall, this proactive approach in quality management ensures the delivery of premium quality bananas to the market, enhancing consumer satisfaction.

3.1 Ripening duration on colour development

Harvested at the green-mature stage, banana fruit ripening is visualised by changes to the peel color from green to yellow due to chlorophyl degradation and synthesis of a few pigments. Temperatures above 24°C can inhibit the chlorophyl breakdown and colour formation plus it increases the rate of senescence (Du et al., 2016). To meet consumer preferences, colour development in banana fruit requires careful management of temperature and ethylene treatment concentration and duration.

Based on our trial work, the following table shows banana fruit colour development in response to 100 ppm ethylene treatment at different temperatures (14 and 16°C) for the duration of 24, 48 and 72 hours.

Table 2. Colour stage development of Cavendish banana fruit exposed to 100 ppm ethylene at 14 or 16°C.

	14°C			16°C		
	Exposure time (hours)					
Day	24	48	72	24	48	72
1	2			1.5		
2	2.4	2.6		2.8	2.6	
3	2.8	3.2	3.2	3	4.1	3.6
4	3.2	4.2	4.1	3.8	5.5	5.4
5				5.1	6	6
6					7	7
7	4	5.8	5.5			
8	4.8	6.8	6.6	6.6		
9	5	7	7			

This table displays data on the colour development of bananas, ripened at various temperatures and durations over a period of up to 9 days. The colour development is recorded at 24-hour intervals for fruit sorted at 20°C.

At 14°C, the fruit colour develops slowly, taking up to 9 days to reach colour stage 7. Bananas exposed to ethylene for only 24 hours did not fully develop at this temperature. In contrast, at 16°C, the fruit ripened more rapidly, requiring only 6 days to achieve colour stage 7. At 18°C (data not shown), the ripening process was even quicker, with the bananas reaching colour stage 7 in less than 6 days.

Overall, the table demonstrates that higher temperatures speed up the ripening process of bananas, consequently reducing the time taken to reach colour stage 7 end of shelf life.

Figure 2. Banana peel 1-7 colour scoring system (Dole Food Company Inc.).

3.2 After ripening colour development

The table below presents the colour development of fruit that were subjected to treatment with 100 ppm ethylene for 48 hours at 16°C. Subsequently, fruits were stored at various storage temperature (12-20°C) to monitor its colour progression until fully ripe.

Table 3. Colour development stages of Banana at different storage temperatures.

Days	12C	13C	14C	15C	16C	18C	20C
0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
1	2.1	2.1	2.1	2.4	2.6	3.1	3.3
2							
3							
4	3.0	3.0	4.4	4.4	5.0	5.3	6.3
5	3.1	3.2	5.2	5.1	5.6	6.1	6.6
6	3.3	3.3	5.6	5.5	5.9	6.1	6.7
7	3.4	4.0	5.5	5.7	5.9	6.3	7.0
8	4.8	5.3	5.7	5.8	6.1	6.8	7.0
9	5.6	5.9	6.0	6.2	6.3	7.0	7.0
10	5.6	5.8	6.1	6.5	6.5	7.0	7.0
11	5.8	5.9	6.1	6.5	6.7	7.0	7.0
12	5.9	5.9	6.1	6.9	7.0	7.0	7.0
13	5.9	6.0	6.3	7.0	7.0	7.0	7.0
14	6.0	6.0	6.0	7.0	7.0	7.0	7.0
15	5.9	6.0	6.0	7.0	7.0	7.0	7.0
18	6.0	6.2	7.0	7.0	7.0	7.0	7.0
19	6.0	6.0	7.0	7.0	7.0	7.0	7.0
20	6.0	6.9	7.0	7.0	7.0	7.0	7.0
21	6.0	7.0	7.0	7.0	7.0	7.0	7.0
22	6.0	7.0	7.0	7.0	7.0	7.0	7.0
25	7.0	7.0	7.0	7.0	7.0	7.0	7.0

For fruit continuously stored at 12°C, colour develops slowly and it took 25 days to achieve the final stage (7) of colour (Table 3). In contrast, fruit stored at 13, 14, 15, 16, 18 and 20°C reached the final stage of colour by 21, 18, 13, 12, 9 and 7 days, respectively. Overall, this data enables the prediction of fruit colour development under different storage temperatures. This information is important for marketers and retailers of banana fruit.

This fruit colour assessment is very important as human consumption perception depends on this. On the other hand, it is an irreversible phenomenon and influences in the commercial value through biochemical, physiological, and organoleptic changes that includes tissue softening, pigment changes, aroma and flavour volatile production, reduction in astringency, and many others.

3.3 Chilling Injury Development on Summer and Winter Fruits

Banana fruit are susceptible to chilling injury (Figure 3); this can be caused both in the field and during transport. It is recommended that bananas should not be stored below 13°C, as temperatures lower than this can cause chilling injury, though its development in fruit can depend on the season (Figures 4, 6). Chilling injury is also a function of the exposure time to low temperatures.

In fruit produced during the north Queensland summer, chilling injury did not occur at 13°C; however, as the temperature decreased, the average level of damage increased (Figure 4). At 12°C, it took 96 hours before early signs of chilling injury appeared. At temperatures of 11°C and 10°C, damage to the fruit manifested within just 24 hours, with more severe damage occurring on the fruit stored at the lower temperature of 10°C. Additionally, the ripening of some fruit exposed to these lower temperatures was impaired as evidenced by partial peel colour development (Figure 5).

Winter fruit is more resistant to low temperature exposure as chilling injury was not found on fruit kept at 12°C for 96 hours (Figure 6). At temperatures of 11°C and 10°C, damage to the fruit manifested within 48 hours, with more severe damage occurring on the fruit stored at the lower temperature of 10°C. Severe chilling injury and impaired ripening (Figure 7) was recorded on fruits when they were stored at 10°C for 96 hours.

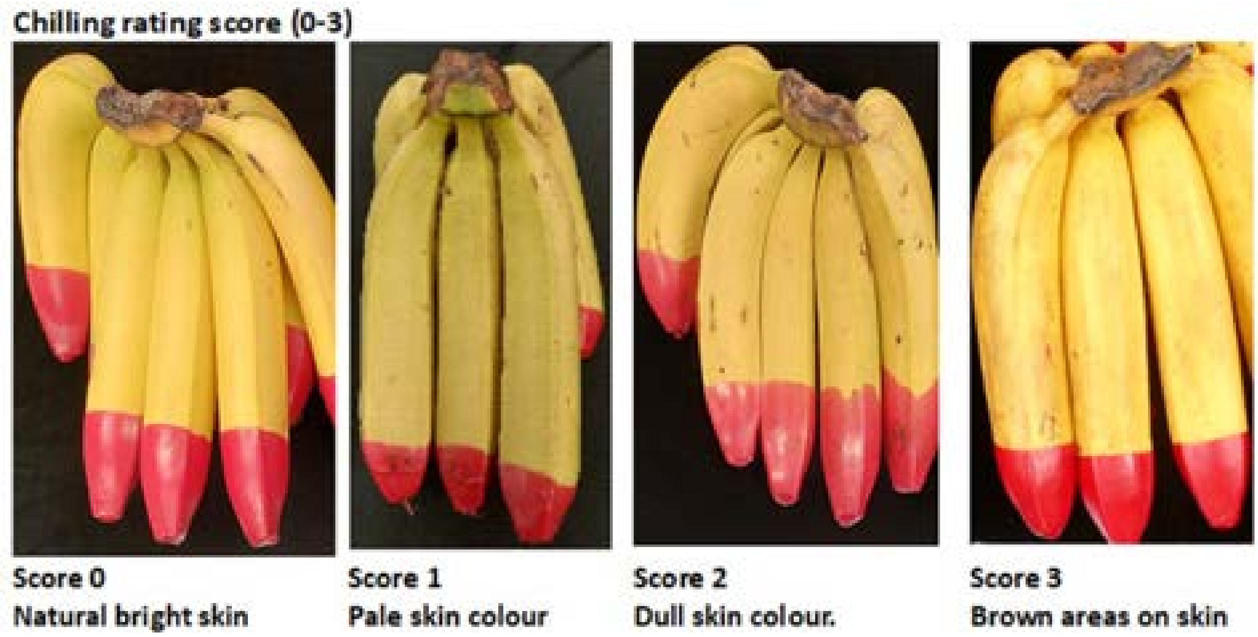

Figure 3. Comparison of Cavendish Ecoganic® bananas exhibiting chilling injury (dull discoloured peel) at full colour, scored from 0 to 3.

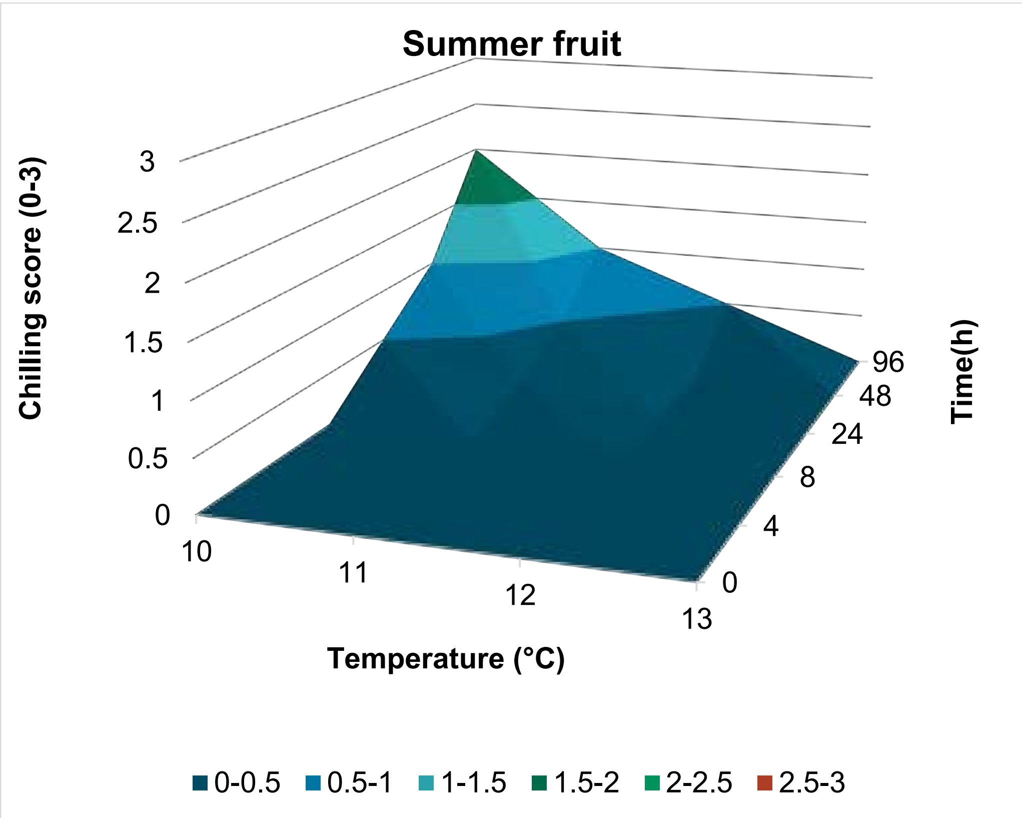

Figure 4: The severity of chilling injury on summer-produced Cavendish banana fruit as influenced by different storage temperatures of various durations.

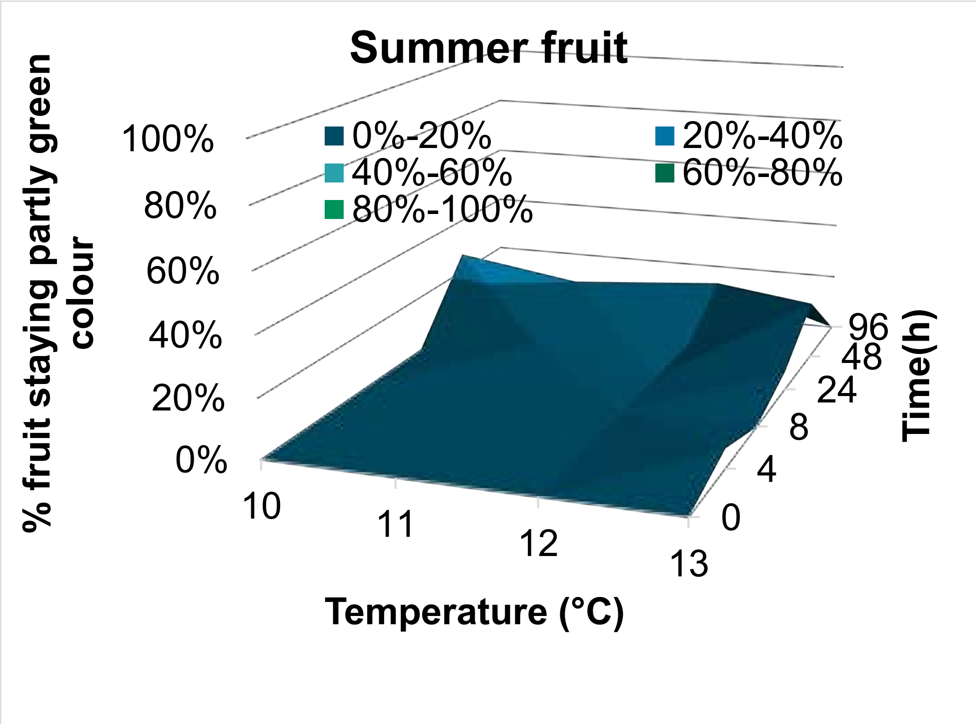

Figure 5: The proportion of summer-produced Cavendish banana fruit that did not fully ripen as influenced by different storage temperatures of various durations.

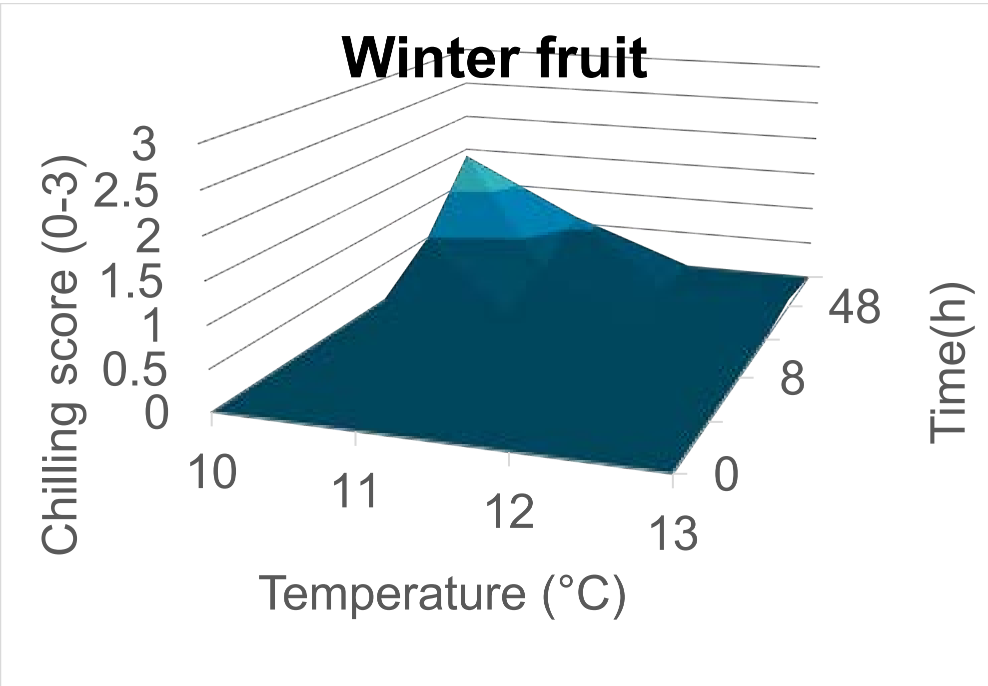

Figure 6: The severity of chilling injury on winter-produced Cavendish banana fruit as influenced by different storage temperatures of various durations.

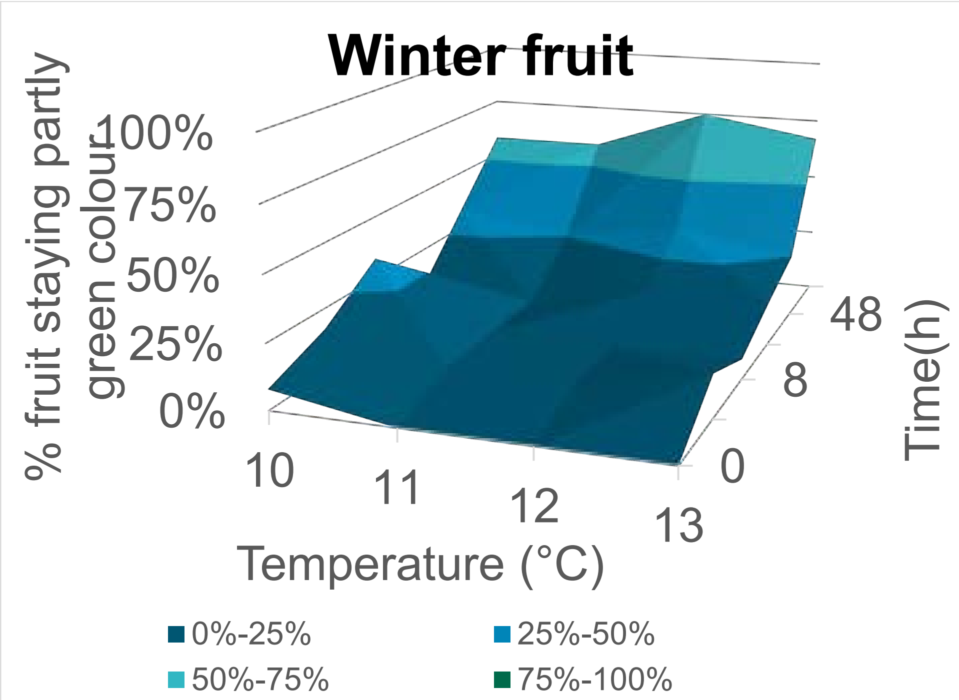

Figure 7: The proportion of winter-produced Cavendish banana fruit that did not fully ripen as influenced by different storage temperatures of various durations.

3.4 Preliminary decision tool

As an interim measure, two posters were developed to visualise some of the key decision points for exporting banana fruit by air (Figure 8) or sea (Figure 9) with respective to potential chilling injury.

Figure 8. Poster showing key considerations for avoiding chilling injury during an airfreight export supply chain.

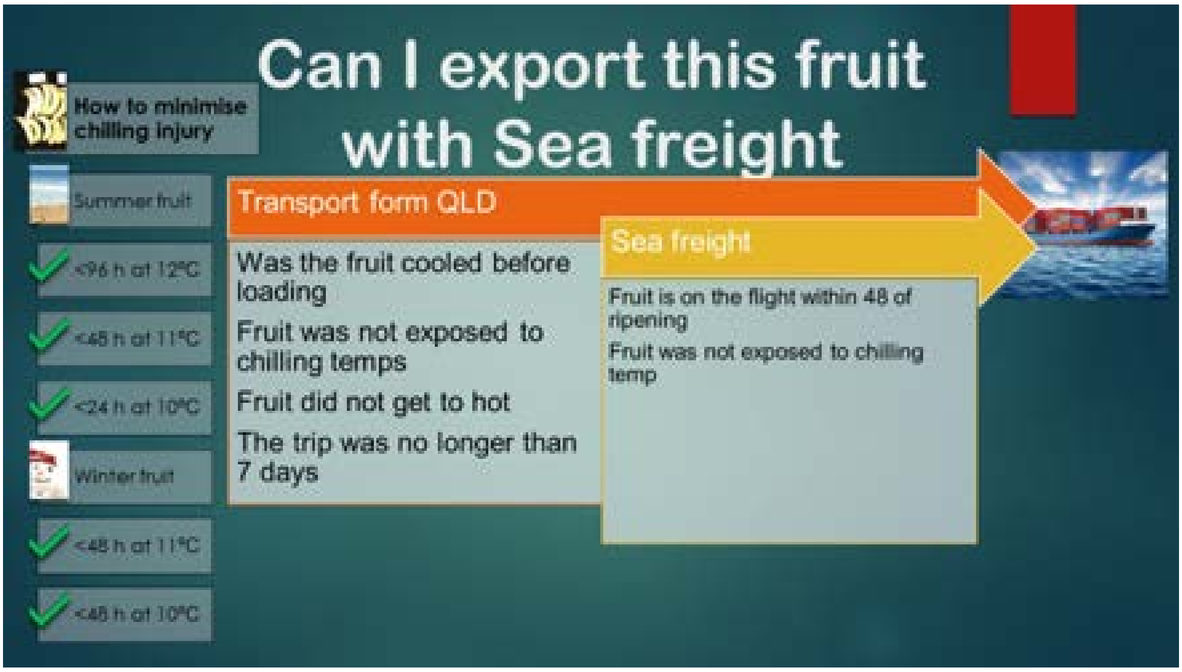

Figure 9. Poster showing key considerations for avoiding chilling injury during a seafreight export supply chain.

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Gas Detection in Ripening Rooms (critical-environment.com): https://www.critical-environment.com/about/cet-blog/expert-insights/monitoring-ethylene-c2h4-and-carbon-dioxide-co2-in-ripening-rooms

Home

Please use this app, which includes decision support tools, to improve efficiency in your banana supply chain and reduce food waste.

Supply chain monitoring and improvement to reduce banana quality loss

Project Leader: Andrew MacNish, State of Queensland acting through the Department of Agriculture and Fisheries

start date (1/03/2020)

Pacific Coast Produce (PCP), a cooperative of six growers in north Queensland, have been exporting organic 'Cavendish' bananas to Asian markets by airfreight since 2009. An estimated 10% of their consignments are discarded each year because the fruit arrive over-ripe or with chilling injury, representing $1.75 million in lost revenue. This 4-year project aims to reduce fruit waste from 10% to 2%, saving an estimated $1.4 million annually, and supports a shift from unrefrigerated airfreight to controlled temperature seafreight. The project includes monitoring shipments to quantify handling temperatures, developing a decision support tool that predicts fruit quality, and encouraging adoption of improved practices in the Australian banana industry.

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Background Information

The banana industry currently enjoys a stable position with near-universal adoption in the domestic market. This widespread acceptance fuels the need to explore new international markets. However, these markets present challenges, including phytosanitary concerns and competition from more affordably produced fruit in countries like the Philippines and Ecuador.

Bananas have been grown in Australia for over a century. Today, they are a popular choice in 93% households, with the banana industry's fresh supply wholesale valued at $607.8 million in the year 2022 (AHSH, 2022) nearly $600 million. , and Banana considered as a Australia's favourite fruit.

Bananas are cultivated commercially in Queensland, New South Wales, Western Australia, and the Northern Territory. Approximately 13,000 hectares of banana plantations are present in Australia where Queensland accounts for lion share (94%) with almost all of that in North Queensland: Tully, Innisfail, Lakeland, and the Atherton Tablelands (AHSH, 2022) . Bananas are cultivated throughout the year, with the Cavendish variety being the most prominent in Australia, accounting for 97% of all production and the other main variety is Lady Finger (3%).

Maintaining fruit quality throughout the supply chain is a critical task, with temperature management being of utmost importance. The ideal temperature range for banana transportation is between 13°C and 15°C. This controlled environment prevents premature ripening and decay, ensuring the bananas reach their destination in optimal condition. In Australia's varied climate, the implementation of refrigerated transportation systems is a key factor in preserving the quality of bananas during long-haul journeys.

This manual will present best practice with the aim of improving Australian banana supply chain efficiency, minimize waste, and deliver quality bananas to markets across Australia and internally.

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ENDFOODWASTE AUSTRALIA

1.1 Pre-Cooling on farm to 13-15°C

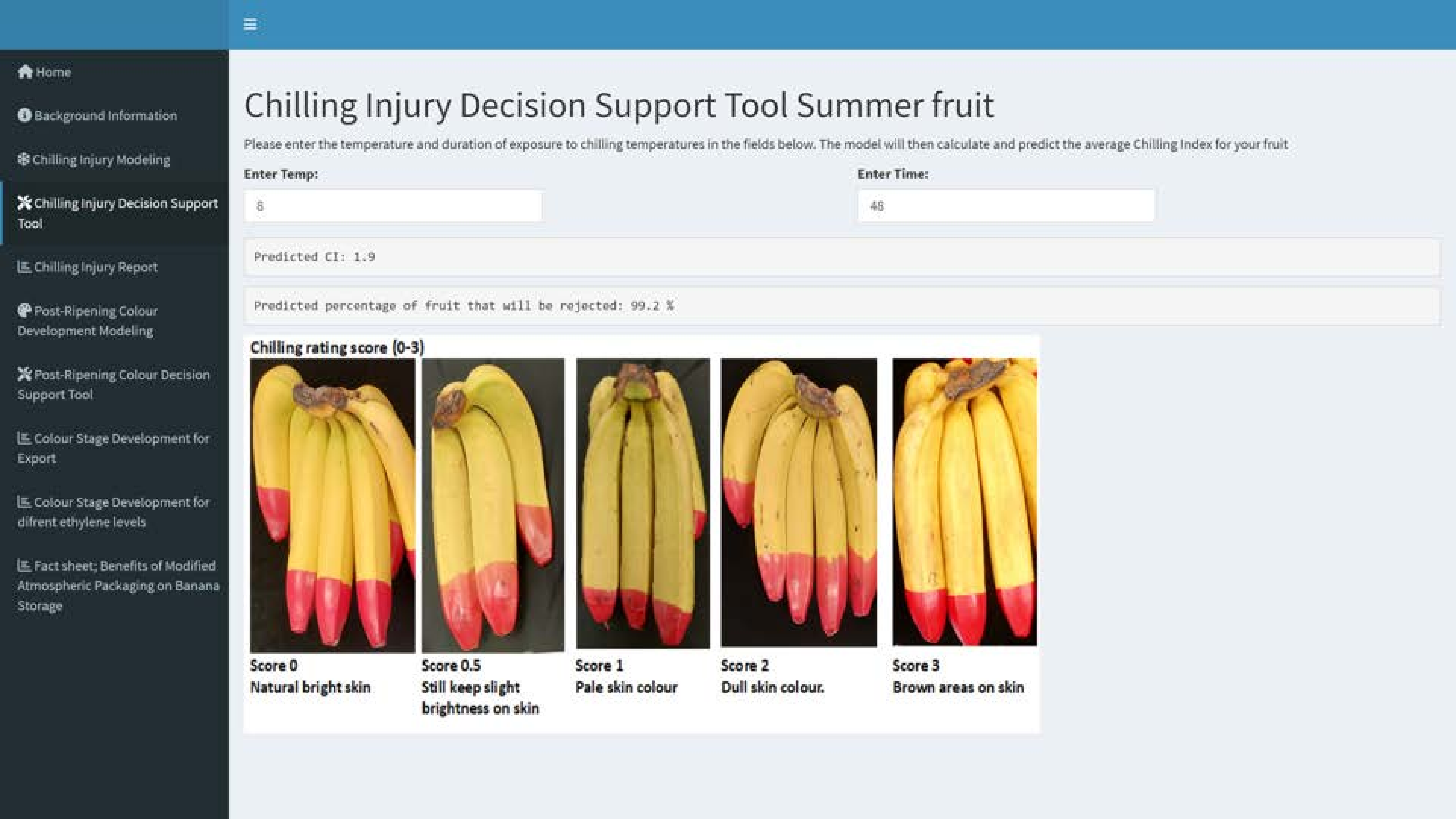
Pre-cooling bananas soon after harvest and packing is important for removing field heat and preventing fruit quality loss along the supply chain. This process involves lowering the temperature of freshly harvested and packed bananas to slow down their ripening process and reduce post-harvest disorders which caused the extension of shelf life.

This is particularly important for bananas destined for long-distance transportation or export that need to arrive in a hard green condition.

Fruit packed and palletised contains a significant thermal mass, which requires considerable time to adequately cool. In laboratory trials, a pallet of fruit with a mass of 858 kg, initially at 21°C, took 50 hours to reach a temperature of 14°C with room cooling. To achieve this temperature reduction, approximately 22,522.5 kJ of energy was removed.

Fruit freshly harvested from the field in summer can have core temperatures of about 35°C, necessitating the removal of this heat before transportation. This step is crucial as most refrigerated trucks are not capable of actively cooling palletised fruit to the required temperature.

When pre-cooling it is important to maintain the right temperature range. For Cavendish bananas, this is between 13°C and 15°C. Temperatures lower than this range can cause underpeel chilling injury, while higher temperatures may not slow ripening.


Home
Background Information
Chilling Injury Modeling
Chilling Injury Decision Support Tool
Chilling Injury Report
Post-Ripening Colour Development Modeling
Post-Ripening Colour Decision Support Tool
Colour Stage Development for Export
Colour Stage Development for difrent ethylene levels
Fact sheet; Benefits of Modified Atmospheric Packaging on Banana Storage
Chilling Injury Decision Support Tool Summer fruit
Please enter the temperature and duration of exposure to chilling temperatures in the fields below. The model will then calculate and predict the average Chilling Index for your fruit
Enter Temp:
8
Enter Time:
48
Predicted CI: 1.9
Predicted percentage of fruit that will be rejected: 99.2 %
Chilling rating score (0-3)
Score 0
Natural bright skin
Score 0.5
Still keep slight brightness on skin
Score 1
Pale skin colour
Score 2
Dull skin colour.
Score 3
Brown areas on skin

Background Information

Chilling Injury Modeling

Chilling Injury Decision Support Tool

Chilling Injury Report

Post-Ripening Colour Development Modeling

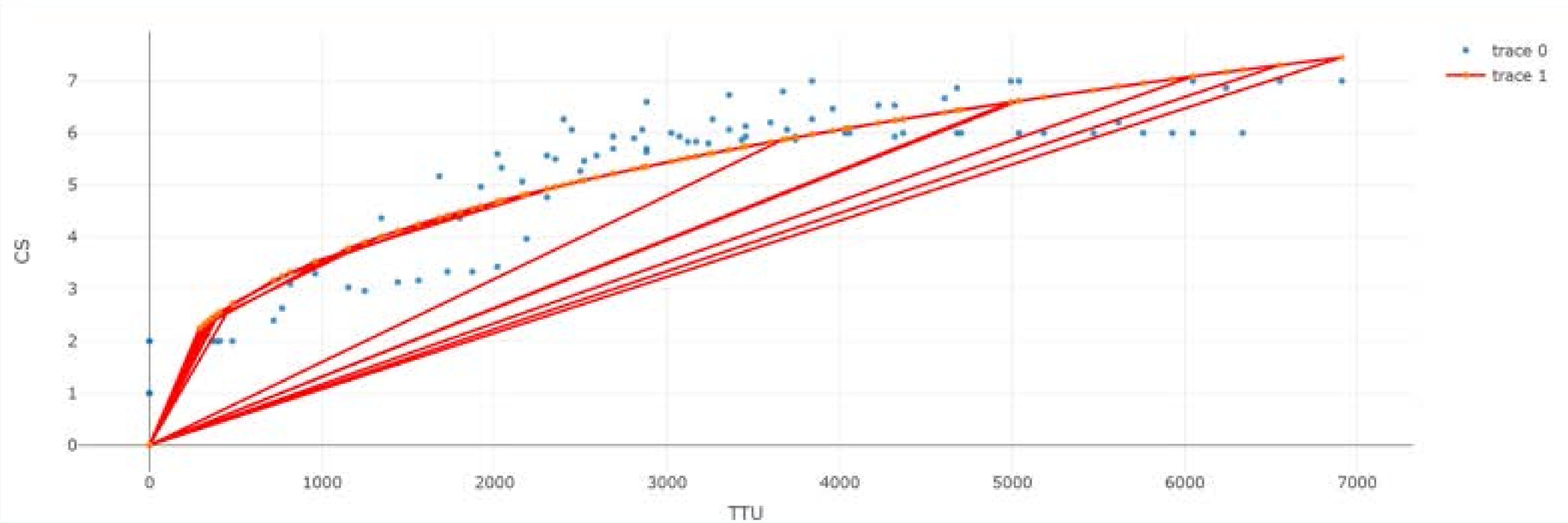
Post-Ripening Colour Decision Support Tool

Colour Stage Development for Export

Colour Stage Development for difrent ethylene levels

Fact sheet; Benefits of Modified Atmospheric Packaging on Banana Storage

Post-Ripening Colour Development Modeling



Modeling Colour Stage Development

```
Formula: CS ~ a * TTU^b

Parameters:
  Estimate Std. Error t value Pr(>|t|)
a  0.26457    0.06017   4.397 2.97e-05 ***
b  0.37766    0.02785  13.558  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7397 on 91 degrees of freedom

Number of iterations to convergence: 18
Achieved convergence tolerance: 3.767e-06
```

Home

Background Information

Chilling Injury Modeling

Chilling Injury Decision Support Tool

Chilling Injury Report

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Post-Ripening Colour Decision Support Tool

Colour Stage Development for Export

Colour Stage Development for difrent ethylene levels

Fact sheet; Benefits of Modified Atmospheric Packaging on Banana Storage

Post-Ripening Colour Development Modeling

Predictive Model: Input Temperature Time Unit (TTU) for Banana Colour Stage

Line 1 - Enter Temp (°C): 0	**Line 1 - Enter Time (hours):** 0
Line 2 - Enter Temp (°C): 0	**Line 2 - Enter Time (hours):** 0
Enter Temperature Time Unit (TTU): 0	

```
Predicted Colour Stage: 2
```

Quality attribute specification

Supermarket 1; Colour stage 4-45(winter) or 3.5-4(summer) Issue; 2 clusters out by 1 full colour, reject; 2 clusters; out by more than 1 full colour

Supermarket 2; Colour stage 4-5 Issue; 2 clusters out by 1 full colour, reject; 2 clusters; out by more than 1 full colour

Supermarket 3; Colour stage 3-3.5 (Eat Later), 4 (Ripe Summer), 4.5 (Ripe winter) All fruit must be uniform colour with in the carton, NIL Tolerance of yellow/ripe fruit

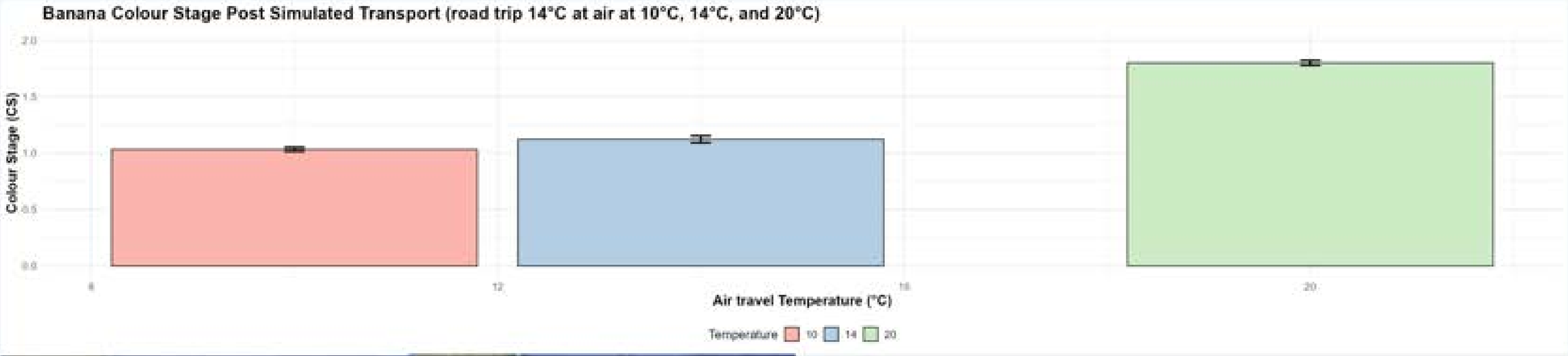
≡

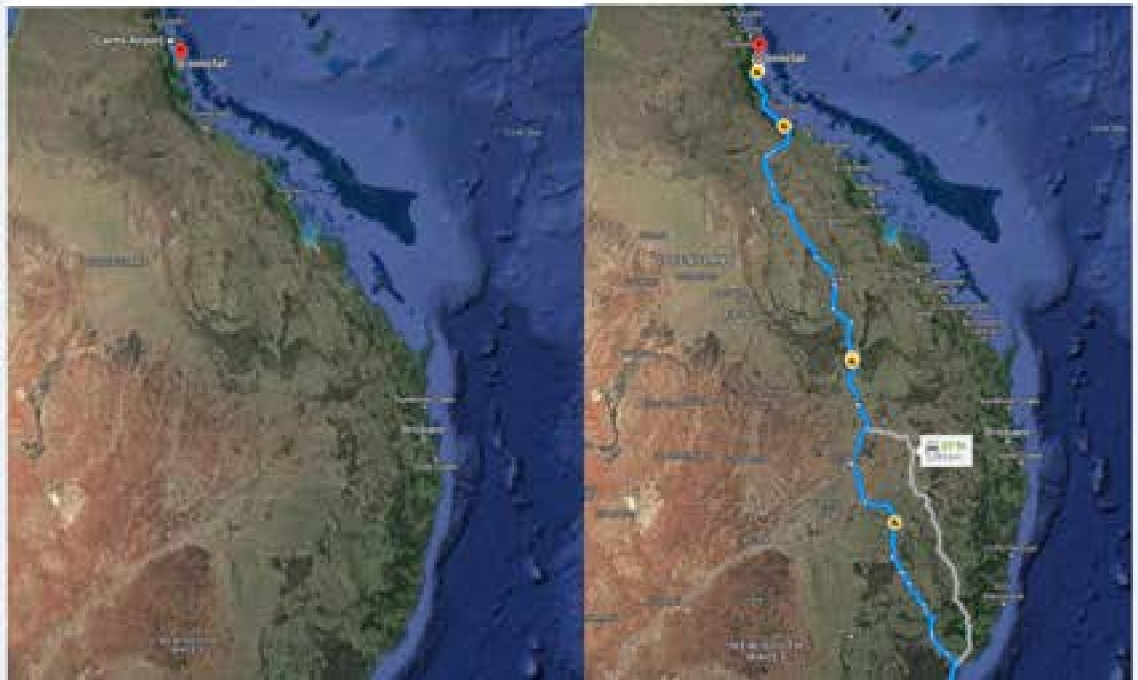
- Home
- Background Information
- Chilling Injury Modeling
- Chilling Injury Decision Support Tool
- Chilling Injury Report
- Post-Ripening Colour Development Modeling
- Post-Ripening Colour Decision Support Tool
- Colour Stage Development for Export
- Colour Stage Development for different ethylene levels
- Fact sheet: Benefits of Modified Atmospheric Packaging on Banana Storage

Colour Stage Development for Export

Simulation trial for fruit exported from Sydney to Japan

The fruit underwent a simulated road trip exposure for 4 days at 14°C, followed by a 3-day simulation of an air trip. The Colour Stage (CS) results are listed below:





- Home
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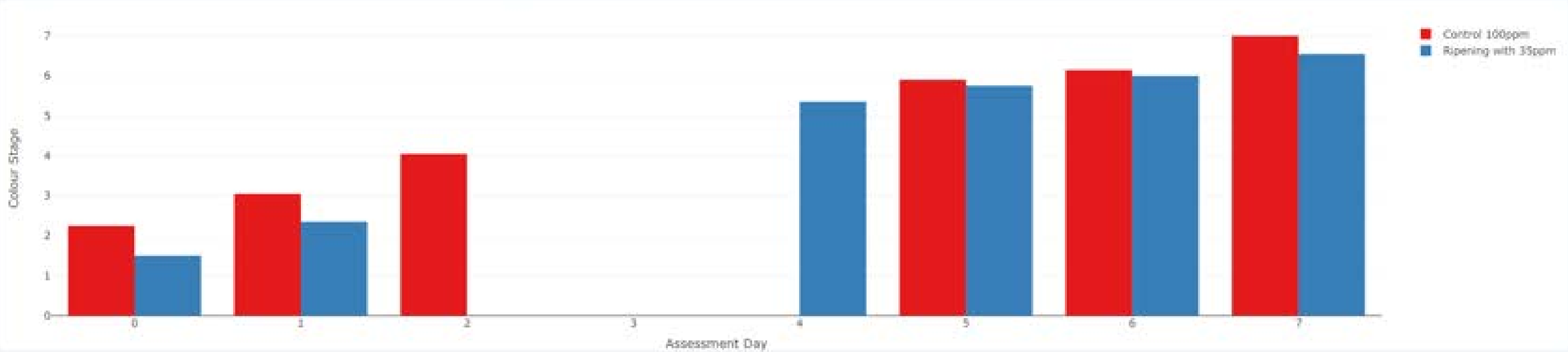
- Post-Ripening Colour Decision Support Tool
- Colour Stage Development for Export
- Colour Stage Development for difrent ethylene levels
- Fact sheet: Benefits of Modified Atmospheric Packaging on Banana Storage

Colour Stage Development for difrent ethylene levels

The fruit underwent a simulated road trip exposure for 4 days at 14°C, then was ripend with 35ppm or 100pm ethylene at 16°C



Benefits of Modified Atmospheric Packaging on Banana Storage

Benefits

Enhanced Shelf Life

Extended Freshness: MAP, particularly through the use of the Perfotec bag, has been shown to significantly delay the ripening process of bananas. By maintaining a slightly lower colour stage at the pre-ripening phase and higher firmness across all ripening stages, the shelf life of bananas is extended, allowing them to stay fresh longer.

Reduced Waste: Extending the shelf life of bananas means that less produce is discarded due to spoilage, contributing to reduced food waste. This is beneficial for both the environment and the economy.

Improved Quality Preservation

Reduced Mould Development: The report highlights the effectiveness of the Perfotec bag in inhibiting mould growth, with a nearly eliminated incidence at the pre-ripening stage. This ensures that the bananas maintain their aesthetic appeal and are healthier for consumption.

Maintained Texture and Appearance: By slowing down the ripening process and preserving the firmness of the bananas, MAP helps maintain the texture and appearance of the fruit, making it more appealing to consumers.

Enhanced Marketability

Superior Product Quality: With the reduced incidence of defects, mouldy appearance, and stem rot, bananas stored in MAP, especially in the Perfotec bag, demonstrate superior quality. This enhances their marketability, as consumers are more likely to purchase produce that looks and feels fresh.

Economic Benefits

Cost-Effectiveness for Retailers and Producers: By reducing spoilage and extending the saleable life of bananas, MAP can offer significant cost savings to producers and retailers. This technology minimizes losses due to unsaleable stock and maximizes the profitability of the produce.

Conducted trial

Economic Benefits

Cost-Effectiveness for Retailers and Producers: By reducing spoilage and extending the saleable life of bananas, MAP can offer significant cost savings to producers and retailers. This technology minimizes losses due to unsaleable stock and maximizes the profitability of the produce.

Conducted trial

trial Objective: To analyse the effectiveness of modified atmospheric packaging in reducing mould development and extending the shelf life of bananas.

Methodology

Bananas were stored under three different packaging conditions: commercial bag, Perfotec bag, and Maze bag for 4 weeks. The evaluation was conducted just before ripening and (5, 6, 7 days) post ripening. Key parameters measured included colour stage, firmness, defects, mouldy appearance, and stem rot incidence.

Results Summary

Colour Stage and Firmness:

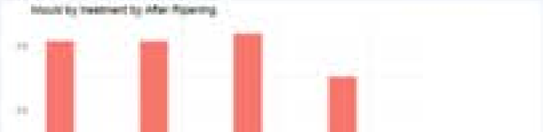
The Perfotec bag consistently showed a slightly lower colour stage at the pre-ripening stage, indicating a slower ripening process compared to the other treatments. This bag also maintained higher firmness across all ripening stages, suggesting it effectively delays ripening and preserves texture.

The Maze bag showed intermediate results in colour stage and firmness, indicating it also contributes to slowing down the ripening process, but to a lesser extent than the Perfotec bag.

once the fruit were removed from the bags there was no detectable different of Colour Stage and Firmness.

Defects and Mouldy Appearance

The bananas stored in the 4-week Perfotec bag exhibited significantly lower average defects and mouldy appearance scores across all evaluated stages. Particularly, at the pre-ripening stage (-3), the mouldy appearance was nearly eliminated (0.03 average), showcasing the bag's effectiveness in inhibiting mould growth.



APPENDIX B – Supporting Materials

A4. Project information products

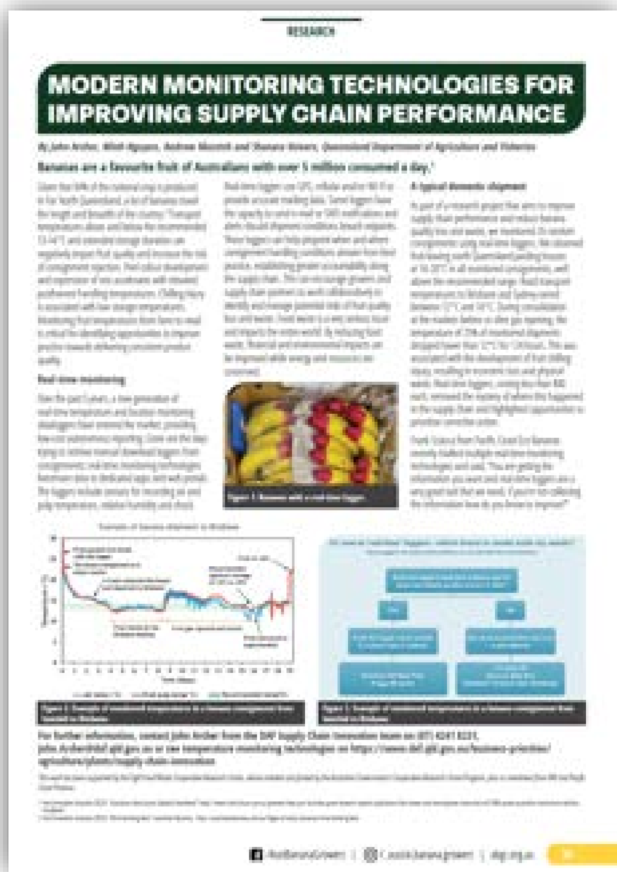
Articles


INDUSTRY NEWS

NEW PROJECT PUTS SUPPLY CHAIN IN SPOTLIGHT

QUALITY BANANA APPROVED NURSERY (QBAN) SCHEME FACILITIES

AUSTRALIAN BANANAS MAGAZINE | APRIL 2020


RESEARCH

MODERN MONITORING TECHNOLOGIES FOR IMPROVING SUPPLY CHAIN PERFORMANCE


RESEARCH

REAL-TIME CONSIGNMENT MONITORING

Unpacking the costs and benefits

Monitoring supply chain performance is critical to delivering more consistent product quality


RESEARCH

AUSTRALIAN BANANAS IMPRESS ON THE INTERNATIONAL STAGE

Trial shipments highlight opportunities for Australian bananas in niche markets

HONG KONG

Fruit performance

Trial consignments 1 and 2

RESEARCH

Market acceptance

JAPAN

Trial consignment 3

Fruit performance

Market acceptance

Conclusions and recommendations

AUSTRALIAN BANANAS MAGAZINE | APRIL 2024

Conference presentations

Banana supply chain monitoring and simulation identifies critical control points

Andrew Macnish, John Archer, Minh Nguyen

Queensland Department of Agriculture & Fisheries

Frank and Dianne Sciacca

Pacific Coast Produce

Greg Picker

Australian Food Cold Chain Council

PACIFIC COAST ECO BANANAS

AFCCC

Australian Government
Department of Industry, Innovation and Science

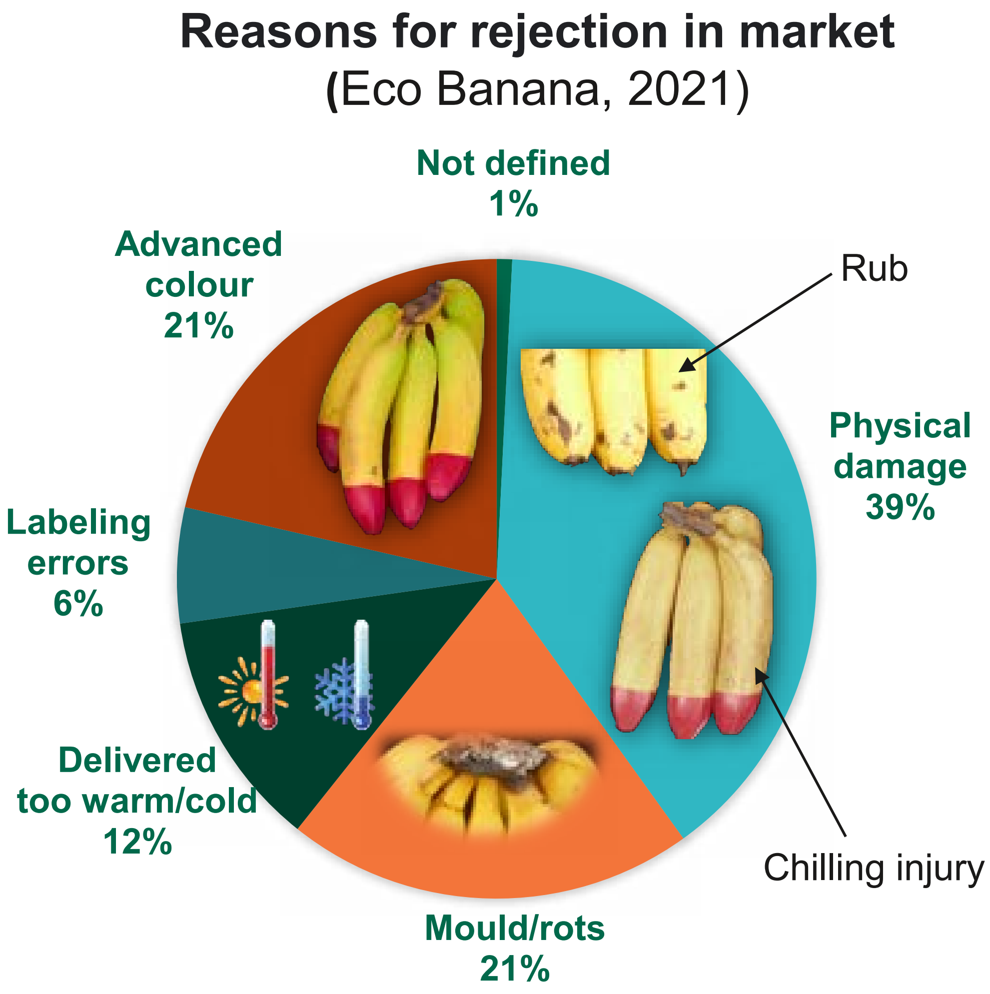
Business
Cooperative Research Centres Program

FIGHT FOOD WASTE
Cooperative Research Centre
REDUCE · TRANSFORM · ENGAGE

Queensland Government

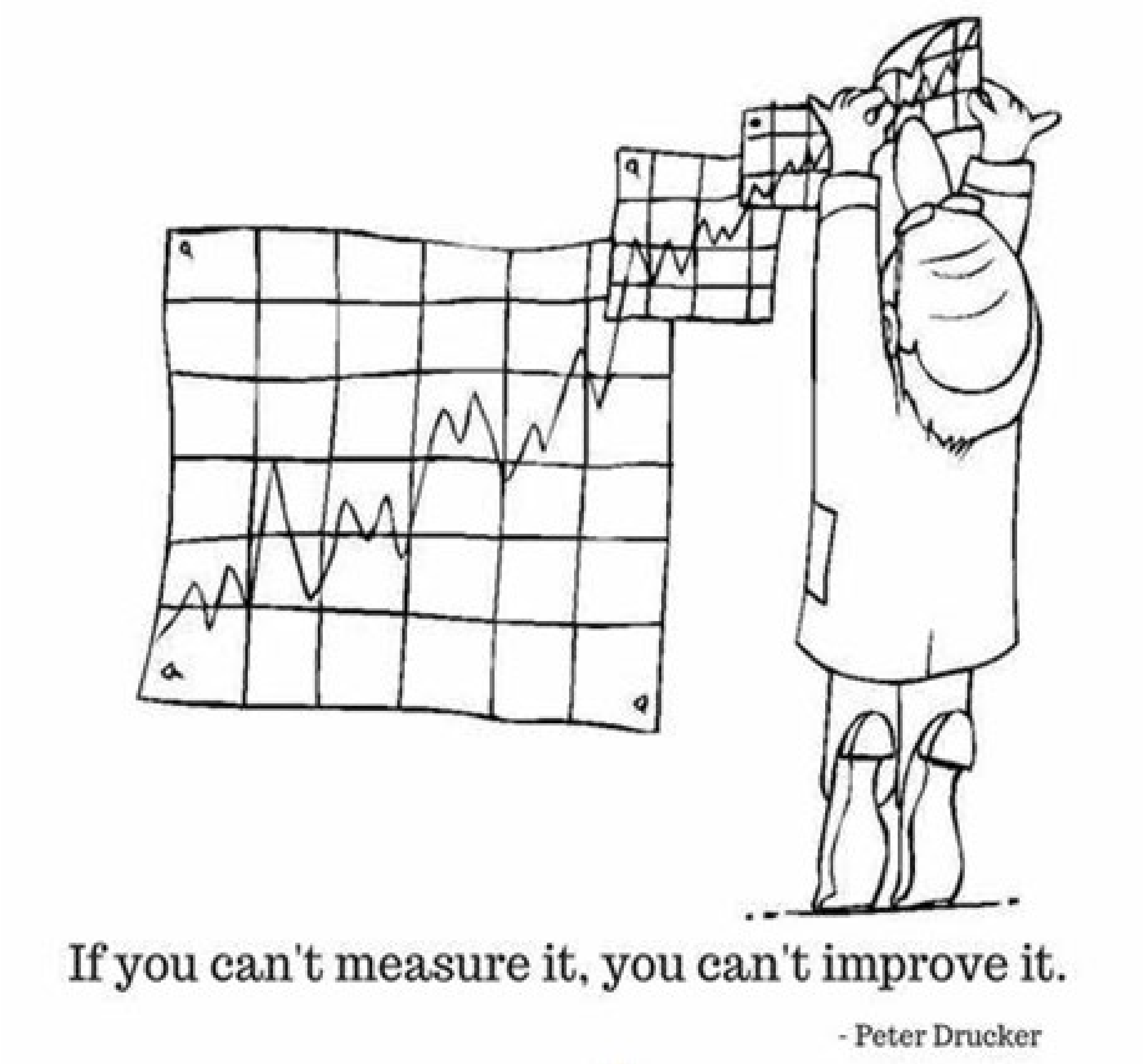
The banana waste challenge

- Up to 15-20% of fruit are culled during grading and packing[1]
- An additional 5-10% of fruit are rejected along the supply chain[1,2]
- Transport conditions are often to blame

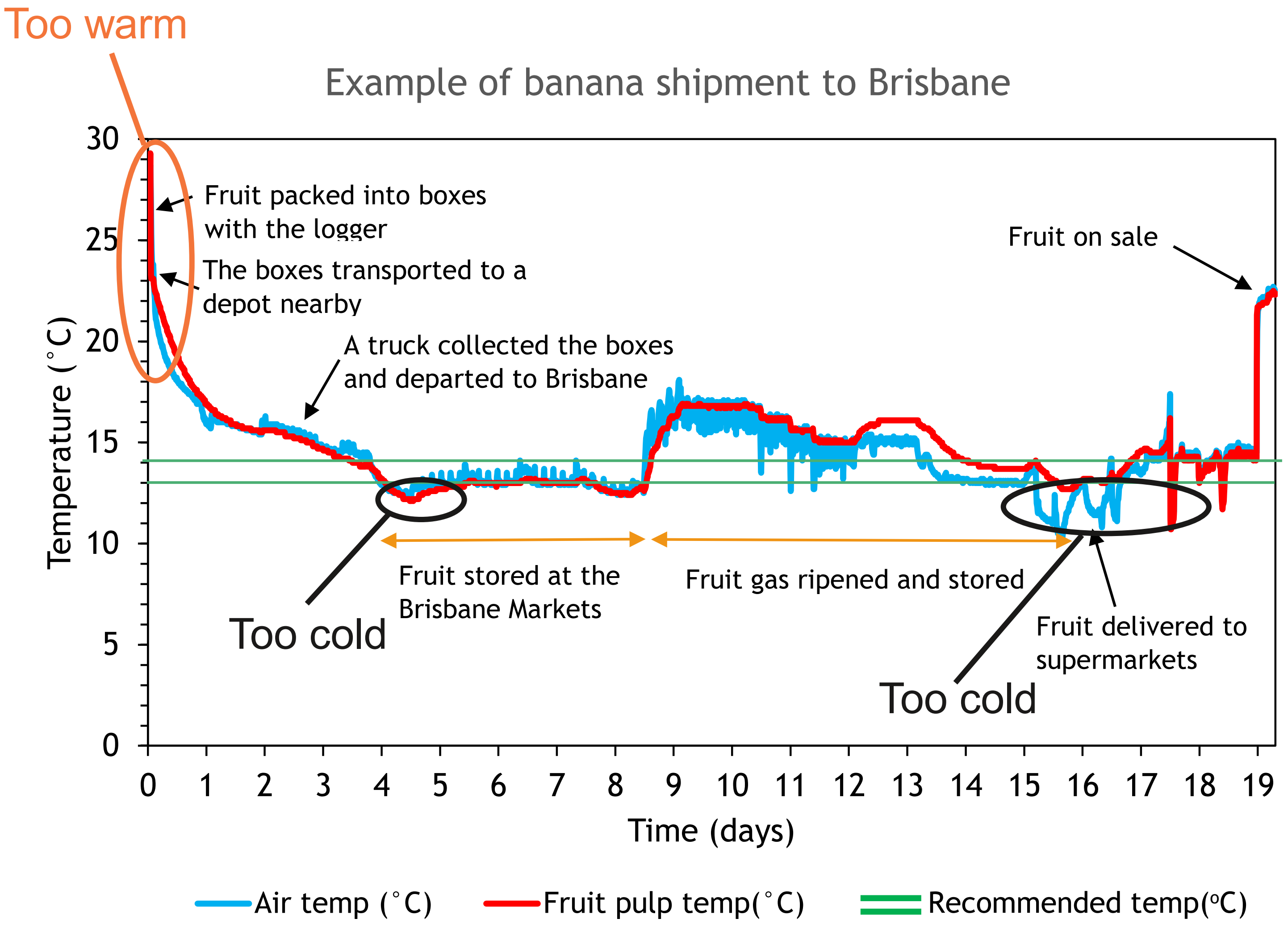


[1] Frank Sciacca, pers comm. (2021)
[2] Kitchener (2016)

Supply chain monitoring



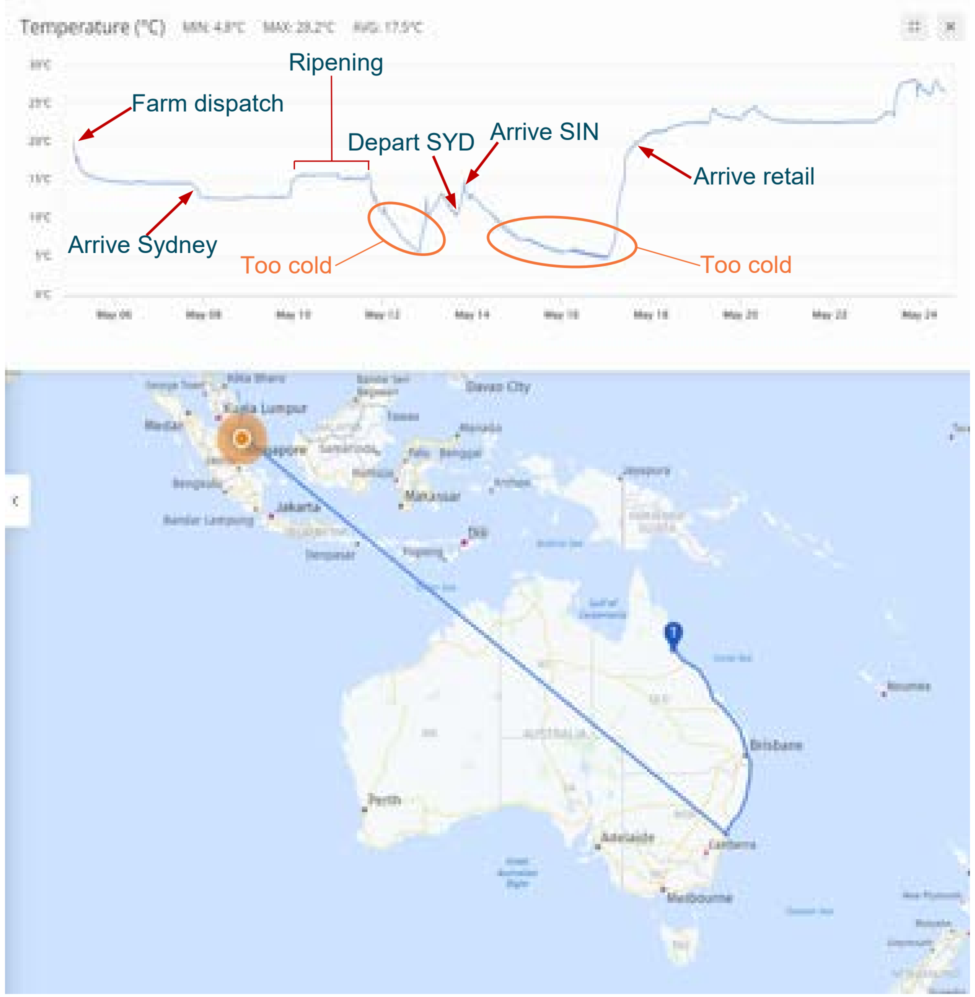
Supply chain monitoring



Range of average air temperatures within domestic and export banana supply chains (n = 35)

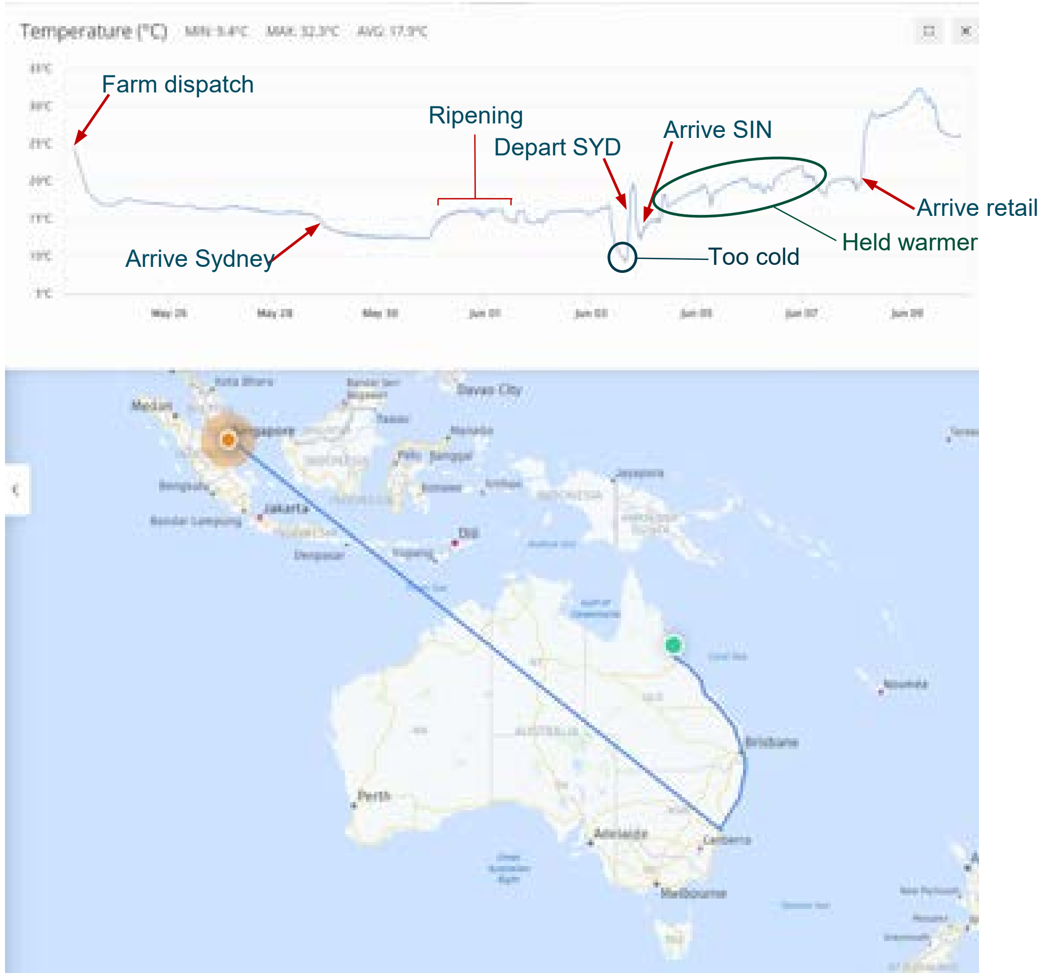
Supply chain step	Range (°C)
Pack shed dispatch	12.3 - 30.1
Road transport	12.4 - 16.7
Consolidation	7.0 - 21.7

Identifying improvement opportunities



Fruit on arrival at retail

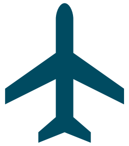
Identifying improvement opportunities



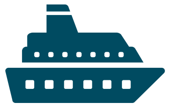
Fruit on arrival at retail

Simulation trials – develop a decision support tool

- Impact of storge temperature on chilling Injury
- Impact of post ripening on banana development
- Modified atmosphere packaging



Air simulation trials



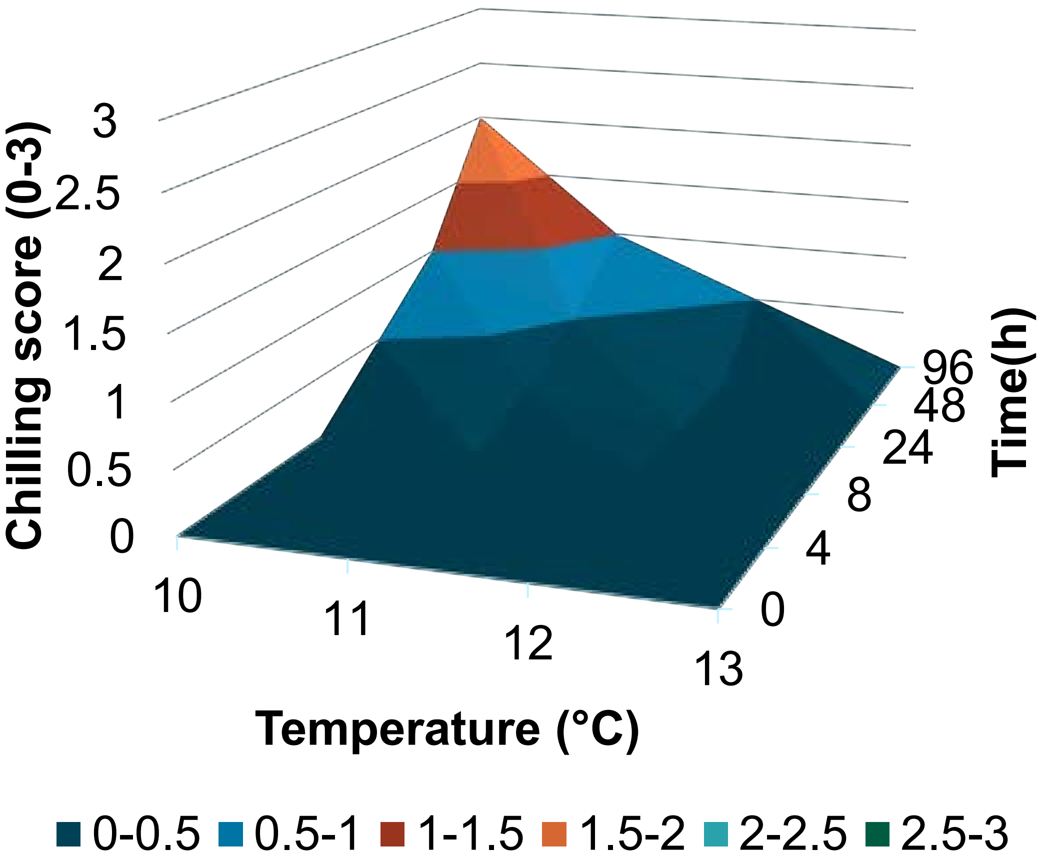
Sea simulation trials

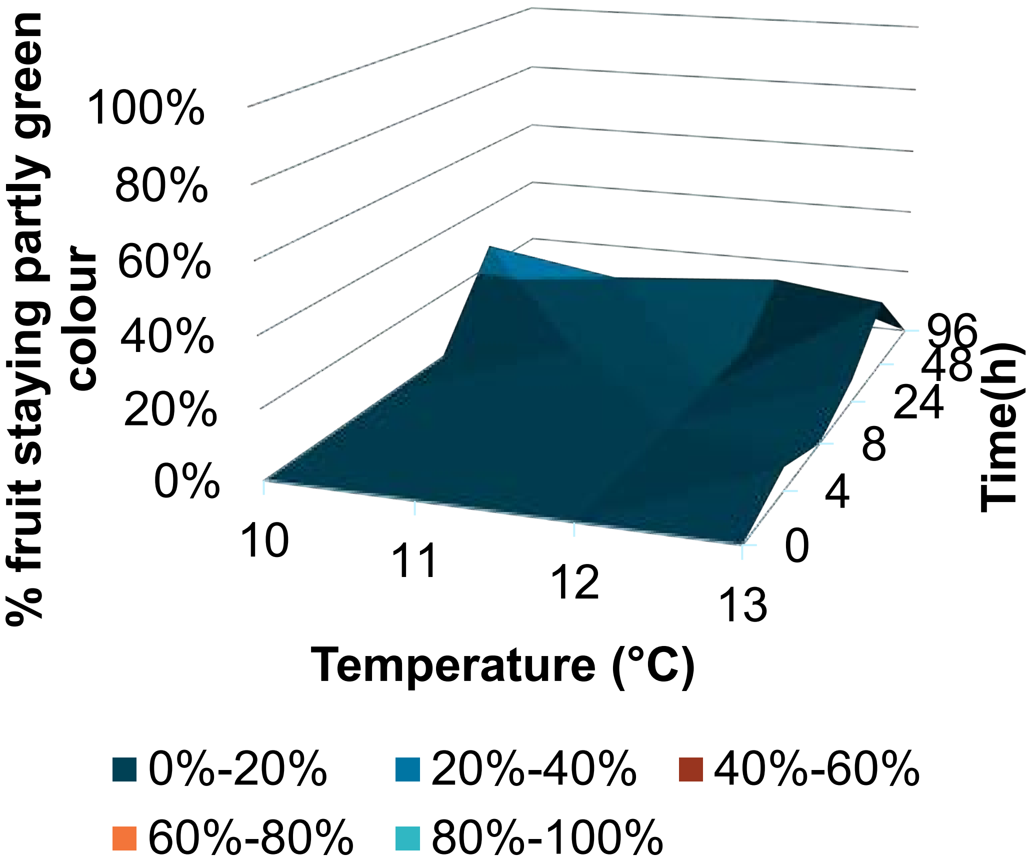
Chilling injury

Chilling injury

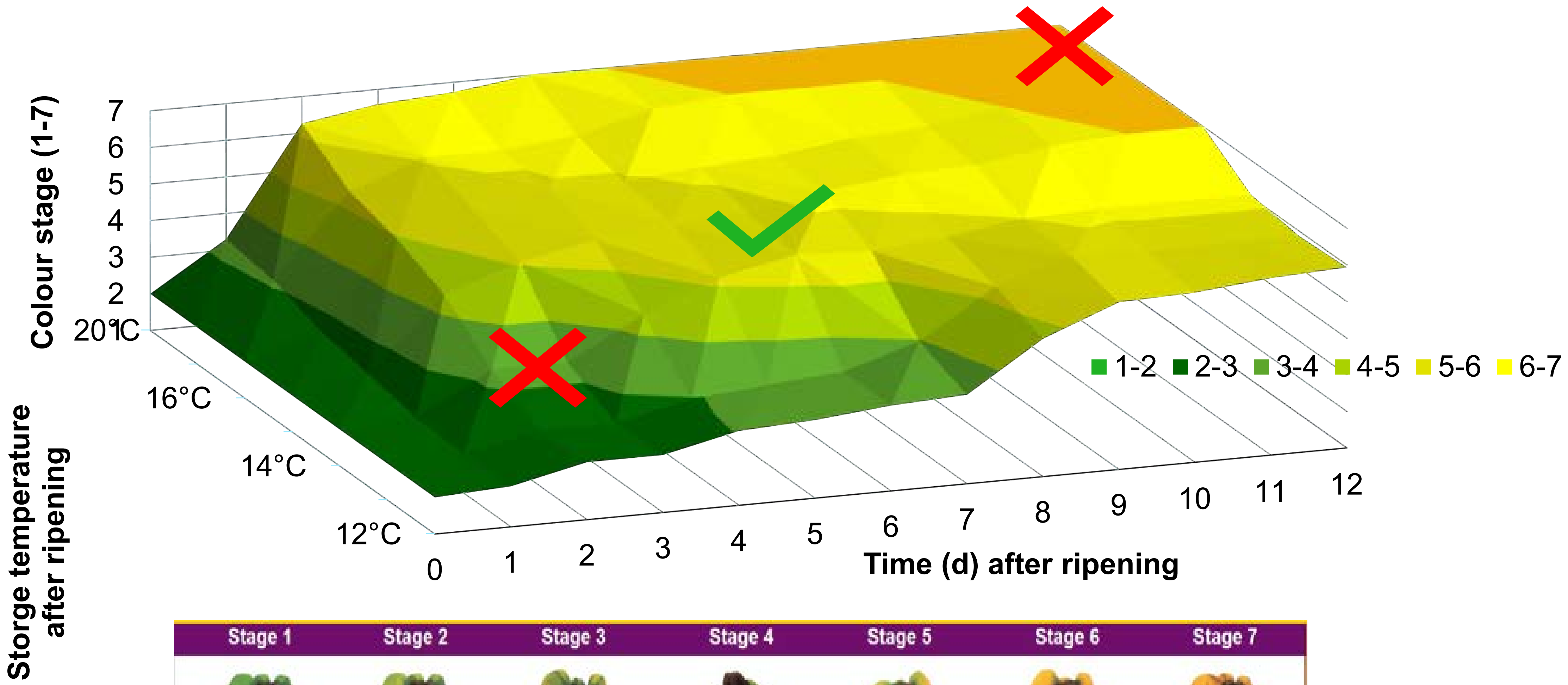
Pale colour development at ripen stage

Chilling injury - Summer fruit





Impact of storge temp(°C) on banana Ripening rate after ripening

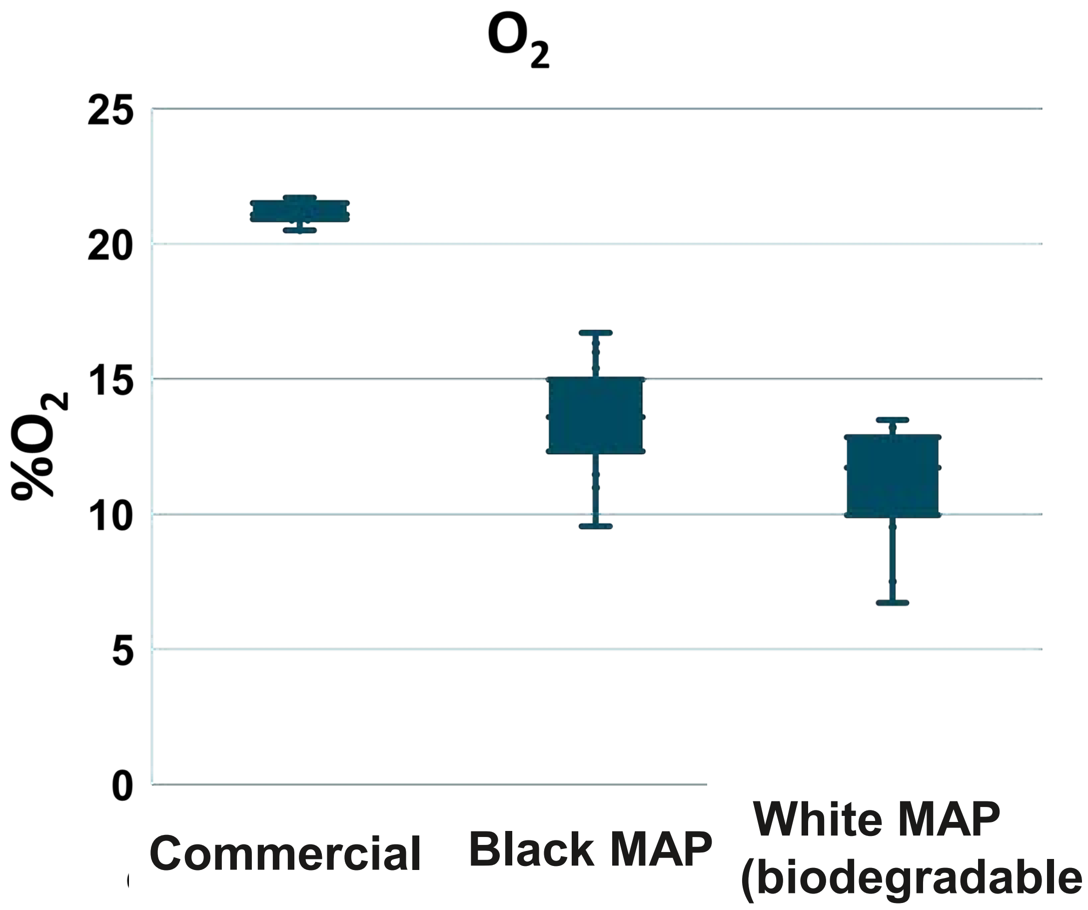


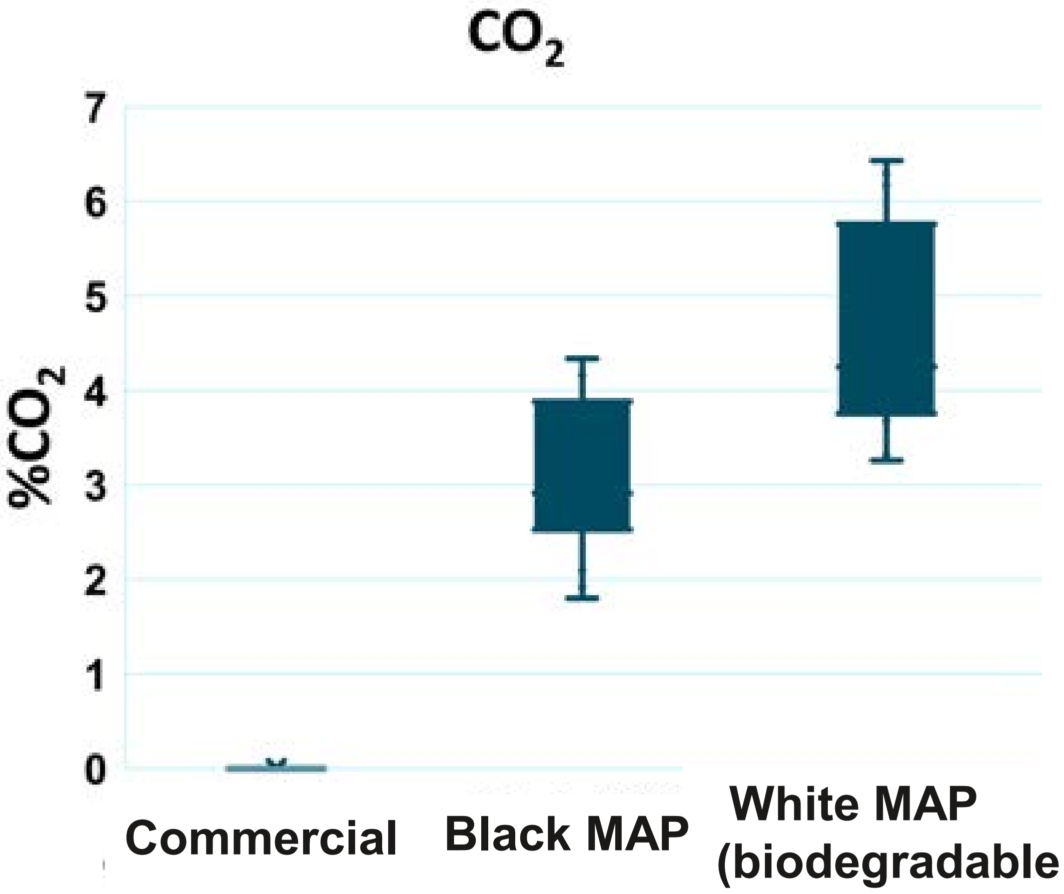
Sea Freight Simulation trials Mouldy 4 weeks

Modified atmosphere packaging (MAP) types

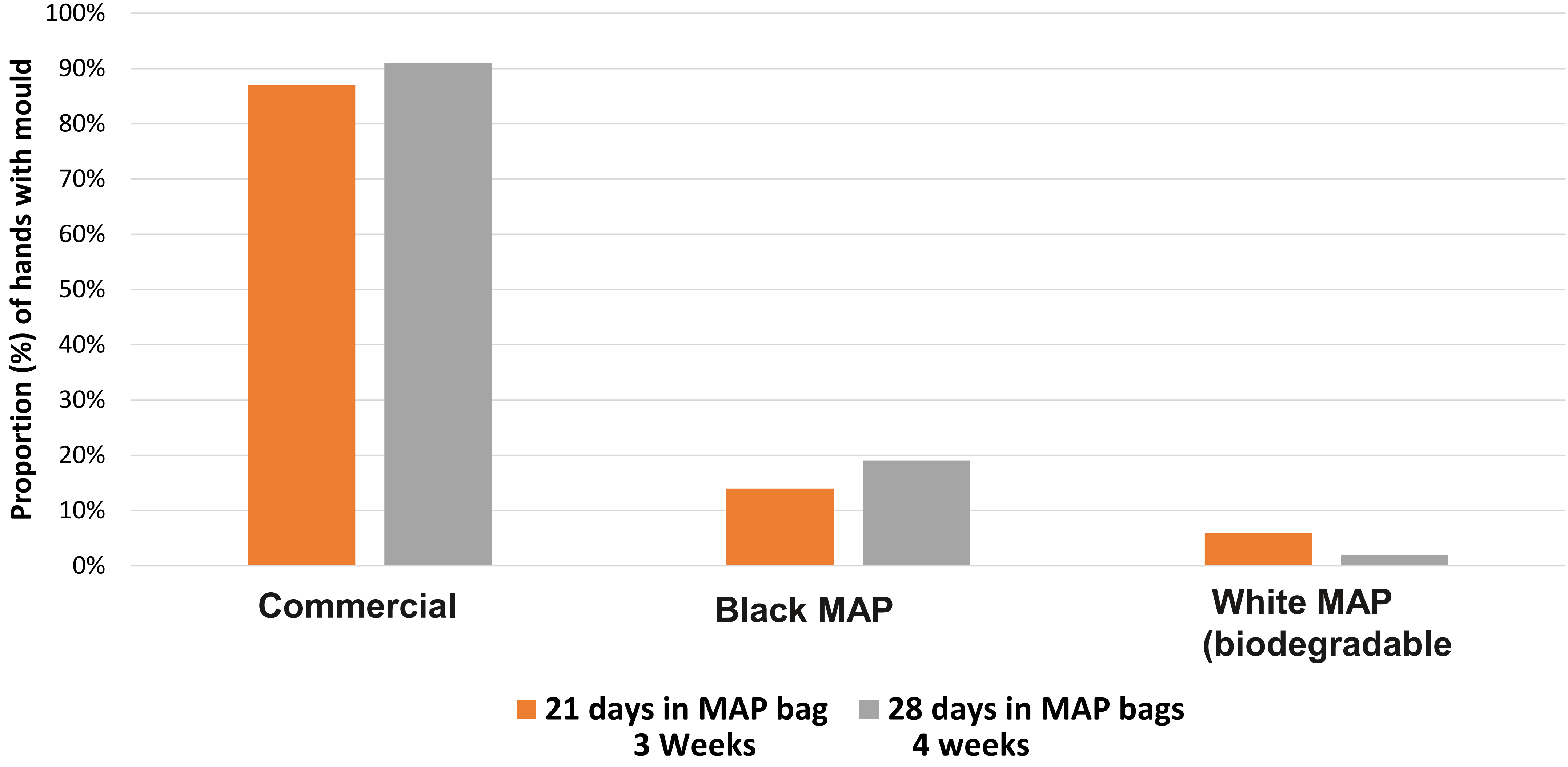
White MAP (biodegradable) | Black MAP | Commercial

Respiration gas concentrations in bags





Proportion of mouldy fruit



Impact of MAP bags on storage life

Commercial Bag

MAP Bag

Outcome – development of decision support tool

- Impact of storge temperature on chilling injury (predict hours vs °C)
- Impact of post ripening on banana development (predict colour stage hours vs °C)
- Modified atmosphere packaging improve allow Ecoganic fruit to sea freight

Air simulation trials

Sea simulation trials

Chilling injury

Thank you!

This work has been supported by the Fight Food Waste Cooperative Research Centre whose activities are funded by the Australian Government's Department of Industry, Science, Energy and Resources, plus co-investment from the Department of Agriculture and Fisheries and Pacific Coast Produce. FFW CRC Publication 2023_34.

Supply chain monitoring and improvement to reduce banana quality loss

Andrew Macnish[1], Frank Sciacca[2], Dianne Sciacca[2], John Archer[1], Minh Nguyen[1], Greg Picker[3]

[1]Queensland Department of Agriculture and Fisheries, [2]Pacific Coast Produce, [3]Australian Food Cold Chain Council

2022 National Food Waste Summit

FIGHT FOOD WASTE Cooperative Research Centre

STOP FOOD WASTE AUSTRALIA

Queensland Government

PACIFIC COAST ECO BANANAS

AFCCC

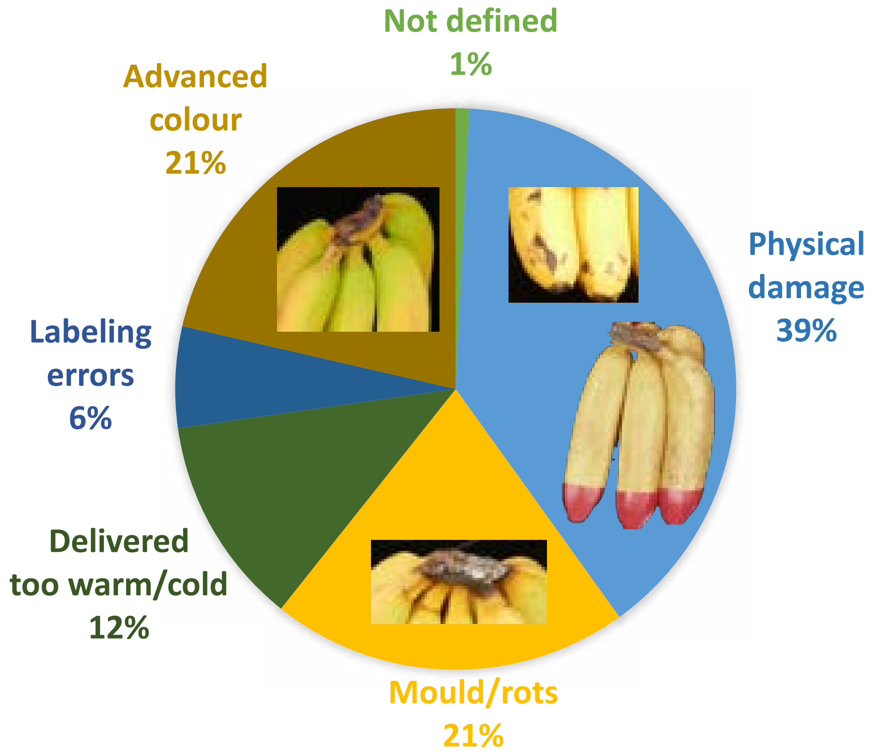
What are Eco Bananas and Ecoganic?

- Sustainably produced bananas from north Queensland
- Grown by Pacific Coast Eco Bananas since 1998
- Sold in domestic and export markets

The banana waste challenge

- Australian bananas are worth $1.3 billion
- 15-20% of fruit are culled at grading/packing
- An additional 5-8% of fruit are rejected along the supply chain
- Transport conditions are often to blame

Reasons for rejection in market
(Eco Banana, 2021)



Project overview

Objective

Improve supply chain performance to minimise waste and consistently deliver more predictable fruit quality

Activities

1. Monitor handling practices
2. Quantify fruit quality responses
3. Support improved practice

Monitoring to improve

Harvest
↓
Pack shed
↓
Transport
↓
Consolidation
↓
Ripening
↓
Export

Monitoring to improve

Harvest
↓
Pack shed
↓
Transport
↓
Consolidation
↓
Ripening
↓
Export

Monitoring to improve

Harvest

Pack shed

Transport

Consolidation

Ripening

Export

Monitoring to improve

Harvest
↓
Pack shed
↓
Transport
↓
Consolidation
↓
Ripening
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Export

Monitoring to improve

Harvest
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Pack shed
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Transport
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Consolidation
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Ripening
↓
Export

Monitoring to improve

Harvest
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Pack shed
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Transport
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Consolidation
↓
Ripening
↓
Export

Monitoring to improve

Harvest
↓
Pack shed
↓
Transport
↓
Consolidation
↓
Ripening
↓
Export

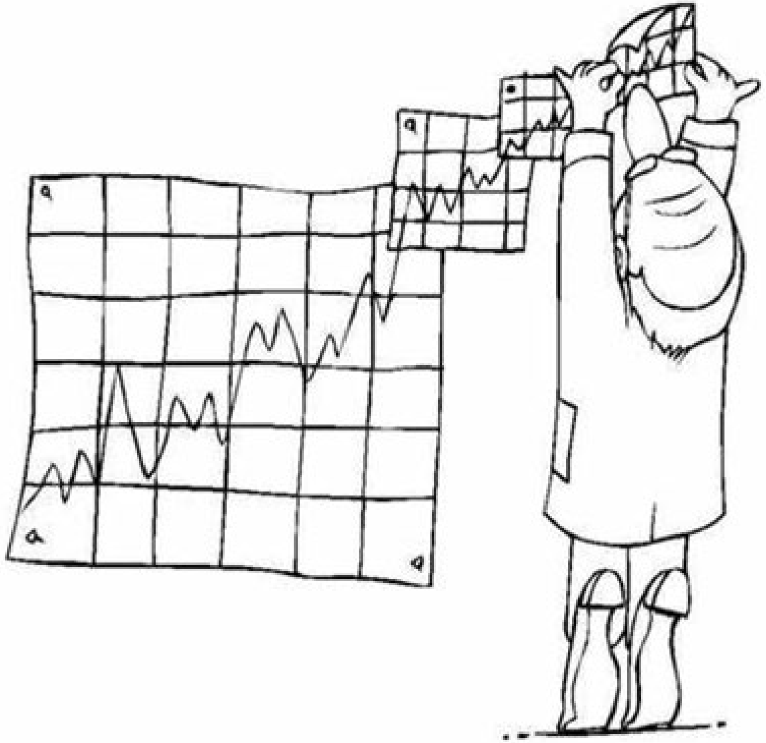
Export supply chains

Monitoring to improve

Harvest
↓
Pack shed
↓
Transport
↓
Consolidation
↓
Ripening
↓
Export

Monitoring to improve

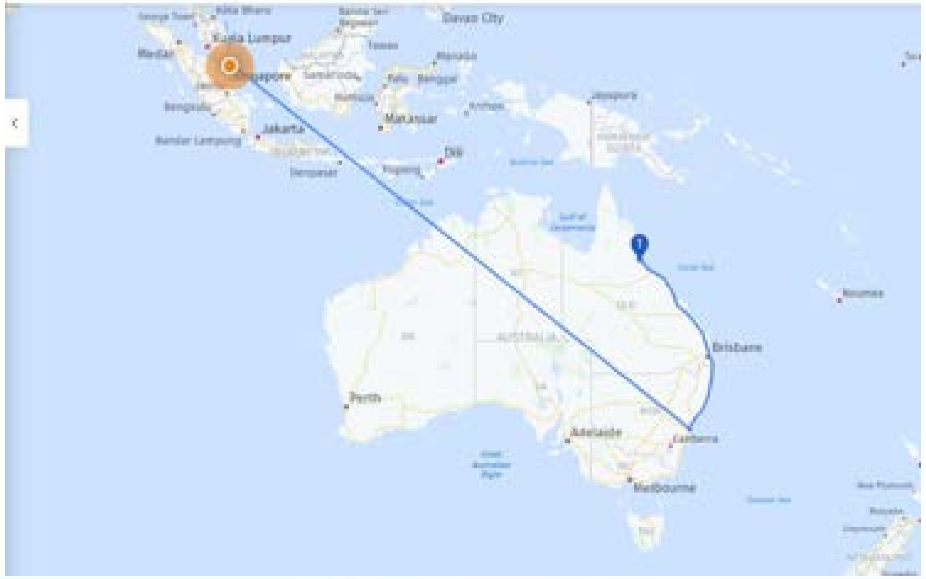
Harvest
↓
Pack shed
↓
Transport
↓
Consolidation
↓
Ripening
↓
Export



If you can't measure it, you can't improve it.

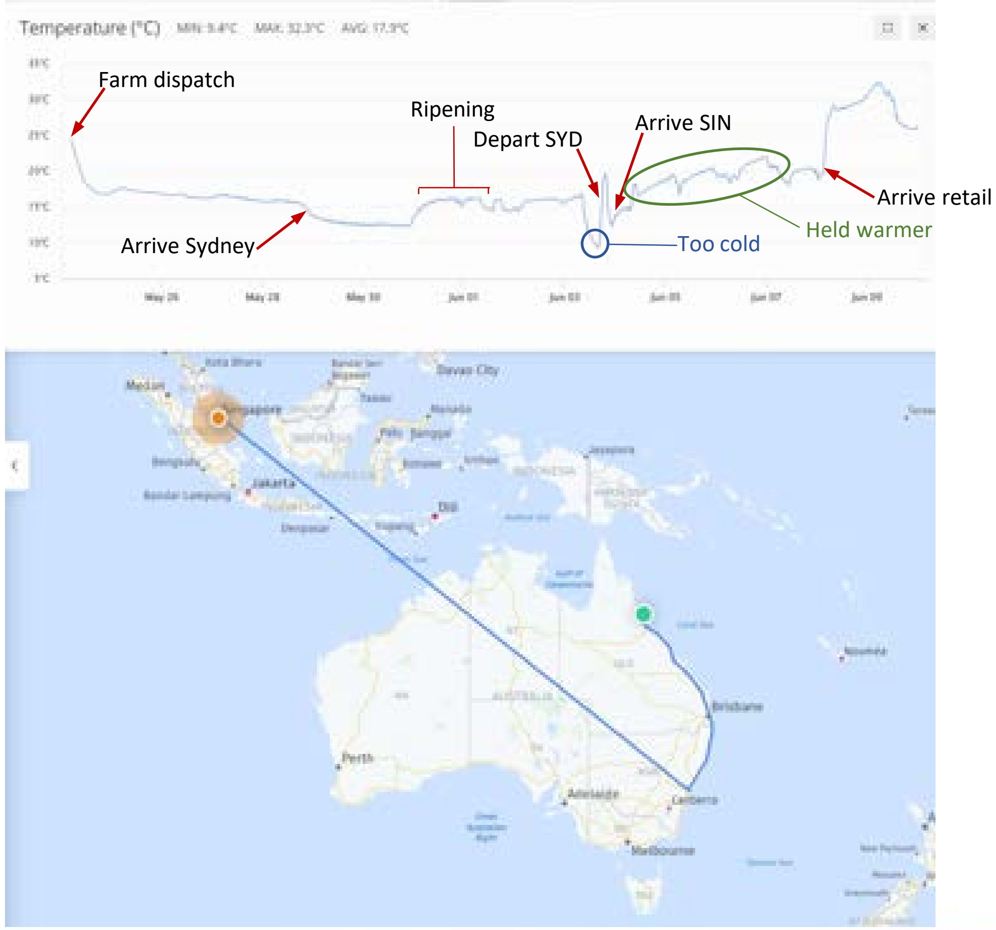
- Peter Drucker

Monitoring export consignments



Fruit on arrival at retail

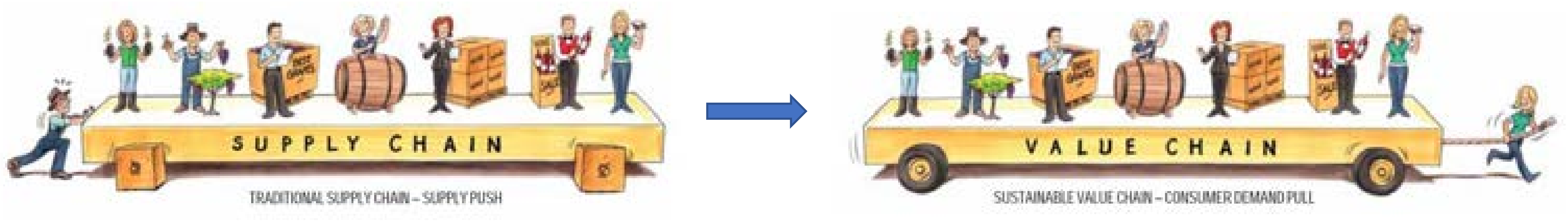
Monitoring export consignments



Fruit on arrival at retail

Challenges and opportunities

- Fragmented supply chain partner relationships
- Limited visibility and control
- Seeking new collaborative partnerships to 'grow the pie'



Fearne (2009)

Evaluating alternative strategies

- Improving knowledge and practices
- Testing shelf life extension technologies
  - Modified atmosphere packaging
  - In-transit ripening

Conclusions

The project has:

- Identified and quantified handling and waste issues
- Generated knowledge, skills and confidence to manage risks
- Underscored the value of business relationships and trust
- Highlighted lessons for other SME growers

Predicting the risk of banana fruit chilling injury based on postharvest handling conditions

John Archer, Minh Nguyen and Andrew Macnish

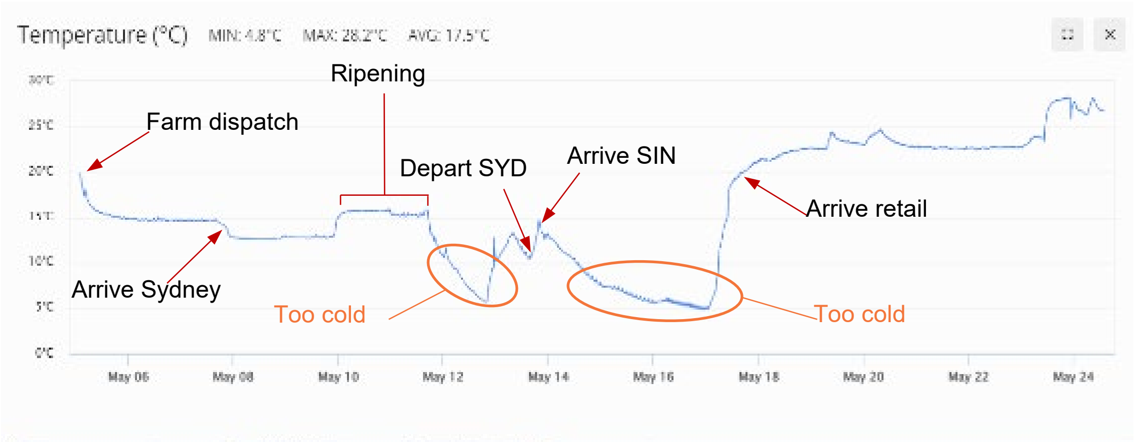
Supply Chain Innovation
Queensland Department of Primary Industries, Australia

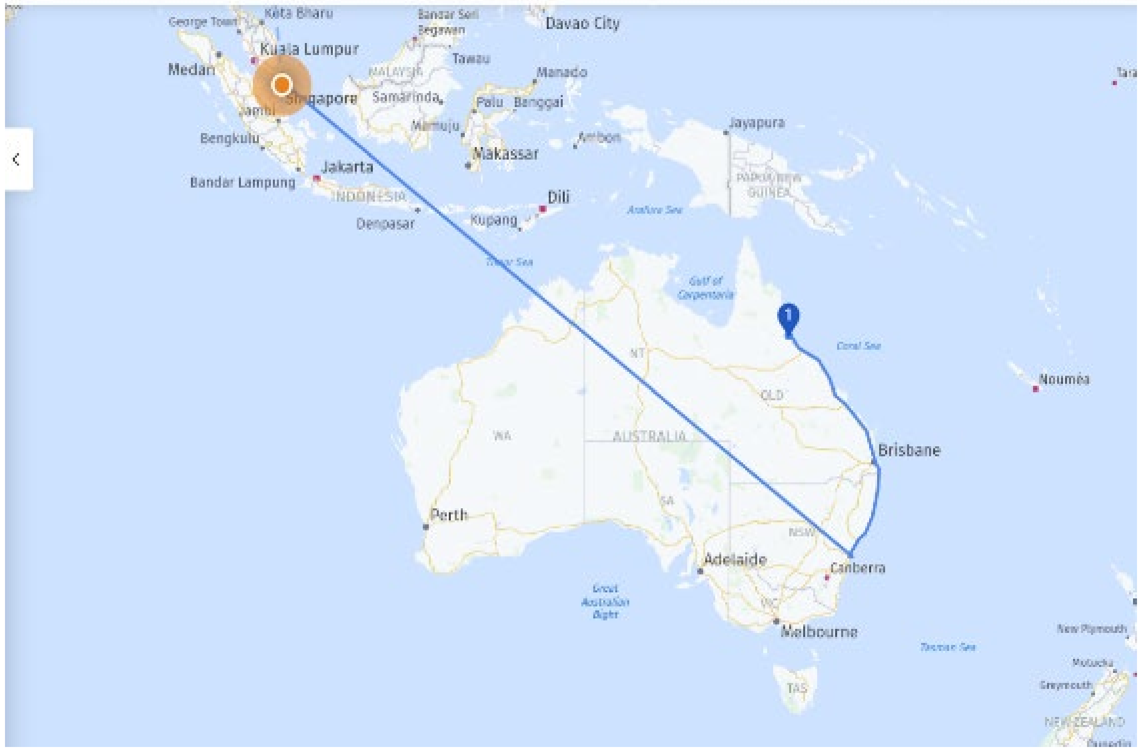
Queensland Government

Introduction

- Bananas (*Musa* spp.) are among one of the most important food crops
- Fruit are typically transported long differences to market
- Cavendish bananas are susceptible to chilling injury when stored below 13°C
- Chilling injury is associated with peel discoloration, pitting and impaired ripening

Introduction





Study objectives

- Quantify the response of Ecoganic® fruit to low storage temperatures
- Develop a simple decision support tool based on predicted risk of chilling injury
- Support the supply chain partners to reduce fruit exposure to low temperature

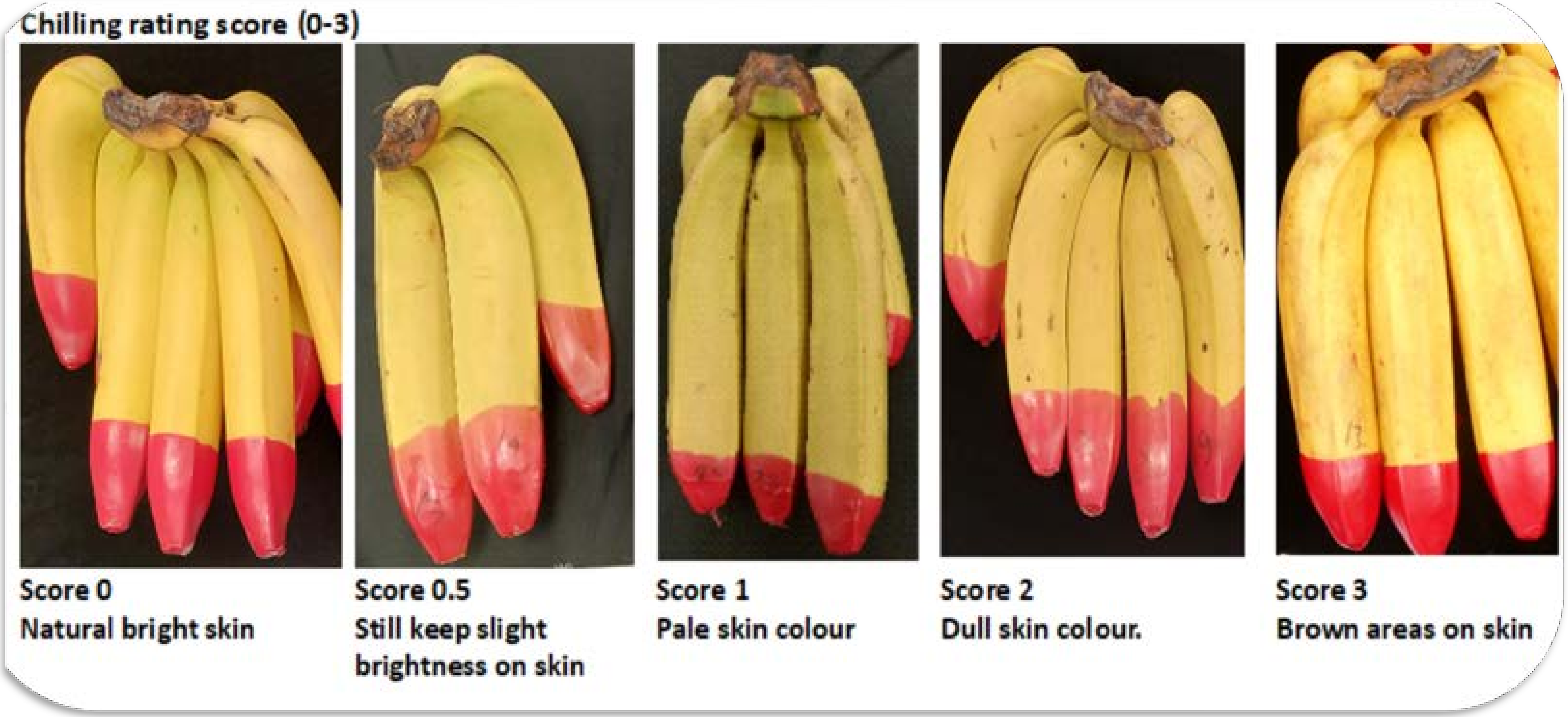
Methods

- Monitored several (n=35) domestic and export consignments from farm to retail
- Completed simulation trials to determine fruit sensitivity to chilling injury
- Fruit were harvested green mature (34-38 mm diameter)
- Evaluated responses of ‘summer’ vs ‘winter’ fruit over two seasons
- Following storage, fruit were treated with 100 μL/L ethylene for 2 days at 16°C

Temperature x time treatments used in experiments

Temperature (°C)	Treatment duration									
	Hours				Days					
	4	8	16	24	2	4	6	14	21	27
3				X	X	X				
5				X	X	X				
7				X	X	X				
10	X	X	X	X	X	X	X			
11	X	X	X	X	X	X				
12	X	X	X	X	X	X	X	X	X	X
13	X	X	X	X	X	X	X	X	X	X
14				X	X	X	X	X	X	X
20	X	X	X	X	X	X	X	X	X	X

Methods



0: No injury; 1: Light injury; 2: Medium injury; 3: Severe injury

Results

- Chilling injury incidence and severity increased with extended time at <13°C

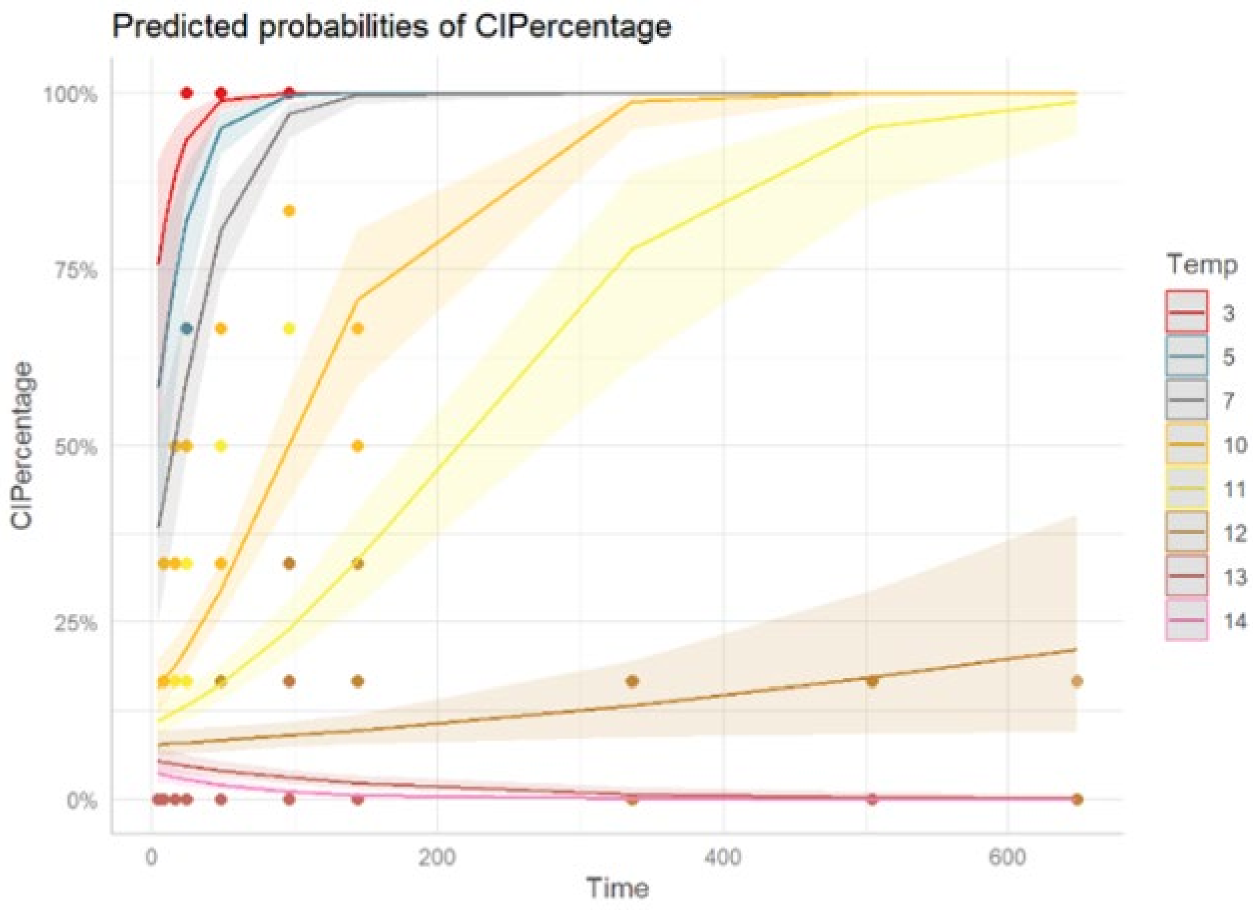
- A generalised linear model was applied to the experimental data

Model Structure:

$$CI = \beta 0 + \beta 1 \times \text{Temperature} + \beta 2 \times \text{Time} + \beta 3 \times (\text{Temperature} \times \text{Time})$$

Results

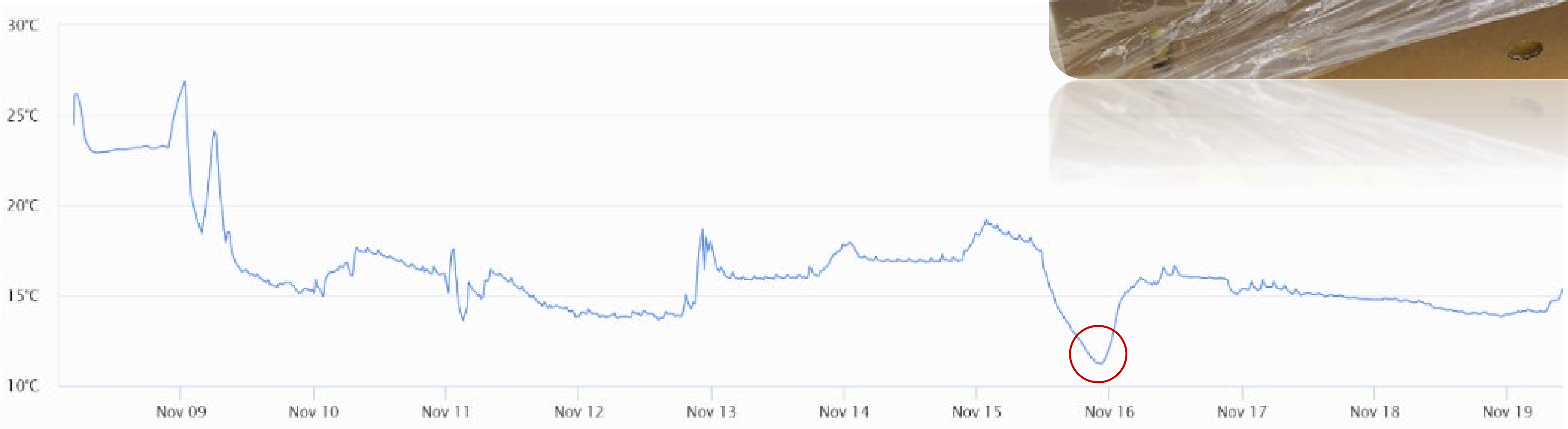
Estimated coefficients
Temperature: $\beta 1$ = -0.368; p<0.001
Time: $\beta 2$ = 0.101; p<0.001
Temperature * Time: $\beta 3$ = -0.008; p<0.001



Predicted probabilities of chilling injury percentage of fruit at different temperatures (3-14°C) and time durations (hours)

Results

- Model validation in commercial supply chains



Temperature profile (°C) of fruit exported from Australia to Japan over a 10-day period

Results

- Model validation in commercial supply chains

Temperature profile (°C) of fruit exported from Australia to Singapore over a 16-day period

Conclusions

- Temperatures <13°C plus extended exposure time influence the development of chilling injury

- A generalised linear model estimated chilling injury risk

- This was adapted into a simple tool to predict chilling injury

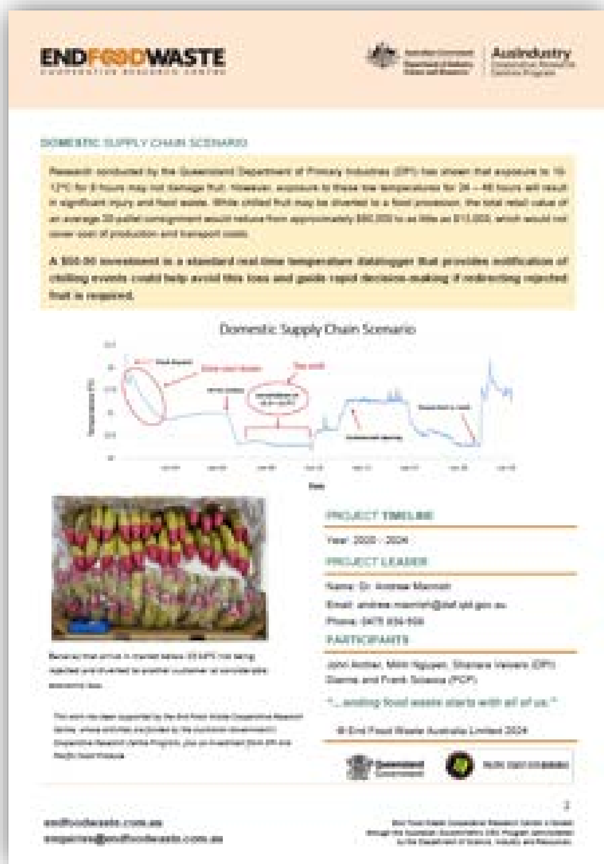
- Opportunity to integrate the model with real-time temperature data?

Acknowledgements

This work has been supported by the End Food Waste Cooperative Research Centre whose activities are funded by the Australian Government's Department of Industry, Science, Energy and Resources, plus co-investment from the Queensland Department of Primary Industries and Pacific Coast Produce.

Factsheets


ENDFOODWASTE
FACT SHEET
Real-time consignment monitoring chain
ENDING FOOD WASTE STARTS WITH ALL OF US.


ENDFOODWASTE
Domestic Supply Chain Scenario


ENDFOODWASTE
FACT SHEET
REDUCING BANANA CHILLING DAMAGE DURING TRANSPORT


ENDFOODWASTE


END FOOD WASTE

FACT SHEET

Benefits of Modified Atmospheric Packaging on Banana Storage

Benefits: Enhanced Shelf Life

Improved Quality Preservation

Enhanced Marketability

Economic Benefits

Trial work

Methodology

Results Summary

ENDING FOOD WASTE STARTS WITH ALL OF US.


END FOOD WASTE

Conclusion

PROJECT LEADER

PARTICIPANTS

DISCLAIMER

endfoodwaste.com.au

enquiries@endfoodwaste.com.au

Webinars

Improving banana supply performance for consistent fruit quality

Andrew Macnish[1], Frank Sciacca[2] and John Archer[1]

[1] Department of Agriculture and Fisheries
[2] Pacific Coast Eco Bananas

Queensland Government

END FOOD WASTE AUSTRALIA

PACIFIC COAST ECO BANANAS

Reflections from Dianne

Project activities

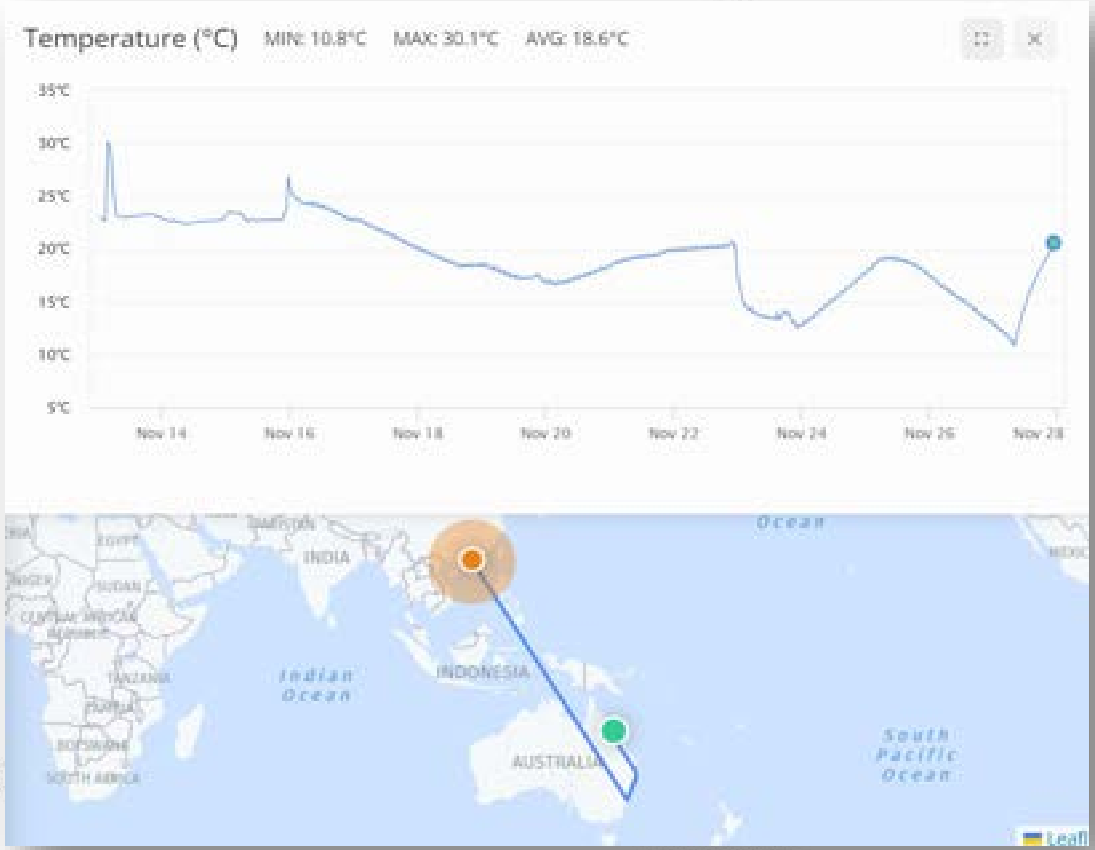
Objective

Improve supply chain performance to deliver more predictable fruit quality

Activities

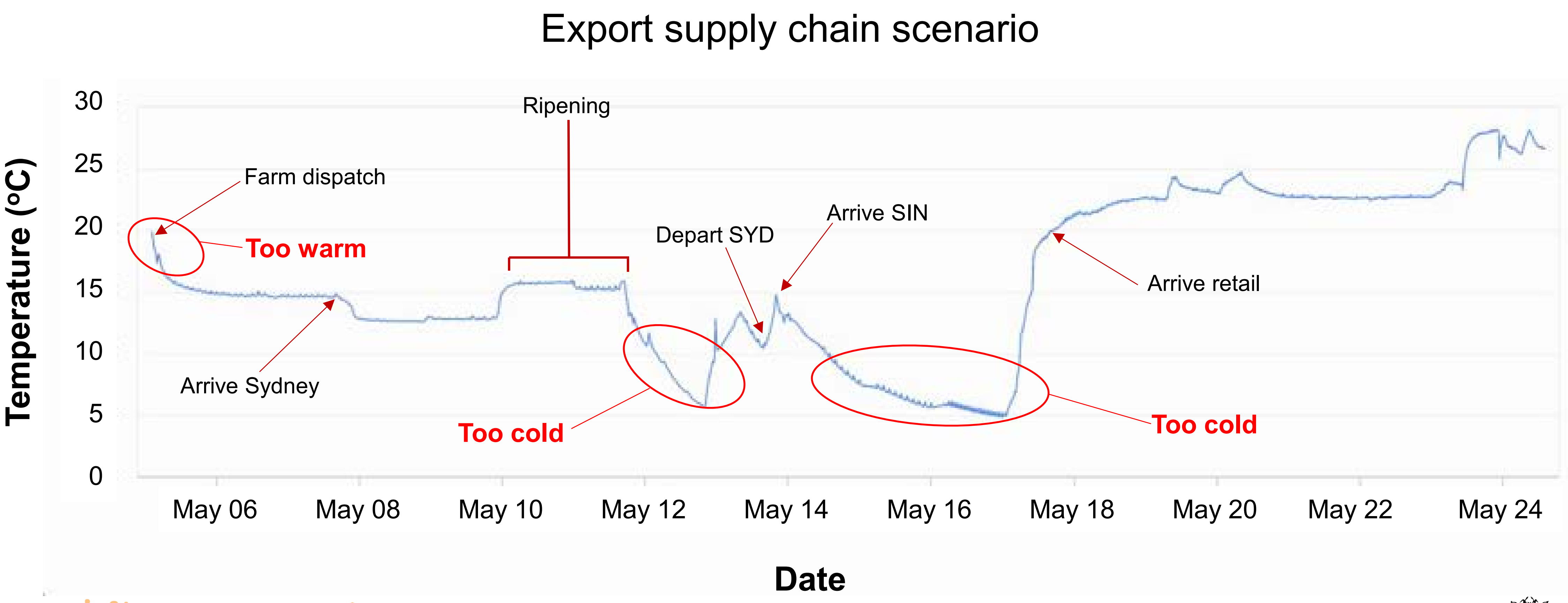
1. Monitor handling practices
2. Quantify fruit responses
3. Deliver decision support

Monitoring to improve



Monitoring to improve

Monitoring to improve



Brief overview of trial work

Technology (Loggers) ✓ → Track Real World Shipments ✓ → Export vs. Domestic Shipments: ✓ → Simulation trials → Modelling trials → Decision support tool

Some fun facts

36 Different Trials

3 Different Varieties Tested

1. Cavendish
2. Lady Finger
3. Little Gem

3 Different Growing Practices

1. Ecoganic
2. Conventional
3. Organic

7,514 Fruits Were Assessed

37,570 Fruit Assessments

Trial Work

Simulation

Air/Sea Simulation

MAP Simulation

Field Heat Simulation

Modelling

Impact of Ripening

Impact of Chilling

Impact of Temperature

Decision Support Tool

Export

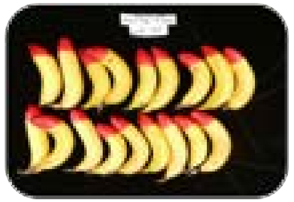
Air Simulation: <2 Weeks Ripened

Over ripe fruit

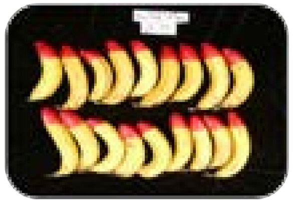
Sea Simulation: 4 Weeks Unripened

Mould

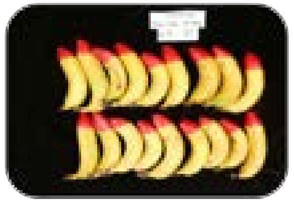
13C-4W 4 day



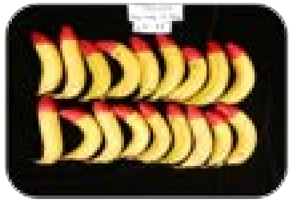
14C-4W 4 day



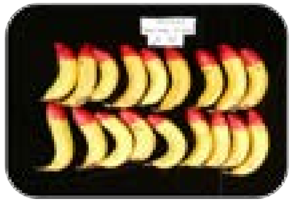
15C-4W 4 day



13C-4W 3 day



14C-4W 3 day



15C-4W 3 day

MAP (Modified Atmosphere Packaging) Sea Simulation

Extended Shelf Life

Maintained Product Quality

Help to control ripening

Biodegradable MAP bag

MAP option 2

Conventional Bag

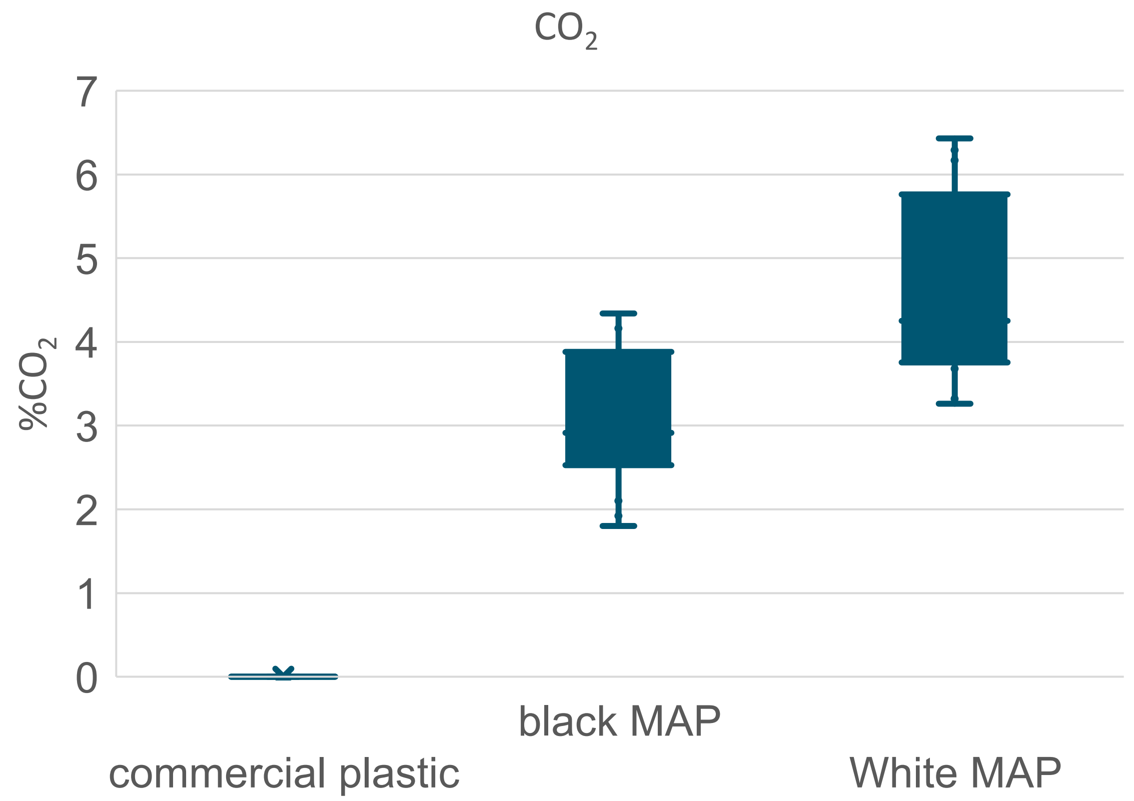
MAP (Mo… …Simulation

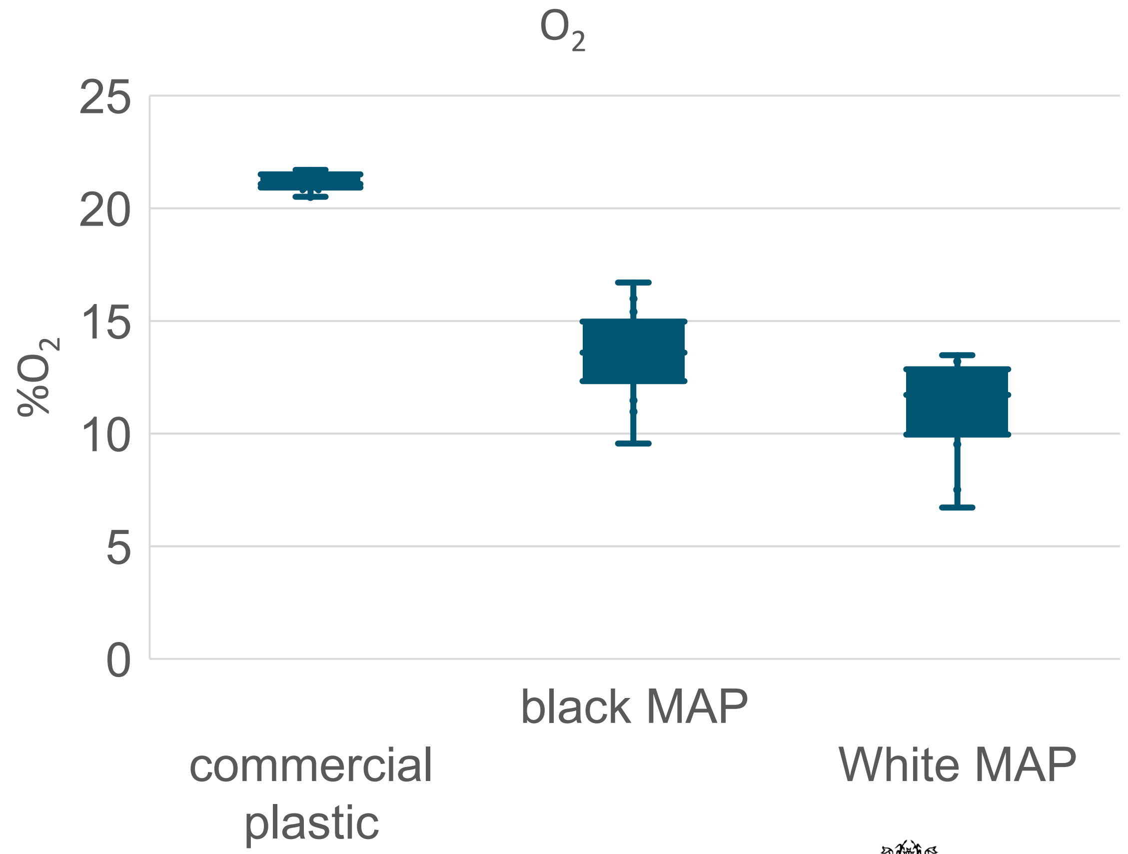
Extended…

Maintain…

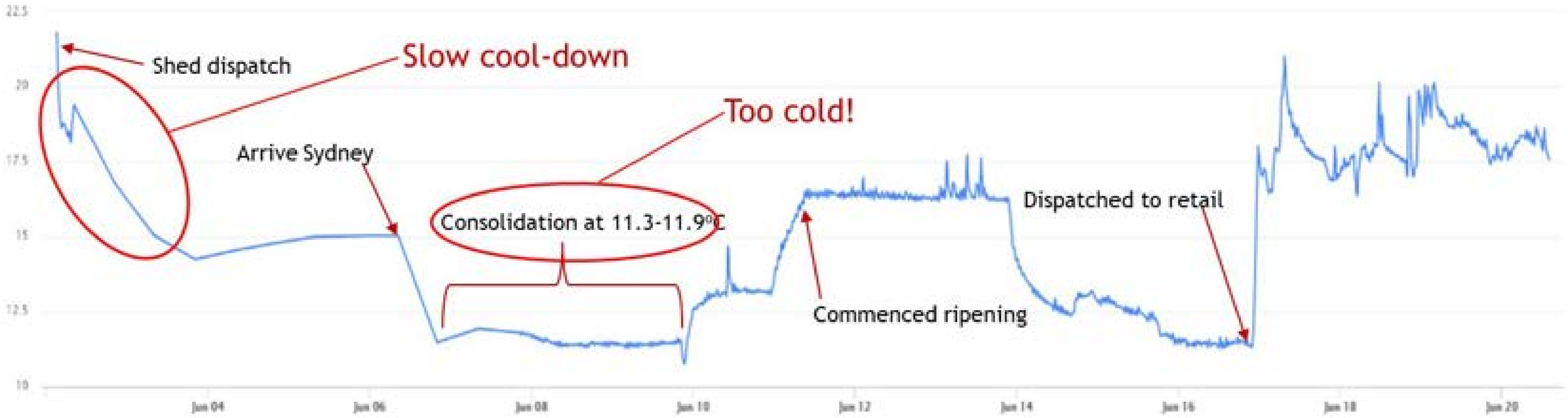
Help to c…

MAP (Modified Atmosphere Packaging) Sea Simulation

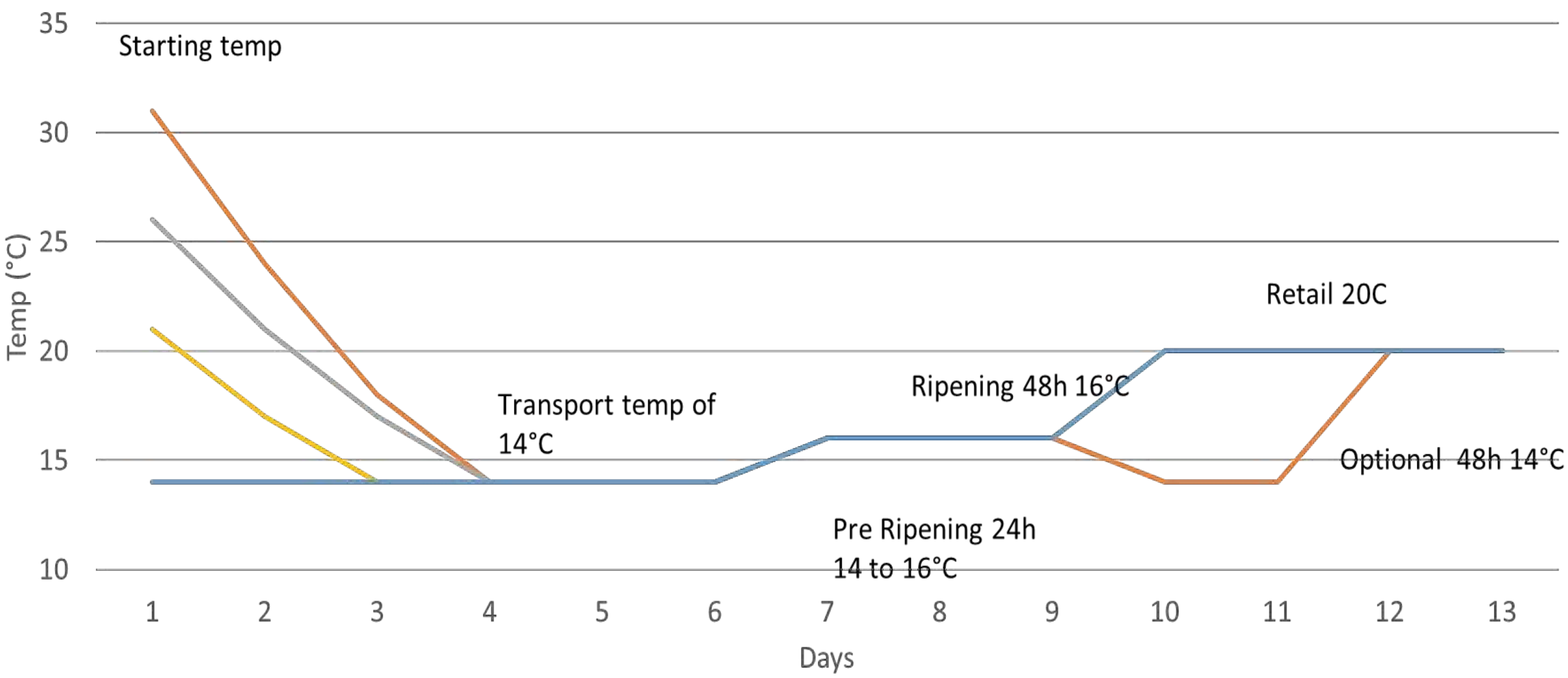




Field Heat Observed during Monitoring

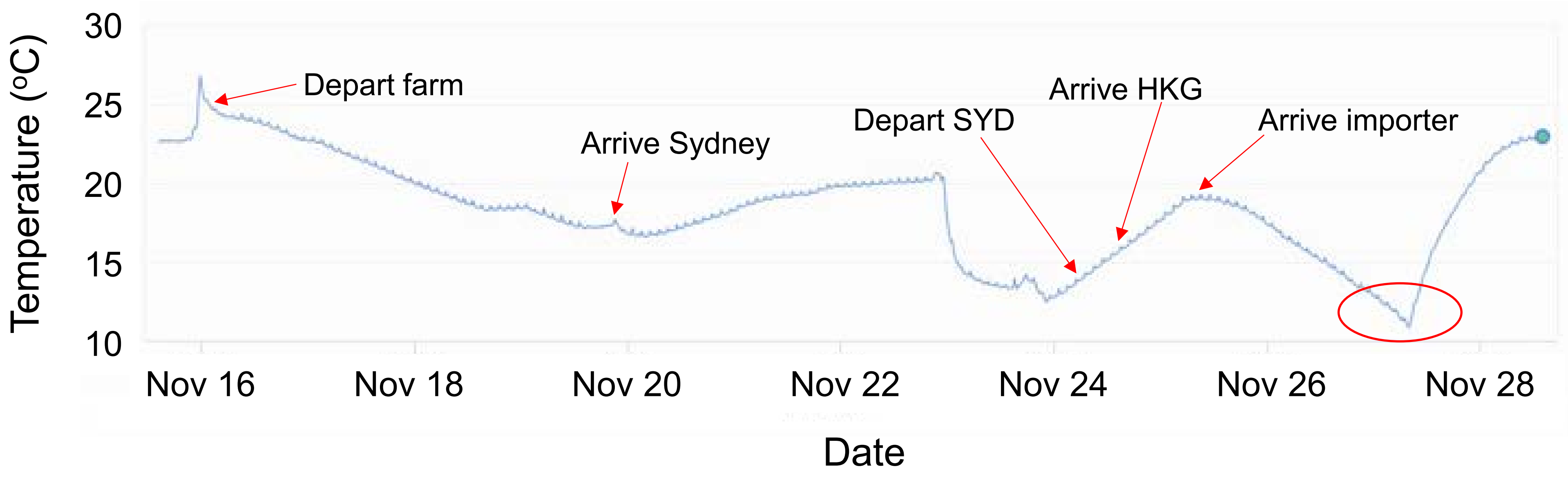


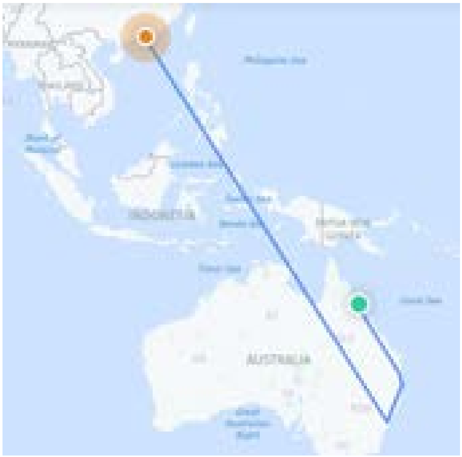
Field Heat Simulation



Implementing improved practice

- Identifying the shortest path to market
- Avoiding low storage temperatures





Implementing improved practice

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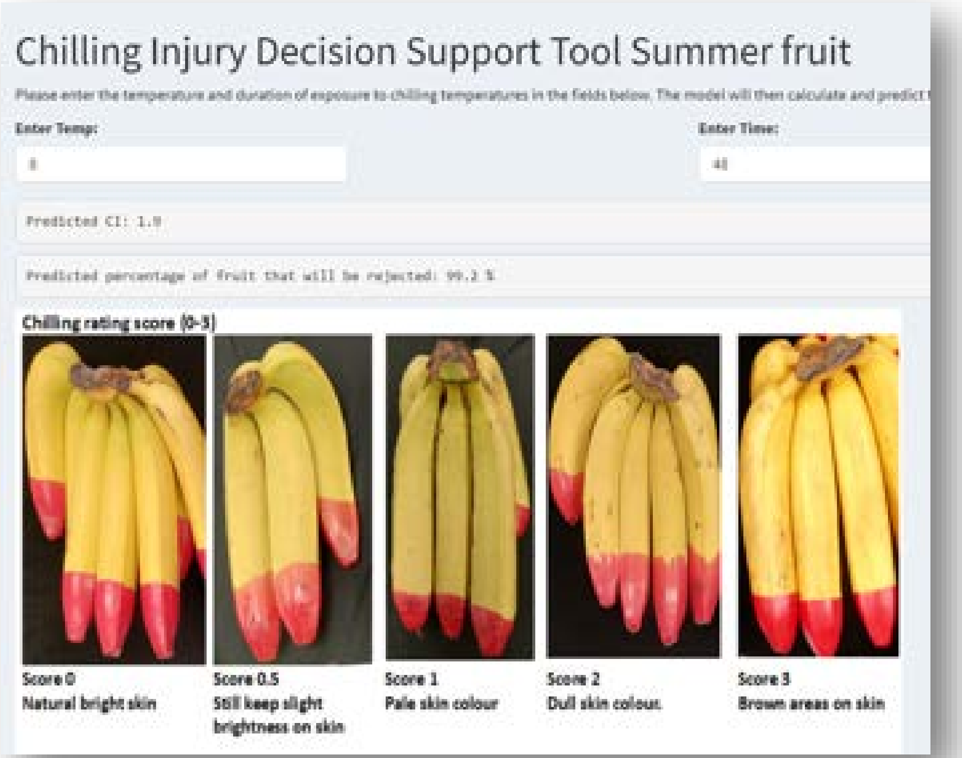
Broader industry resources

- Factsheets, case studies, decision support tool



Conclusions

- Monitor to improve quality outcomes
- Use the decision support tool to prioritise interventions
- Talk to your supply chain partners
- Build collaborative relationships

Acknowledgements

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- End Food Waste CRC

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Questions?

Thank you