Fresh on Demand, DP4: Optimization of the tropical fruit supply chain

Papaya 'Tainung', experiments 2022

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Preface

This is the final report of the four-year program Fresh on Demand, subproject 'Optimization of the tropical fruit supply chain'. The research in this sub-project aims at offering a higher proportion of high quality, ready-to-eat tropical fruit (papaya) to retailers and/or consumers, taking into account sustainability requirements. In this project a unique chance is provided to reach this goal, thanks to the project partnership which brings various experts together.

The results achieved are the outcome of a fruitful cooperation between the industry partners Agricola Famosa, Frankort & Koning B.V., PerfoTec B.V. and RipeLocker LLC and experts of Wageningen Food & Biobased Research (WFBR).

In the period 2019-2022 we have carried out a number of trials. In shipments from Brazil to the Netherlands (2019-2021) and in trials on site in Brazil (2022), new technologies were tested which are commercially available or will be launched on short term.

Furthermore, scientific innovations were achieved. Colour analysis and near-infrared spectroscopy (NIR) were being explored as objective and non-destructive techniques for evaluation of maturity and quality of papaya.

The project deliverables contribute to an increased understanding and optimisation of the tested postharvest technologies. We believe these meet the intended goals of this project and are a good basis for the further progress of postharvest practices with papayas.

I would like to thank the project partners from the industry and the WFBR research team for all the work that has been done. We had to overcome some challenges, such as the transport conditions which were not always under our control. A solution was found by starting trials on location near the production farm in Brazil. Also, travel restrictions due to COVID19 complicated the execution of trials .

I want to thank warmly everyone who has contributed to the success of this project. We have achieved very useful results that can certainly be built upon further.

Hans de Wild
Project Lead

Summary

This report describes the results of trials done in year 2022, the last year of the four-year program Fresh on Demand, subproject 'Optimization of the tropical fruit supply chain'. This sub-project aimed at maintaining a good quality for the consumer, while taking into account sustainability requirements. From this perspective, the transport of 'Tainung' papaya overseas instead of by air transport is relevant and brings both economic and environmental advantages. The challenge and goal is to maintain papaya quality as high as possible. The main points of attention for papaya quality are better control of the ripening, less water loss, and reduction of mould. To reach this, focus of the research is on two new technologies: Modified Atmosphere (MA) Packaging with liners based on a high precision laser perforation system (PerfoTec) and the use of managed-atmosphere chambers (RipeLocker).

First of all, two trials were done with these two technologies in Brazil (location Agricola Famosa) in the periods April-May 2022 and May-June 2022. As a reference, a hot-needle (HN) perforated flowpack for individual papayas was used (the current standard packaging). These two trials were guided on site by Wageningen FBR researchers. Overseas transport in reefer containers was simulated by storing papayas at 11°C for 33 and 30 days in the first and second trial, respectively. Storage was followed by a shelf-life of 3 days at 20°C.

Quality assessments were done after 0 and 3 days of shelf-life. The observed papaya quality after these simulated transports would not have been suitable for a commercial shipment, neither for the standard HN flowpack, nor for the tested technologies. Especially the amounts of *anthracnose* and other moulds were high. These high percentages are related to the production time of year and the long storage duration. Additionally, the relative humidity in the storage room was very high (mostly 95-100 % RH) compared to reefer settings for commercial sea transport (65 % RH).
Overall, there was no clear effect of the treatments (alternative technologies) on moulds. However, the advantage of both PerfoTec liners and RipeLocker chambers ('RipeLockers' in short) over HN-bags was found in reduced weight loss, decreased shrivelling and delayed colouring, leading to a fresher look, both after 0 and 3 days of shelf-life.
Papayas from RipeLockers showed a reddish translucent discolouration of the pulp (associated with softer fruit) that needed to be further investigated to better understand this phenomenon.

A third trial in November-December 2022 with RipeLockers was aimed at understanding the problem of reddish translucent tissue. Variation in papaya maturity stages and in RipeLocker settings led to valuable insights. The observed discoloration seems to be a sign of very advanced ripening, which was especially seen for fruits that were relatively ripe at harvest and were stored under conditions that enhanced ripening, e.g. temperatures above optimal and possibly ethylene accumulation as well.

For various other aspects, the trials contributed to a better understanding of both technologies to optimize practical application.

A main problem for papaya quality is *anthracnose*, the infection with which originates in the field. In practice, the mould pressure was compared to previous years due to new restrictions on fungicide use. *Anthracnose* infections may decrease in the drier season, but will remain a major concern. For successful commercial sea transport to Europe, a solution to reduce *anthracnose* seems is paramount.

The reported results and conclusions are valid for the papayas tested under the described circumstances.
For additional information about this report, see the publication colophon.

Abbreviations

HN-bag	Hot-needle bags (flowpack)
MA	Modified Atmosphere
RH	Relative Humidity
RL	RipeLocker
WFBR	Wageningen Food & Biobased Research

1 General introduction

The popularity of papaya (Carica Papaya L.) fruit in Europe is growing. Brazil is one of the largest producing countries and has Europe as an important export market. The 'Tainung' (Formosa) belongs to the most important varieties. It has a relatively long storage life compared to other varieties such as the 'Golden' variety. That is why transport by sea from Brazil to Europe is possible for 'Tainung', as long as the initial quality of the fruit is good enough. The transport of 'Tainung' papaya overseas, instead of by air, has economic and environmental advantages. However, quality must be maintained as high as possible. Controlling maturity, water loss, and reduction of moulds are of major importance to achieve this.

Within the four-year Fresh on Demand program (2019-2022), the subproject 'Optimization of the tropical fruit supply chain' aimed at good quality papayas for the consumer, taking into account sustainability requirements.

Looking for opportunities to optimize the postharvest chain for 'Tainung', this project started in 2019 with an assessment of already available knowledge and identification of the main postharvest problems for papaya 'Tainung' (*Find opportunities to optimize the postharvest chain for 'Tainung', H. de Wild; 2020*). These main problems are the following:

- Fungal diseases. Mainly *anthracnose* in the rainy growing season and stem-end rots *Fusarium* and *Alternaria* in the dry season.
- Skin damage. The highly sensitive fruit skin easily leads to damage that leads to cosmetic problems and susceptibility to fungal growth.
- Dehydration leading to shrivelling.
- Limited storage life of about 3 weeks, which is critical for overseas transport to Europe.

Chilling injury was not seen as a problem, transport temperature at a minimum of 10 °C is considered safe for the product.

The focus of this project was on two new technologies: Modified Atmosphere Packaging based on a high precision laser perforation system (PerfoTec) and the use of managed-atmosphere chambers (RipeLocker). With the PerfoTec technology, the film permeability can be adapted during packing via perforation adjusted according to fruit requirements. The permeability can be optimised based on the PerfoTec fast respiration meter that measures the product respiration rate and thus enables to respond to product and seasonal variations. Over the course of this project, a new biodegradable packaging became available as well, making it possible to achieve low O_2 while maintaining a sufficient permeability for water vapor. This packaging was used in the presently described trials.
The RipeLocker technology makes use of pallet-sized hypobaric storage chambers. The chamber system can precisely manage its internal atmosphere (pressure, humidity, oxygen) and is remotely-monitored.

The trials on-site in Brazil (2022) could be realized with both technologies thanks to the industrial partners in this project. In addition to PerfoTec B.V. and RipeLocker Inc., these were Agricola Famosa (producer and exporter, Brazil) and Frankort & Koning (importer, the Netherlands).

The use of hot-needle (HN) perforated bags for individual papayas had already been implemented to reduce dehydration and better protect the papayas from skin damage. These bags lead to higher humidity around the fruits, while O_2 and CO_2 are similar to the environment. MA packaging (PerfoTec) and atmosphere-managed chambers (RipeLocker) with reduced O_2 and increased CO_2 are interesting because of the expected additional effect on ripening inhibition. In addition, this potentially can also reduce mould growth and keep the skin firmer, resulting in better resistance to mechanical damage and extending storage and shelf-life.

Within Fresh on Demand (subproject 'Optimization of the tropical fruit supply chain'), a number of shipments with papaya 'Tainung' were realized from Brazil to the Netherlands in previous years (2019-2021). Unfortunately, the unstable chain conditions (especially with regard to temperature) hindered a conclusive evaluation of the technologies tested. Therefore, it was decided with all project partners to carry out on-site

trials in Brazil in 2022 under better controlled conditions. These trials were guided by Wageningen FBR researchers on site.
The scope and result details of the research are described in the report. For additional information about this report, see the colophon.

Finally, this study was carried out by Wageningen Food & Biobased Research, subsidised by stichting TKI Tuinbouw & Uitgangsmaterialen (Ministry of EZ) TKI number TU18098 and commissioned by Agricola Famosa, Frankort & Koning B.V., PerfoTec B.V. and RipeLocker LCC.

2 First trial PerfoTec liners and RipeLockers in Brazil (April-May 2022)

2.1 Introduction

The aim of this first test is to gain insight in the performance of the PerfoTec and Ripelocker technologies compared to the currently applied technology to preserve the quality of papayas throughout the chain. The research questions were:

- What is the effect of applying PerfoTec liners on the quality and shelf life of papayas during a simulation of a commercial shipment from Brazil to retail in Europe in comparison with standard HN-bags?
- What is the effect of transporting papayas in RipeLockers on the quality and shelf life of papayas during a simulation of a commercial shipment from Brazil to retail in Europe in comparison with standard HN-bags?

The first on-site trial was carried out in the period April-May 2022 in Brazil. For this purpose, papayas 'Tainung' were stored at Agricola Famosa (Northeast Brazil, Macacos farm) in HN-bags, PerfoTec liners and RipeLockers. The applied storage times and temperatures were a simulation of a commercial shipment between packaging at the farm to retail in Europe.

2.2 Methods/Design of the research and realized conditions

2.2.1 Material

Papayas 'Tainung' were harvested and selected at Agricola Famosa (Brazil) on 13 April 2022. Papayas were all from the same harvested batch and sorted by size in boxes containing 6, 7, 8, 9 or 11 fruits (corresponding to sizes 6, 7, 8, 9 and 11). Most of the fruit were size 8 and 9. Quality was classified as class I. The selected maturity was the Agricola Famosa's standard for export to Europe, with 1-2 yellow stripes. Papayas were stored overnight in a room with setpoint 10 °C as a minimum. Next morning, fruit temperature was 11.0 °C (Figure 1). All following activities were performed under these cooled conditions.

Figure 1. Temperature measurement of papayas (size 8) at start of the trial.

For the packaging in boxes (HN-bag and PerfoTec liner), fruit sizes '8' and '9' were used. Boxes were randomly divided over these two treatments. Boxes within each treatment are considered replicates. Papayas were packed individually in HN-bags using a flow-pack machine, and manually in PerfoTec liners (Figure 2). The amount of papayas packed in PerfoTec liners was 6 papayas (size 8) or 8 papayas (size 9). All boxes were labelled with a unique code and the total fruit weight per box was noted. Boxes were then randomly stacked on a pallet (Figure 3).

Filling of the 6 RipeLockers (coded as RL 1-6) was also done using fruit sizes '8' and '9' for later quality assessments. Other fruit sizes were added to fill the RipeLockers completely. For each RipeLocker, 10 individual fruit were numbered and weighed. The total number of fruit per RipeLocker was approximately 125 with a total estimated weight of 150 kg. Each papaya was packed in a foam net to protect against the edges of the trays. After closing the RipeLockers with their lids, the settings for O_2, CO_2 and pressure were done by RipeLocker LLC (RipeLocker confidential). Three sets of two RipeLocker settings were applied. RipeLockers with equal settings (such as RL1 and RL2) are considered replicates.

Six temperature loggers (LogTag TRIX-8, LogTag Recorders Ltd) were added to the boxes: 3 loggers were placed in random boxes outside the bags/liners, and 3 loggers were placed within the PerfoTec liners. In each RipeLocker 2 temperature loggers were added, 1 at the bottom layer and 1 at the top layer.
To register air temperature and relative humidity, 3 loggers (Escort RH iLog, www.cryopak.com) were placed in the storage room.
An overview of treatments is given in Table 1 and Figure 2.

Table 1 Overview of treatments.

	Description	**Total**
HN-bag	**Hot-needle, flowpack**	**22 boxes**
PerfoTec	**biodegradable liner, TV 20.000 40x30 30 mu**	**22 boxes**
RipeLocker	**Pressure, O_2 and CO_2 settings by RipeLocker LLC**	**6 RipeLockers (3 sets of 2 RipeLockers with equal setting)**

Figure 2. Photo left: box with HN-bags and with PerfoTec Liner. Right, RipeLocker before sealing.

For initial quality, samples of 8 fruit were measured on pulp firmness (hand penetrometer with 1.0 cm^2 plunger) and °Brix (hand refractometer). Pulp firmness of all fruit was higher than 13 kg (upper limit of the penetrometer). °Brix ranged from 8.0 to 13.0 with an average of 9.9.

2.2.2 Storage

The storage period was 33 days at a target temperature of minimum 10 °C (realized 11 °C). This period of 33 days is a simulation of the (maximum) total time between packaging at the farm and arrival at the final store in Europe. It is based on ± 24 days shipment from Brazil to the importer in the Netherlands (Frankort & Koning) + 6-7 days buffer-time at Frankort & Koning + 3 days via distribution centre to retail.
After 33 days of storage, papayas were transferred to simulated consumer shelf-life at 20 °C. For HN-bags and PerfoTec liners, two possible scenarios were tested in this shelf-life simulation: from half of the boxes the bags were removed, for the other half of the boxes the papayas remained in closed bags.

2.2.3 Realized conditions

Papayas were harvested on 13 April 2022 and transferred to a refrigerated storage room the same day. Papayas from the different treatments were stored for 33 days in this temperature-controlled room (Figure 3). The relative humidity (RH) in the room was not controlled. The realized air temperature was around 11 °C while the realized RH was high at 95-100% (Figure 4).

Figure 3. Position of the RipeLockers and pallet with boxes during 33 days of storage.

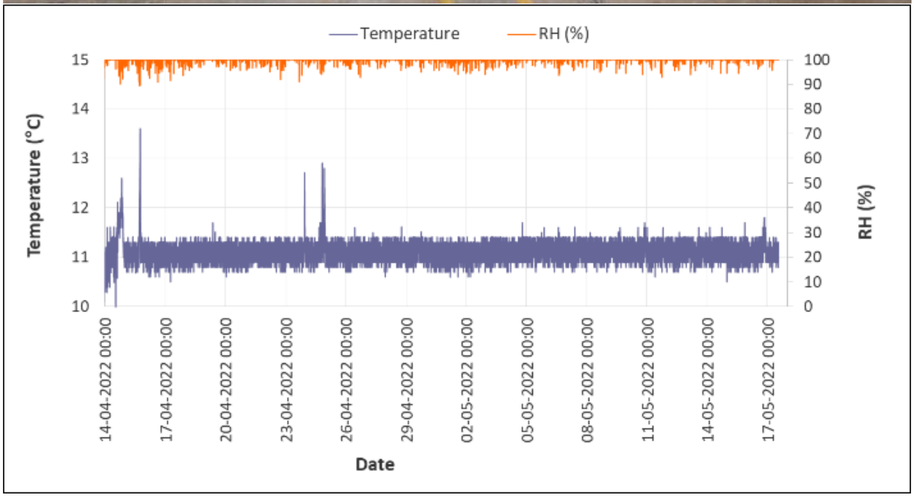

Figure 4. Room air temperature and RH during storage (logger placed on the lid of a RipeLocker).

During the storage period, the average air temperature in the RipeLockers was 0.9°C higher than room temperature and 0.6 °C higher than in the Perfotec liners. The average air temperature in the Perfotec liners was 0.3 °C higher than the room air (Table 2). Air temperature at different positions in the RipeLockers (bottom layer versus top layer) was similar. The temperature differences probably reflect the differences in removal of papaya respiratory heat due to differences in air circulation.

Table 2 Average temperatures during storage between 15 April – 16 May on various spots (LogTag data).

	Position	Average temperature (°C)
RipeLocker 1	Bottom layer	11.7
RipeLocker 1	Top layer	11.8
RipeLocker 2	Bottom layer	11.6
RipeLocker 2	Top layer	11.6
RipeLocker 3	Bottom layer	11.7
RipeLocker 3	Top layer	11.5
RipeLocker 4	Bottom layer	11.8
RipeLocker 4	Top layer	11.7
RipeLocker 5	Bottom layer	11.8
RipeLocker 5	Top layer	11.8
RipeLocker 6	Bottom layer	11.9
RipeLocker 6	Top layer	12.0
RipeLocker 4	Room air (on top of RipeLocker lid)	11.2
Box 6	Room air (outside liner)	11.0

	Position	Average temperature (°C)
Box 8	Room air (outside liner)	11.1
Box 12	Room air (outside liner)	11.2
Box 24	In PerfoTec liner	11.4
Box 30	In PerfoTec liner	11.4
Box 36	In PerfoTec linter	11.3

The air temperature in the liners and in the RipeLockers (Figure 5 upper and middle graph respectively) was clearly more stable than the surrounding air (bottom graph).

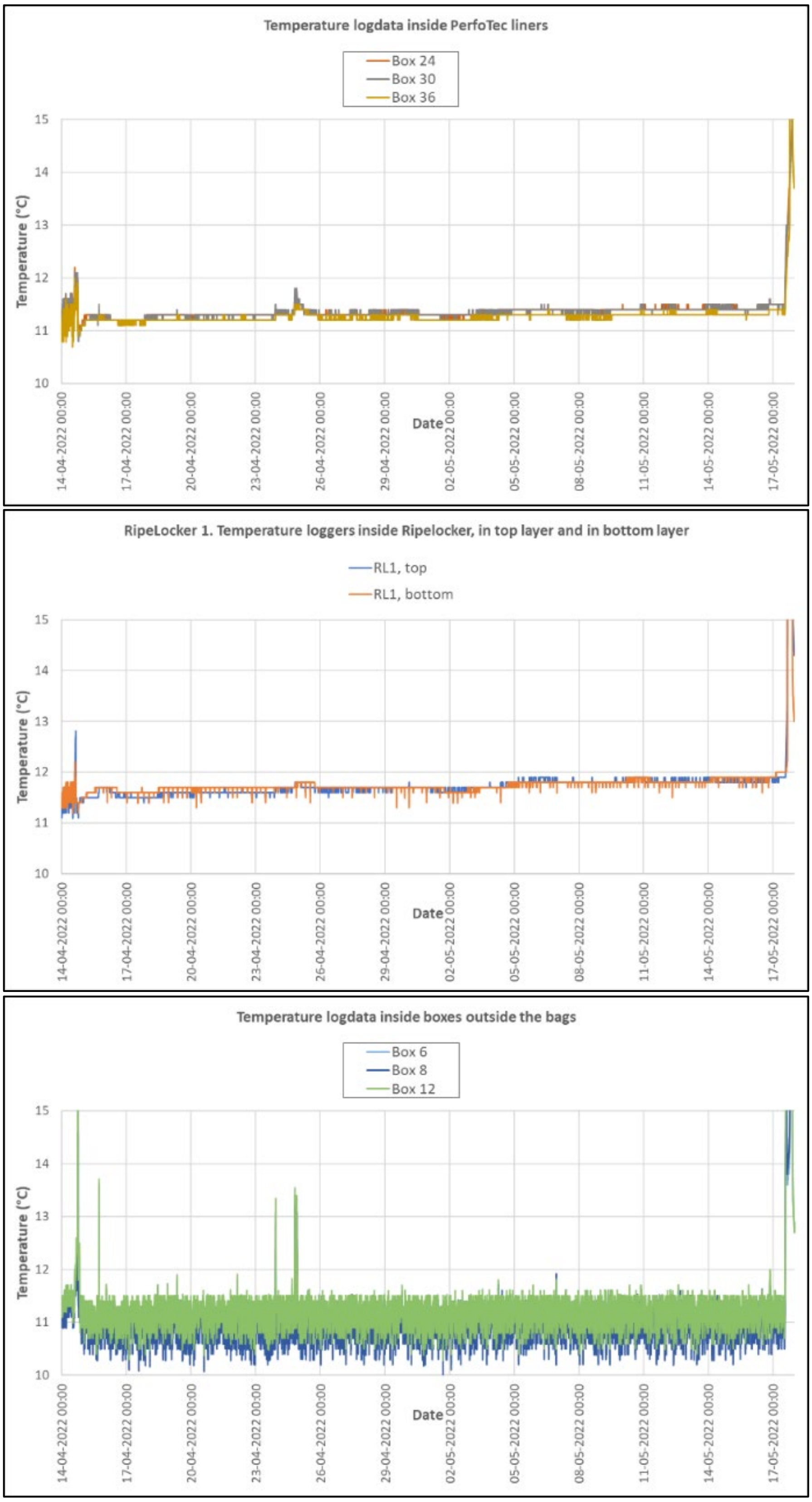

Figure 5. Air temperature during storage measured in liners (upper graph), in a RipeLocker (middle graph, RipeLocker 1 as an example) and of surrounding air (bottom graph).

After 25 days storage, a limited intermediate quality inspection was done by Agricola Famosa on 4 boxes (2 with HN-bags and 2 with PerfoTec liner). This timing corresponds to a realistic shipment time between Brazil and importer in the Netherlands.

After 32 days of storage, RipeLocker LLC started a venting program so that the RipeLockers were ready to be opened the next day (15.5 hours venting).

The main quality assessments took place after 33 days of storage and after 3 days subsequent shelf-life at 20 °C and 60-80% RH. Due to the high percentage of decayed fruit, it was decided to limit the shelf-life period to 3 days. Papayas that were initially intended for an evaluation after longer shelf-life (6 days) were now added to the assessments after 3 days shelf-life.

The realized timetable is summarized in Table 3.

Table 3   Realized timetable.

Date	**Activity**
13 April	Harvesting and sorting at Agricola Famosa, Brazil. Start of refrigerated storage (air temperature 11 °C, 95-100% RH)
14 April	Packaging at Agricola Famosa (HN-bags, PerfoTec liners) and filling RipeLockers
9 May	Intermediate inspection of few packages
16 May	Start of venting RipeLockers (15.5 hours venting time)
17 May	Quality assessments; transfer of remaining papayas from 11 to 20 °C
20 May	Quality assessments

2.2.4 Quality measurements

Papayas were scored individually on the parameters as shown in table 4.

Table 4 Measurement and methods used.

	Method / Classes
Weight loss (%)	Total fruit weight per box (MA) and weight of numbered fruits (RipeLocker) was measured with a balance (9094 Plus, Toledo Brazil).
Shrivelling (dehydration)	No = not clearly visible, Yes = clearly visible (commercially important)
°Brix	Juice squeezed by hand from a slice of papaya. Measured by optical refractometer (RHB-32ATC AKSO PRODUTOS ELECTRONICOS ltda, Brazil).
Firmness	Spot measurement of pulp firmness after cutting papaya in half. Handheld penetrometer (Model FT 327 QA Supplies, Brazil, with 1.0 cm^2 plunger).  ***Figure 6. Spot measurement of pulp firmness***
Skin colour	Visual: 1= 0-25% yellow; 2=25-50% yellow; 3>=50% yellow
Anthracnose	Yes/no. Resulting in % of fruits with a*nthracnose*.  ***Figure 7. Papaya with anthracnose.***
Mould and rot other than *anthracnose*: at stem-end, nose-end (= crown-end / bottom-end), fruit body	Score 0-3 for stem-end (0=no mould/rot; 1= slight, 2=moderate, 3=severe) Yes/No for other mould/rot, resulting in % of fruits with mould/rot.
Other disorders (with description/photo)	Yes/No. Resulting in % of fruits which show the disorder.

2.2.5 Statistical analyses

The data are expressed in mean values with error bars, corresponding to the 95% confidence interval.

PerfoTec and Ripelocker results are presented and discussed separately. The same reference/control data (Hot-needle flowpack bags) was used for both technologies result sections.

2.3 Results PerfoTec liner

2.3.1 Realized gas conditions

Intermediate gas analyses were done after 25 days of storage in two PerfoTec liners and two HN-flowpacks. Gas concentrations in the two measured PerfoTec liners were 11.2% O_2/8.6% CO_2 and 9.3% O_2/9.2% CO_2. Gas concentrations in both HN-bags were 20.9% O_2/0.0% CO_2, so equal to the surrounding atmosphere.

After 33 days of storage, gas analyses were carried out for all PerfoTec liners. After a subsequent period of 3 days shelf-life, gas analyses were carried out for the liners that had remained closed during this period. The data are shown in Table 5. Boxes of 'size 8' papayas had on average a lower weight but also a lower O_2 and higher CO_2 compared to 'size 9' papayas. This indicates a higher respiratory activity for the papayas of 'size 8'. Particularly for 'size 8' papayas, the gas conditions varied substantially between the boxes. During shelf-life, the % O_2 decreased and the % CO_2 increased, as can be expected at higher temperatures. Given the incidence of moulds (see later paragraphs), these data should be interpreted with care.

***Table 5** O_2 and CO_2 concentrations in PerfoTec liners after 33 days storage at 11 °C, and after 3 days shelf-life at 20 °C for the Perfotec liners that had remained closed. The upper half of the table shows results with 'size 8' papayas, the lower part of the table shows results of 'size 9' papayas.*

PerfoTec Liner Code	Size papaya	Number of papayas per box	Total start weight fruits (kg)	11 °C, 0 days shelf-life		20 °C, 3 days shelf-life	
				O_2 (%)	CO_2 (%)	O_2 (%)	CO_2 (%)
20	8	6	8.613	7.4	11.4		
21	8	6	8.853	16.1	4.9	8.2	12.3
22	8	6	7.638	11.8	8.3		
23	8	6	8.043	16.4	4.4	8.1	11.1
24	8	6	8.424	9.0	10.2		
26	8	6	8.273	10.0	9.5		
27	8	6	7.918	8.1	10.7	1.4	15.9
28	8	6	8.323	9.7	9.7		
29	8	6	7.638	9.5	9.6	1.1	15.3
30	8	6	8.674	12.0	8.0		
Means ± 95% CI			***8.24 ± 0.26***	***11.0 ± 1.9***	***8.7 ± 1.5***	***4.7 ± 3.9***	***13.7 ± 2.3***
31	9	8	8.533	16.1	4.8		
32	9	8	9.173	12.9	7.4	6.1	13.3
33	9	8	8.608	16.3	4.9		
34	9	8	8.198	13.0	7.2	8.8	13.7
35	9	8	8.363	13.0	7.4		
36	9	8	8.659	12.2	7.5		
37	9	8	8.823	18.6	2.5	7.0	12.6
38	9	8	8.818	13.0	7.4		
39	9	8	8.523	14.2	5.9	4.2	13.8
40	9	8	9.118	13.3	7.1		
Means ± 95% CI			***8.68 ± 0.31***	***14.3 ± 1.3***	***6.2 ± 1.0***	***6.5 ± 1.9***	***13.4 ± 0.5***

2.3.2 Intermediate quality inspection after 25 days storage

After 25 days storage, 2 boxes per treatment were inspected (the same boxes used for the gas condition measurements). Some fruits with *Anthracnose* and stem mould were found in both treatments. Due to the

small number of inspected fruits, differences between treatments were not clear. Overall, a*nthracnose* was found on 10% of the fruits inspected, stem mould was found on 24% of the fruits inspected.
There were no clear differences between treatments with respect to firmness (5.5 kg average) and °Brix (11.4 ° average). No internal disorders were found.
Shrivelling seemed less for papayas in PerfoTec liners (0% of the fruit) compared to HN-bags (18%). Papayas from PerfoTec liners were rated as greener (all score 2) compared to HN-Bags (most score 3). The difference in colour is shown in Figure 8.

Figure 8. Papayas after 25 days storage after removal of HN-bags (2 boxes left) and after opening of PerfoTec liners (2 boxes right).

2.3.3 General observations

After 33 days of storage, boxes with HN-bags and with PerfoTec liners were inspected. In some of the PerfoTec liners, moisture droplets were seen (Figure 9). These moisture droplets may be due to transpiration as result of the observed respiratory activity (as shown in table 5). This is strengthened by the fact that more droplets are visible after 3 days of shelf-life. It should also be noted that the RH in the storage room was high (95-100%). Possible water vapour transmission through the package is hereby reduced.
After an additional 3 days shelf-life at 20 °C (60-80% RH), most HN-bags and PerfoTec liners contained some moisture droplets. This strengthen the assumption that the water droplets are the results of fruit transpiration.

Figure 9. Box with HN-bags and PerfoTec liner after 33 days storage. Some water droplets are visible to the right of the knot of the PerfoTec liner.

2.3.4 Weight loss

There seemed to be less weight loss during storage in PerfoTec liners compared to HN-bags. This was also the case during the subsequent shelf-life, even for unbagged fruits (Table 6).

Table 6 Fruit weight loss (%) for the different treatments. Data represent means ± 95% CI (n = amount of boxes).

Bag type	**Average % weight loss in closed bags**		
	33 days period between packaging and start shelf-life	**During 3 days shelf-life (20 °C) unbagged**	**During 3 days shelf-life (20 °C) in closed bags**
HN-bag (flowpack)	4.7 ± 0.2 (n=16 boxes)	2.9 ± 0.2 (n=8 boxes)	1.2 ± 0.3 (n=7 boxes)
PerfoTec liner	1.5 ± 0.0 (n=20 boxes)	1.7 ± 0.2 (n=8 boxes)	0.6 ± 0.0 (n=7 boxes)

2.3.5 Quality

After 33 days of storage, there was a large variation in firmness between papayas, with no clear difference between HN-bags and PerfoTec liners (Table 7). The external colour also varied considerably, but papayas from PerfoTec liners seemed to be greener. Papayas from PerfoTec liners showed no signs of shrivelling, while most papayas from HN-bags showed shrivelling of commercial (negative) impact. This difference in colour and shrivelling created a fresher look for the papayas of Perfotec liners (Figure 10).

For all treatments, there was a high % of observed *anthracnose* and other moulds. This high percentage was related to the time of year, the long storage time and a strict judgement by trained eye experts (performed by Agricola Famosa). The percentage of fruits with mould/rot varied greatly between the boxes, and in general there was no clear effect of treatment (Table 7). However, rot seemed less pronounced (less visible, smaller lesions) for the PerfoTec treatments (Figure 11). Overall visual quality was the lowest for papayas from the HN bags that had been kept closed during the shelf-life period at 20 °C.

In all treatments, some fruits with browning on the skin were found.

Tasting some fruit from either treatment did not indicate off-flavour.

Table 7 Results of quality assessments for papayas after 33 days storage (0 days shelf-life) and after additional 3 days shelf-life. Data represent means ± 95% CI

Treatment	**Days shelf-life**	**Firmness (kg/cm^2)**	**Colour external (score 1-3)**	**Shrivel-ling (% fruits)**	**Stem-end mould/rot (score 1-3)**	**Nose-end mould/rot (% fruits)**	**Anthrac-nose (% fruits)**	**Other belly mould/rot (% fruits)**	*Data represent means ± 95% CI of:*
HN-bag	**0 days at 20 °C**	4.1 ± 0.4	2.1 ± 0.3	70 ± 48	1.7 ± 0.5	0 ± 0	63 ± 5	10 ± 12	*4 boxes [1]*
PerfoTec		4.4 ± 0.7	1.7 ± 0.2	0 ± 0	1.5 ± 0.3	11 ± 8	55 ± 20	54 ± 8	*4 boxes [2]*
HN-bag	**3 days at 20 °C without bags**	6.7 ± 1.7	2.5 ± 0.2	59 ± 21	2.9 ± 0.2	18 ± 9	100 ± 0	15 ± 13	*8 boxes [3]*
PerfoTec		5.5 ± 0.7	2.1 ± 0.2	0 ± 0	2.5 ± 0.3	34 ± 21	96 ± 8	17 ± 9	*8 boxes [4]*
HN-bag	**3 days at 20 °C with bags**	4.5 ± 0.6	2.5 ± 0.1	60 ± 15	2.8 ± 0.2	11 ± 12	82 ± 11	18 ± 11	*8 boxes [5]*
PerfoTec		4.6 ± 1.2	2.0 ± 0.2	0 ± 0	2.5 ± 0.4	34 ± 15	79 ± 16	20 ± 5	*8 boxes [6]*

[1] and [2] Total 28 fruits assessed on firmness, 28 fruits other assessments

[3] [4] [5] [6] Total 28 fruits assessed on firmness, 56 fruits other assessments

Figure 10   Papayas after 33 days storage (11 °C). Papayas were positioned with most yellow side up. Left 4 boxes: just after removing the HN-Bags. Right 4 boxes: just after opening the PerfoTec liners.

Figure 11   Papayas after 33 days storage (11 °C) + 3 days 20°C . Papayas were positioned with most yellow side up. From left to right:
PerfoTec +   : liners closed also during 3 days 20°C   (little yellow, decay less pronounced)
PerfoTec -   : liners open during 3 days 20°C   (little yellow, decay less pronounced)
HN Flowpack + : HN-bags during 3 days 20°C   (most yellow, decay most pronounced
HN Flowpack - : no HN-bags during 3 days 20°C   (intermediate yellow and decay)

2.4 Results RipeLockers

2.4.1 General observations

When removing the lids after 33 days storage, the interior of the RipeLockers turned out to be wet. There were water droplets on trays and fruits, throughout the RipeLockers. The general impression was that the lower layers were less wet. Papaya quality was clearly better for RipeLockers 1 and 2 (both with the same settings) compared to RipeLocker sets 3 and 4 (both with the same settings) and 5 and 6 (also both with the same settings). In total 3 RipeLocker settings were tested (for each set of settings 2 RipeLockers). The papayas of RipeLockers 1 and 2 were generally greenest with fewer moulds. Figure 12 gives an impression of these quality differences. Since the papayas of RipeLockers 1 and 2 were generally greenest and showed fewer moulds it was decided to focus further quality assessments on papayas of RipeLockers 1 and 2.

Figure 12. Papayas originating from RipeLockers 1, 2, 4 and 5 (3 boxes per RipeLocker) after 33 days storage. Papayas have been positioned with most yellow side up.

2.4.2 Weight loss

The weight loss of papayas during storage in RipeLockers seemed less compared to the reference HN-bag (Table 8). During the subsequent shelf-life, the weight loss for papayas of the RipeLockers seemed slightly less.

Table 8 Weight loss (%) for the different treatments. Data represent means ± 95% CI (n=amount). HN-flowpack data is the same as shown in Table 6.

Treatment	33 days period between packaging and start shelf-life	During 3 days shelf-life (20 °C) unbagged
HN-bag (flowpack)	4.7 ± 0.2 (n=16 boxes)	2.9 ± 0.2 (n= 8 boxes)
RipeLocker 1-2	0.9 ± 0.1 (n=2 RipeLockers [1])	2.5 ± 0.1 (n=2 RipeLockers [1])

[1] *10 fruits per RipeLocker were used for weight loss measurements*

2.4.3 Quality

Firmness varied greatly between individual fruits within each treatment, indicated by the large ± 95% Confidence Interval (Table 9). The average firmness of papayas from RipeLockers seemed lower than that of papayas from HN-bags on both assessment days. After 3 days shelf-life, the softest papayas from

RipeLockers were associated with a reddish discolouration of the pulp (Figure 13). About 80% of fruits originating from the RipeLocker showed this discolouration of the pulp which did not occur for the HN-bags. This discolouration could be due to localized stress and tissue rupture, leading either to leakage of cell contents into the cell wall matrix providing colour enhancement or to middle lamellae damage also leading to colour generation. Both would be able to cause reduced penetrometer values. The reddish discolouration was not observed after 0 days shelf-life.
On the other hand, dehydration (more for HN bags) could have contributed to higher firmness readings for the HN-bags. Dehydration could lead to more rubbery fruit and therefore more force is required when pressing the probe against the fruit fresh.

Directly after storage, the papayas taken from the RipeLockers seemed slightly greener on average and had a fresher appearance than papayas from HN-bags due to less shrivelling (Figure 14). After 3 days shelf-life, the yellowing was clearly advanced (Figure 15).

For all treatments, there was a high % of observed *anthracnose* and also other moulds. Also here, the high percentage was related to the time of year, the long storage time and a strict judgement by trained eye experts (performed by Agricola Famosa). It is remarkable that *anthracnose* seemed lower, while 'nose-end mould/rot' and other moulds on the fruit surface (='other belly mould/rot') seemed higher for papayas from RipeLocker chambers compared to HN-bags (Table 9).

Tasting some fruit from either treatment did not indicate off-flavour.

Table 9 Results of quality assessments for papayas after 33 days storage (0 days shelf-life) and after additional 3 days shelf-life. Data represent means ± 95% CI.

Treatment	Days shelf-life	Firmness (kg/cm^2)	Colour external (score 1-3)	Shrivel-ling (% fruits)	Stem-end mould/rot (score 1-3)	Nose-end mould/rot (% fruits)	Anthrac-nose (% fruits)	Other belly mould/rot (% fruits)	*Data represent means ± 95% CI of:*
HN-bag	**0 days at 20 °C**	4.1 ± 0.4	2.1 ± 0.3	70 ± 48	1.7 ± 0.5	0 ± 0	63 ± 5	10 ± 12	*4 boxes* [1]
RL 1-2		2.8 ± 1.2	1.9 ± 0.0	1 ± 1	1.5 ± 0.2	43 ± 23	36 ± 20	83 ± 9	*2 RipeLockers* [2]
HN-bag	**3 days at 20 °C unpacked**	6.7 ± 1.7	2.5 ± 0.2	59 ± 21	2.9 ± 0.2	18 ± 9	100 ± 0	15 ± 13	*8 boxes* [3]
RL 1-2		3.5 ± 1.6	2.7 ± 0.3	2 ± 0	2.4 ± 0.6	48 ± 4	83 ± 9	62 ± 2	*2 RipeLockers* [4]

[1] *Total 28 fruits assessed on firmness, 28 fruits other assessments*

[2] *Total 28 fruits assessed on firmness, 80 fruits other assessments*

[3] *Total 28 fruits assessed on firmness, 56 fruits other assessments*

[4] *Total 28 fruits assessed on firmness, 48 fruits other assessments*

Figure 13. Typical reddish discolouration of pulp, found in papayas of RipeLockers.

Figure 14. Papayas after 33 days storage (11 °C). Papayas were positioned with most yellow side up. Left 4 boxes: papayas originating from HN-Bags. Middle 4 boxes: RipeLocker 1. Right 4 boxes: RipeLocker 2.

Figure 15. Papayas after 33 days storage (11 °C) + 3 days 20 °C. Papayas were positioned with most yellow side up. Left 4 boxes: papayas originating from HN-Bags. Middle 4 boxes: RipeLocker 1. Right 4 boxes: RipeLocker 2.

2.5 First trial. Discussion and Conclusions

2.5.1 General

The papaya quality in this simulated transport would not have been suitable for a commercial shipment, neither for the standard HN-bag, nor for both tested technologies. Especially the amounts of *anthracnose* and other moulds were high. It should be noted that this trial was done during the rainy season and thus a challenging time of year regarding fungal pressure on the fields. Moreover, fruits with barely visible mould were also scored as 'mould', thanks to the well-trained eye of experts from Agricola Famosa. To what extent a small mould growth (for instance on the stem) is tolerated by the European importer is debatable. Also, the humidity in the storage room was very high (95-100%), much higher than the reefer setting for commercial sea transport (65% RH).

A main problem for papaya quality is *anthracnose*, the infection with which originates in the field. In practice, this situation has worsened compared to previous years due to new restrictions on fungicide use, such as the ban on the fungicide imazalil for the EU-market. *Anthracnose* infections may decrease in the drier season, but remain a major concern. This means that commercial sea transport to Europe, which took place in previous years, is uncertain to continue in the short term. In commercial practice, treatments such as alternative postharvest fungicides are being investigated to fight *Anthracnose*.

In this trial, a room storage temperature was realized around 11 °C. The average air temperature was higher inside the PerfoTec liners (± 0.3 °C higher) and inside the RipeLockers (± 0.6 °C higher). This can be attributed to the respiratory heat produced by the papayas, while the air exchange with the cooler room air is reduced by the closed liner and sealed RipeLocker. This also explains the smaller temperature fluctuations in liners and RipeLockers, compared to surrounding air. This information can be relevant for temperature settings in reefer containers.

2.5.2 PerfoTec liner

A high incidence of *anthracnose* and other moulds occurred both in HN-bags and in PerfoTec liners. *Anthracnose* is expected to be difficult to control in the postharvest phase. For other moulds, such as stem-end mould, they may be less of a problem in commercial shipments where RH can be better controlled (target 65% RH) than in our current trial. In earlier shipments within the 'Fresh on Demand' project, the incidence of mould was less of an issue, especially at arrival (0 days shelf-life).
The advantage of PerfoTec over HN-bags was seen in seemingly reduced weight loss, decreased shrivelling and delayed colouring, leading to a fresher look both at 0 and 3 days shelf-life. Interestingly, papayas from PerfoTec liners seemed to lose less weight compared to papayas from HN-bags even for unbagged papayas during the 3 days shelf-life.

The gas conditions achieved in this trial seem to be a good target for delayed colouring, i.e. in average about 13% O_2 and 7% CO_2 at the storage temperature of 11 °C.
Especially for 'size 8' papayas the gas conditions varied between the boxes. The variation between boxes is expected to decrease with a higher number of packed fruits. In that case, the influence of individual (deviating) fruit respiration on the total gas concentration will be less. In our trial, 'size 8' papayas had to be repacked from 8 per box (before packaging) to 6 per box as this was the maximum amount fitting in the liner. 'Size 9' papayas were repacked to 8 per box for the same reason. A larger liner bag would be needed to pack the normal amount per box, and will probably be beneficial also in reducing variation in gas concentrations.

2.5.3 RipeLockers

It turned out that the RipeLockers contained a lot of water droplets. This had not been seen in earlier trials within the 'Fresh on Demand' project. A high incidence of *anthracnose* and other moulds occurred in the HN-bags and RipeLockers. The moulds (other than *Anthracnose*) may be less in a commercial shipment when the humidity in the surrounding air can be better controlled (target 65% RH) than in our current trial (95-100% RH).

Anthracnose is expected to be difficult to control in the postharvest phase. A possible reduction in *anthracnose* by RipeLocker technology seemed indicated in this trial. Due to the large variation in fungal infestation, conclusions cannot be drawn though. However, the possible anthracnose reduction in the RipeLockers in this trial is in line with the early work on hypobaric storage of papaya where *anthracnose* development was suppressed (Alvarez 1980, Chau and Alvarez 1983). Given the great importance for the industry to combat *anthracnose*, the possible reducing effect of the RipeLocker technology on *anthracnose* is worth investigating further, perhaps in combination with other mitigation measures (hurdle technology).

Other positive effects observed by the RipeLocker technology compared to the reference HN-bags are the seemingly reduced weight loss and associated reduced shrivelling and a better retention of greener colour (at 0 days 20 °C). This confirms findings in earlier trials in this Fresh on Demand project.

For two quality aspects RipeLocker seemingly performed less than the reference HN-bags. That is the increase in moulds and the internal disorder. The increase in moulds is probably related to the very wet conditions (wet fruits) inside the RipeLockers which in turn can be related to the high RH in the surrounding room. This is different from commercial sea transport (reefer setting 65% RH). Therefore, it is likely an issue that can be solved. In earlier trials within this Fresh on Demand project, fruits arrived with only minor mould issues in the Netherlands following real sea transport.
The occurrence of the internal pulp discolouring and associated softening could be due to the release of pressure of the RipeLockers at the end of the storage period (venting protocol). Therefore, RipeLocker LLC is investigating improved settings for pressure reduction and pressure release of the RipeLockers.

3 Second trial PerfoTec liners and RipeLockers in Brazil (May-June 2022)

3.1 Introduction

Based on the results of the previous test a number of adjustments was done with the objective of improving the application of both technologies and hence gain more insight in the performance of the PerfoTec and Ripelocker technologies compared to the currently applied technology in preserving the quality of papayas throughout the chain. The research questions were:

- What is the effect of applying PerfoTec liners on the quality and shelf life of papayas harvest on another moment during a slightly shorter simulation of a commercial shipment from Brazil to retail in Europe in comparison with standard HN-bags?
- What is the effect of transporting papayas in RipeLockers on the quality and shelf life of papayas harvest on another moment during a slightly shorter simulation of a commercial shipment from Brazil to retail in Europe in comparison with standard HN-bags?

In the period May-June 2022 (expected end of the rain season), a second trial was carried out on site in Brazil. Papayas 'Tainung' were stored at Agricola Famosa (Northeast Brazil, Macacos farm) in HN-bags, PerfoTec liners and RipeLockers. The storage time was 30 days at 11 °C. This period is 3 days shorter than in the first trial, but is still a realistic scenario for the total time between packaging at the farm and arrival at the final store in Europe.

3.2 Methods/Design of the research and realized conditions

3.2.1 Materials

Papayas 'Tainung' were harvested and selected at Agricola Famosa (Brazil) on 18 May 2022. Papayas were all from the same harvested batch and sorted in boxes containing 5 fruits ('size 5'). Boxes are considered replicates. Quality was classified as class I. The selected maturity was the Agricola Famosa's standard for export to Europe, with 1-2 yellow stripes. Papayas were stored overnight in a room with setpoint 10 °C as a minimum. All following activities were performed under these cooled conditions. Boxes were randomly divided over the two treatments with HN-bags and PerfoTec liners. A flow-pack machine was used for the HN-bags, while papayas for PerfoTec liners were manually packed. The amount of papayas packed in PerfoTec liners was 3 per liner. All boxes were labelled with a unique code and the total fruit weight per box was noted. Boxes were then randomly stacked on a pallet.

The two RipeLockers (RL1 and RL2), with similar parameters applied, are considered replicates. They were filled with 60 fruits each with a total estimated weight of 142 kg. The top layer of trays was not filled with papayas but instead with water-absorbing paper. Papayas were covered by foam nets to protect against the edges of the trays. For each RipeLocker, 10 individual fruits were numbered and weighed. After closing the RipeLockers with their lids, settings for O_2, CO_2 and pressure were done by RipeLocker LLC (RipeLocker confidential).

Figure 16 gives an impression of the papayas at start of the trial. An overview of treatments is given in Table 9.

Samples of 8 fruits were measured on pulp firmness (hand penetrometer with 1.0 cm^2 plunger) and °Brix (hand refractometer). Pulp firmness of all fruits was higher than 13 kg (upper limit of the penetrometer). °Brix ranged from 9.0 to 11.4 with an average of 10.6.

 

Figure 16. Boxes with PerfoTec liners and a RipeLocker tray with papayas (before covering them in protective foam nets and loading in the RipeLocker).

Table 9 Overview of treatments in the 2nd trial

	Description	Total
HN-bag	**Hot-needle, flowpack**	**24 boxes**
PerfoTec	**biodegradable liner, TV 20.000 40x30 30 mu**	**24 boxes**
RipeLocker	**Pressure, O_2 and CO_2 settings by RipeLocker LLC**	**2 RipeLockers (with different settings)**

To register air temperature and relative humidity, two loggers (Escort RH iLog, www.cryopak.com) were placed in the storage room. One logger was placed on the lid of RipeLocker No. 2, the other logger was placed in one of the boxes in the stack on the pallet. NB: The number of loggers used in this trial was limited due to the lack of the docking station to reset available loggers. (WUR brought the docking station from the Netherlands, but the luggage with the docking station was lost during the flight to Brazil).

3.2.2 Storage

The storage time was 30 days at 11°C. After 30 days storage, papayas were transferred to simulated shelf-life at 20°C. The same storage temperature was chosen as in the first trial (setting minimum 10°C with 11°C realized) in order to eliminate the risk on chilling injury at lower temperature setting.
For HN-bags and PerfoTec liners, again two possible scenarios were tested for the final phase up to the consumer: After 30 days of storage, bags were removed from half of the boxes before being transferred to shelf-life simulation room at 20°C. The bags remained closed for the other half of the boxes during the shelf-life.
Due to a limited availability of papayas, the trial with RipeLockers was done this time with two RipeLocker chambers. Based on experiences in the first trial, measures were taken by RipeLocker LLC to eliminate the risk on water droplets and the pulp disorder issue encountered during quality assessment in the first trial.

3.2.3 Realized conditions

Papayas were harvested on 18 May 2022 and transferred to a refrigerated storage room the same day. Papayas of the different treatments were stored for 30 days in this temperature-controlled room at a realized average air temperature of 11.0 °C (Figure 17). The relative humidity in the room was not controlled and varied between 70 and 100%. It is remarkable that between 30 May and 13 June the temperature was slightly lower (10.8 °C average) and RH was clearly lower (average 82%). Both loggers in the room showed the same pattern (only data of 1 logger shown).

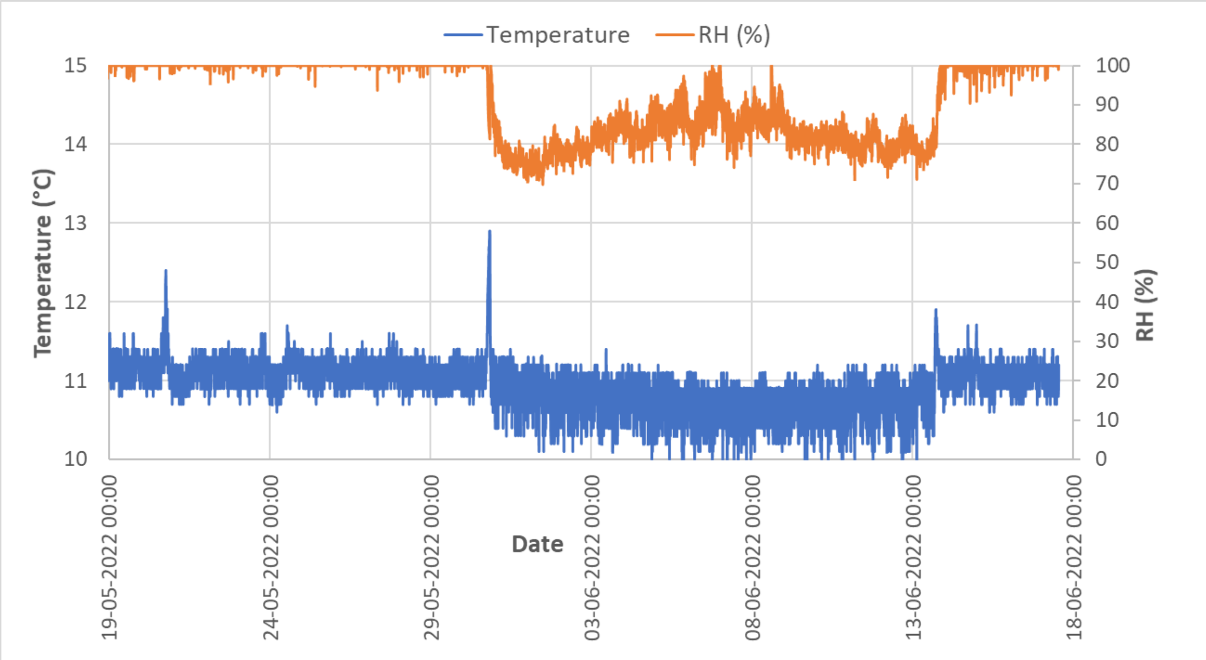

Figure 17. Room air temperature and RH during the storage period (logger placed on the lid of a RipeLocker).

After 29 days of storage, RipeLocker LLC started a venting program so that the RipeLockers were ready to be opened the next day (adjusted 24 hours venting protocol).
Quality assessments took place after 30 days of storage and after 3 days subsequent shelf-life at 20°C and a relative humidity between 60-80%.
Due to the high percentage of decayed fruit, it was decided to limit the shelf-life period to 3 days. Papayas that were initially intended for an evaluation after longer shelf-life (6 days) were now added to the assessments after 3 days shelf-life.

The realized timetable is summarized in Table 10.

Table 10. Realized timetable.

Date	Activity
18 May	Harvesting and sorting at Agricola Famosa, Brazil Start of refrigerated storage (air temperature 11 °C, 70-100% RH)
19 May	Packaging at Agricola Famosa (HN-bags, PerfoTec liners) and filling RipeLockers
19 June	Start of venting RipeLockers (20 hours venting time)
20 June	Quality assessments; transfer of remaining papayas from 11 to 20 °C
23 June	Quality assessments

3.2.4 Quality measurements

Measurements were done as described for the first trial (see paragraph 2.2.4), but stem-end mould/rot is now scored as ‘no’ if absent or ‘yes’ if observed for each fruit.

3.2.5 Statistical analyses

The data are expressed in mean values with error bars corresponding to the 95% confidence interval (95% CI).

PerfoTec and Ripelocker results are presented and discussed separately. The same reference/control data (Hot-needle flowpack bags) was used for both technologies result sections.

3.3 Results PerfoTec liner

3.3.1 Realized gas conditions

After 30 days of storage, gas analyses were carried out for all PerfoTec liners. Data for individual liners are shown in Table 11. Given the incidence of fungus (see later paragraphs), these data should be interpreted with care. The average O_2 and CO_2 was 12.2% and 7.1% respectively. After a subsequent period of 3 days shelf-life at 20 °C, gas analyses were carried out for the liners that had remained closed during this period. The average O_2 and CO_2 was 3.8% and 11.8% respectively.
The gas conditions in two HN-bags were also measured after 30 days of storage and subsequent 3 days shelf-life. These were 20.7 % O_2 and 0.1 % CO_2, so equal to the surrounding atmosphere as could be expected.

Table 11 O_2 and CO_2 concentrations in Perfotec liners after 30 days storage at 11 °C, and after 3 days shelf-life at 20°C for the Perfotec liners that had remained closed.

PerfoTec Linerbag	Total start weight fruits (kg)	11 °C, 0 days shelf-life		20 °C, 3 days shelf-life	
		O_2 (%)	CO_2 (%)	O_2 (%)	CO_2 (%)
25	7.185	11.9	7.3		
26	7.620	13.1	6.4		
27	7.270	6.9	9.7		
28	7.335	11.6	7.7		
29	7.045	12.0	7.5		
30	7.090	13.0	6.5		
31	6.975	14.0	6.1		
32	7.650	15.5	5.1		
33	7.005	11.9	7.3		
34	7.420	15.6	4.9		
35	7.225	13.4	6.6		
36	7.850	13.3	6.6		
37	7.275	11.3	7.9		
38	6.990	13.0	7.0		
39	6.790	7.4	9.3		
40	6.915	12.9	6.5		
41	7.435	14.7	5.6	4.4	12.2
42	7.375	14.3	5.9	8.0	9.3
43	7.555	12.2	7.5	3.1	13.4
44	7.370	10.3	8.5	2.1	12.7
45	7.080	11.6	7.6	2.3	12.6
46	6.720	9.9	8.0	1.4	11.8
47	7.210	10.3	8.2	2.7	11.6
48	7.185	11.7	7.2	6.6	10.6
Means ± 95% CI	***7.23 ± 0.11***	***12.2 ± 0.9***	***7.1 ± 0.5***	***3.8 ± 1.6***	***11.8 ± 0.9***

3.3.2 General observations

After 30 days of storage, the boxes with HN-bags and boxes with PerfoTec liners were inspected. In some of the PerfoTec liners, few small droplets of moisture were seen on the inner surface of the liner. These moisture droplets may be due to transpiration as result of the observed respiratory activity (as shown in table 11).
After an additional shelf-life period of 3 days at 20 °C (60-80% RH), all closed HN bags and PerfoTec liners contained some water droplets. Most probably also due to transpiration.

3.3.3 Weight loss

There seemed to be less fruit weight loss during storage in PerfoTec liners compared to HN-bags. This was also the case during subsequent shelf-life, even for unbagged fruits. (Table 12).

Table 12 Weight loss (%) for the different treatments. Data represent means ± 95% CI (n=amount).

Bag type	**Average % weight loss in closed bags**		
	30 days period between packaging and start shelf-life	**During 3 days shelf-life (20 °C) unbagged**	**During 3 days shelf-life (20 °C) in closed bags**
HN-bag (flowpack)	3.5 ± 0.2 (n=24 boxes)	1.5 ± 0.2 (n=8 boxes)	1.4 ± 0.2 (n=8 boxes)
PerfoTec liner	1.1 ± 0.1 (n=24 boxes)	0.9 ± 0.1 (n=8 boxes)	0.6 ± 0.1 (n=8 boxes)

3.3.4 Quality

Taking into account the large variation between boxes, there seemed to be no clear difference in °Brix and firmness between the treatments (Table 13). Papayas from PerfoTec liners seemed to be greener than papayas from HN-bags, a difference that remained during shelf-life. The greener fruit without shrivelling led to a fresher appearance for the papayas from the PerfoTec liners compared to HN-bags (Figure 18 and 19).

For all treatments, there was a high % of observed *anthracnose* and other moulds. This high percentage was related to the time of year (despite being the expected end of the rain season, there had been much rain fall), the long storage time and a strict judgement by trained eye experts (performed by Agricola Famosa). The percentage of fruits with mould/rot varied greatly between the boxes, and in general there seemed to be no clear effect of treatment (Table 13). The apparent decrease of some fungal species over time can be explained by mould becoming less visible (under drier conditions) or overgrown by *anthracnose*.

Tasting some fruit from either treatment did not indicate off-flavour.

Table 13 Results of quality assessments for papayas after 30 days storage (0 days shelf-life) and after additional 3 days shelf-life. Data represent means ± 95% CI for °Brix and firmness of 4 boxes and for other assessments of 8 boxes (3 papayas per box).

Treatment	**Days shelf-life**	**Brix (°)**	**Firmness (kg/cm^2)**	**Colour external (score 1-3)**	**Shrivel-ling (% fruits)**	**Stem-end mould/rot (% fruits)**	**Nose-end mould/rot (% fruits)**	**Anthrac-nose (% fruits)**	**Other belly mould/rot (% fruits)**
HN-bag	**0 days at 20 °C**	8.9 ± 1.1	9.7 ± 0.5	2.3 ± 0.3	75 ± 24	67 ± 0	50 ± 17	13 ± 17	21 ± 17
PerfoTec		10.4 ± 0.3	8.9 ± 1.8	1.3 ± 0.1	0 ± 0	58 ± 20	46 ± 21	25 ± 16	13 ± 12
HN-bag	**3 days at 20 °C without bags**	11.2 ± 0.5	6.9 ± 1.4	2.7 ± 0.2	79 ± 21	92 ± 11	0 ± 0	67 ± 17	0 ± 0
PerfoTec		11.0 ± 0.3	6.2 ± 0.7	1.7 ± 0.3	0 ± 0	96 ± 8	29 ± 26	100 ± 0	8 ± 16
HN-bag	**3 days at 20 °C with bags**	10.6 ± 0.4	7.4 ± 2.0	2.5 ± 0.2	83 ± 17	88 ± 17	4 ± 8	83 ± 12	4 ± 8
PerfoTec		10.9 ± 0.5	6.2 ± 1.5	1.3 ± 0.1	0 ± 0	100 ± 0	29 ± 19	100 ± 0	33 ± 28

Figure 18. Papayas after 30 days storage (11 °C). Left 2 boxes just after opening the PerfoTec liners. Right 2 boxes just after removing the HN-Bags.

Figure 19. Papayas after 30 days storage (11 °C) + 3 days 20 °C. From left to right: HN-bag was closed during shelf-life, PerfoTec liner was closed during shelf-life (just opened), PerfoTec opened before shelf-life, HN-bag opened before shelf-life.

3.4 Results RipeLockers

3.4.1 General observations

When removing the lids after 30 days storage, the interiors of the RipeLockers were inspected. The water-absorbing paper in the trays of the top layer felt a little damp. Small water droplets were visible on the inside of the lid, the inner wall of the chamber and on the trays. The fruits were free from moisture. (Figure 20).

Figure 20. Interior of RipeLocker (RL 2) just after opening and water-absorbing paper removed.

3.4.2 Weight loss

The weight loss of papayas during storage in RipeLockers was much less compared to the reference HN-bag (Table 14). During the subsequent shelf-life period, the weight loss was similar for the two treatments.

Table 14 Weight loss (%) for the different treatments. Data represent means ± 95% CI (n=amount).

Treatment	30 days period between packaging and start shelf-life	During 3 days shelf-life (20 °C) unbagged
HN-bag (flowpack)	3.5 ± 0.2 (n=24 boxes)	1.5 ± 0.2 (n= 8 boxes)
RipeLocker 1-2	0.5 ± 0.0 (n=2 RipeLockers [1])	1.4 ± 0.2 (n=2 RipeLockers [1])

[1] *10 fruits per RipeLocker were used for weight loss measurements*

3.4.3 Quality

After 30 days of storage, there was a large variation in firmness between papayas. Papayas from the RipeLockers were on average less firm than papayas from HN-bags (Table 15). This was also the case after 3 days shelf-life. The lower firmness may be related to the reddish discolouration of the pulp observed on the papayas from RipeLockers. This discolouration was somewhat visible after 0 days shelf-life and became more pronounced after 3 days shelf-life (Figure 21).
Papayas from RipeLockers were free of shrivelling and greener compared to papayas from HN-bags, leading to a fresher look. The difference in colour was more clear directly after 30 days storage (Figure 22).
Yellowing progressed during subsequent 3 days shelf-life (Figure 23).

For all treatments, there was a high % of observed *anthracnose* and also other moulds. No clear difference between the treatments was observed. This high percentage was related to the time of year, the long storage time and a strict judgement by trained eye expert (performed by Agricola Famosa). The percentage of fruits with mould/rot varied greatly, and in general there was no clear effect of treatment. The apparent decrease of some fungal species over time may be explained by mould becoming less visible (under drier conditions) or overgrown by *anthracnose*.

Tasting some fruit from either treatment did not indicate off-flavour.

Table 15 Results of quality assessments for papayas after 30 days storage (0 days shelf-life) and after additional 3 days shelf-life.

Treatment	Days shelf-life	Brix (°)	Firmness (kg/cm^2)	Colour external (score 1-3)	Shrivel-ling (% fruits)	Stem-end mould/rot (% fruits)	Nose-end mould/rot (% fruits)	Anthrac-nose (% fruits)	Other belly mould/rot (% fruits)
HN-bag	**0 days at 20 °C**	8.9 ± 1.1	9.7 ± 0.5	2.3 ± 0.3	75 ± 24	67 ± 0	50 ± 17	13 ± 17	21 ± 17
RL 1-2		10.7 ± 0.1	6.7 ± 1.1	1.4 ± 0.3	0 ± 0	83 ± 1	37 ± 18	11 ± 12	28 ± 10
HN-bag	**3 days at 20 °C unpacked**	11.2 ± 0.5	6.9 ± 1.4	2.7 ± 0.2	79 ± 21	92 ± 11	0 ± 0	67 ± 17	0 ± 0
RL 1-2		10.4 ± 0.1	5.1 ± 1.3	2.2 ± 0.2	0 ± 0	67 ± 24	35 ± 12	60 ± 4	8 ± 8

For HN-bag, the data represent means ± 95% CI for °Brix and firmness of 4 boxes and for other assessments of 8 boxes. For RL 1-2, the data represent means ± 95% CI for °Brix and firmness of 2 RipeLockers (assessed 12 papayas per RL) and for other assessments of 2 RipeLockers (assessed 24 papayas per RL).

Figure 21. Papayas cut longitudinally after 30 days storage (11 °C) + 3 days 20 °C. From left to right: papayas originating from HN-Bags, RipeLocker No. 1 and RipeLocker No. 2.

Figure 22 Papayas after 30 days storage (11 °C). From left to right: papayas originating from HN-Bags, RipeLocker No. 1 and RipeLocker No. 2.

Figure 23 Papayas after 30 days storage (11 °C) + 3 days 20 °C. From left to right: papayas originating from HN-Bags, from RipeLocker 1, from RipeLocker 2.

3.5 Second trial. Discussion and conclusions

3.5.1 General

In general, papaya quality after storage in this trial was better compared to the first trial (chapter 2). Perhaps the period of lower RH in the storage room contributed to this. However, the papaya quality in this simulated transport would not have been suitable for a commercial shipment, nor for the standard HN-bag neither for both tested technologies. It should be noted that the trials were done at a time of year which is not yet optimal (although it was the end of the expected rain season) and once again the humidity in the storage room has been higher than the reefer setting for commercial sea transport (65% RH). For successful commercial sea transport to Europe, a solution to reduce *anthracnose* seems to be needed in the first place.

3.5.2 PerfoTec liner

The advantage of the PerfoTec liners over HN-bags seemed confirmed: reduced weight loss, decreased shrivelling and delayed colouring. This led to a fresher look, both at 0 and 3 days shelf-life. As in the first trial, papayas from PerfoTec liners seemed to lose less weight compared to papayas from HN-bags, even for unbagged papayas during the 3 days shelf-life.
The gas conditions achieved in this trial seem to be a good target for delayed colouring, i.e. average 12.2% O_2 and 7.1% CO_2, at a storage temperature of 11 °C. This was in line with the first trial (12.7% O_2 – 7.5% CO_2). Keeping the papayas in the closed bags for 3 days at 20°C seemed to lead to higher CO_2 levels. However no adverse effects of this higher concentration were seen or tasted.
Three papayas of 'size 5' fitted in a liner. A bigger liner bag would be needed to pack the normal amount of 5 papayas per box.

3.5.3 RipeLockers

In this trial, there was no problem with excessive water droplets in the RipeLockers. Fruit was free of water droplets, while weight loss seemed limited and no shrivelling was visible. The difference with the first trial, in which the interior of RipeLockers was wet, may have several explanations: the larger fruit size (less water loss due to a smaller fruit surface-to-volume ratio), the presence of water-absorbing material (although it only felt slightly damp) and/or the period of lower RH in the storage room.

Positive effects by the RipeLocker technology compared to the reference HN-bags are the seemingly reduced weight loss and associated reduced shrivelling and a better retention of green colour (at 0 days 20 °C). Unlike the first trial, there seemed to be no clear treatment effect on *Anthracnose*. Moreover, there seemed to be no clear difference in mould incidence between both treatments (Ripelocker and HN-bags).

The occurrence of internal pulp discolouring (and associated softening) was less severe than in the first trial. It is not clear whether the changed venting time (24 hours instead of 15.5 hours) contributed to this. RipeLocker LLC is investigating settings for pressure build-up and pressure release of the RipeLockers. Papaya softening associated with rapid pressure changes has been previously reported (Chau and Alvares 1983). In addition, the same disorder issue was also observed in one of the previous trials within Fresh on Demand, when the pressure was accidently released very quickly. Hence these are indications that this problem is related to the pressure release settings by opening of the RipeLockers.

4 Third trial RipeLockers in Brazil (Oct-Dec 2022)

4.1 Introduction

Based on the results of the previous trials, modifications were made in RipeLocker pressure control and room temperature setpoint. Also two different fruit maturity stages were tested this time. The time between vacuum release and transfer to shelf-life conditions was increased. The objective of this trial is to test the possible performance improvement of these adjustments in the application of Ripelockers, compared to the currently applied technology in preserving the quality of papayas throughout the chain.

The research questions were:
- What is the effect of different RipeLocker settings on the quality and shelf life of papayas during a simulation of a commercial shipment from Brazil to retail in Europe in comparison with standard HN-bags?
- What is the effect of papaya's maturity stage at harvest on the quality and shelf life of papayas transported in RipeLockers during a simulation of a commercial shipment from Brazil to retail in Europe?

In the period October-December, a third trial with RipeLockers was carried out on site in Brazil. Papayas 'Tainung' were stored at Agricola Famosa (Brazil) in RipeLockers and in control boxes as references. The storage time was 35 days.

4.2 Methods/Design of the research and realized conditions

4.2.1 Materials

Papayas 'Tainung' were harvested and selected at Agricola Famosa (Brazil, Macacos farm) on 24 October 2022. Quality was classified as class I and all papayas were packed individually in protective foam nets. The papayas were cooled down to the target temperature of 10 °C (no data available) at the day of harvest. Papayas available for the trial were from two different maturities, indicated as 'standard' and 'ripe'. The 'standard' maturity is Agricola Famosa's standard for export to Europe, with 1-2 yellow stripes. Papayas with 'ripe' maturity were on average slightly more yellow than the standard. The standard maturity was supplied in one size (size 7), the ripe maturity was supplied in various sizes with most fruits of sizes 9 and 11 (Table 16).

The next day, 25 October, the papayas were transported in a refrigerated truck to the Flamengo farm, because a storage room for the trial was available at that site. The setpoint for the air temperature of this storage room was 10 °C. All following activities were performed in these rooms.
The next day (26 October) all papayas received a stem end treatment with a fungicide. Subsequently papayas (per size) were randomly divided over the different treatments. In all cases, papayas stayed packed in individual foam nets. This was different from the previous trials where control fruits were packed in HN-bags (flow-pack). In this trial this could not be realized because there was no flow-pack machine available at the farm.

Figure 24 gives an impression of the papayas at start of the trial. An overview of treatments is given in Table 16.

Figure 24. Pallet with boxes filled with control fruits (left) and a view inside a RipeLocker during loading (right).

Table 16 Overview of treatments in the 3th trial with RipeLockers.

	Description	Amount of fruits
Controls	**Fruits in foam nets. Each box with plastic inlet and covered with a paper sheet.**	**45 fruits 'standard', size 7** **21 fruits 'ripe', size 9** **24 fruits 'ripe', size 11** 3 fruits 'ripe size 7' (not included in quality assessments) 5 fruits 'ripe size 6' (not included in quality assessments)
RipeLocker	**Fruits in foam nets. Pressure, O_2 and CO_2 settings by RipeLocker LLC.**	**3 RipeLockers with settings 'wide' (RipeLocker confidential)** **3 RipeLockers wtih settings 'narrow' (RipeLocker confidential)** **Per RipeLocker (approximately):** **40 fruits 'standard', size 7** **25 fruits 'ripe', size 9** **25 fruits 'ripe', size 11** 5 fruits 'ripe size 8' (not included in quality assessments) 3 fruits 'ripe size 7' (not included in quality assessments) 6 fruits 'ripe size 6' (not included in quality assessments)

RipeLockers were filled with approximately 104 fruits each with a total estimated weight of 135 kg. For each RipeLocker, 10 individual fruits were numbered and weighed. The fruit temperature at time of fruit loading was 11.5 °C. After closing the RipeLockers with their lids, settings for O_2, CO_2 and pressure were done by RipeLocker LLC (RipeLocker confidential). Two sets of parameters were applied, 3 RipeLockers (3 replicates) with setting 'narrow span' and 3 RipeLockers (3 replicates) with setting 'wide span'. The terms narrow and wide span refer to fluctuations in pressure during the course of the trial, the exact settings are RipeLocker confidential.

The control boxes were labelled to indicate the papayas maturity and size. The weight of 15 fruits each for 'standard' (size 7), 'ripe' size 9 and 'ripe' size 11 were weighed. Boxes were then randomly stacked on a pallet.

To have an indication of the initial product quality, samples of fruits were measured on pulp firmness (hand penetrometer with 1.0 cm^2 plunger) and °Brix (hand refractometer). There appeared to be a large variation in both pulp firmness and °Brix, without clear differences between the maturities and sizes. (Table 17).

Table 17 Initial quality measurements of firmness (kg/cm^2) and °Brix on a limited amount of fruits. ** 12 is the maximum on scale*

Maturity	Size	# fruits	Firmness			°Brix		
			average	minimum	maximum*	average	minimum	maximum
Standard	7	5	9.0	4.2	12	15.9	12.4	16.4
Ripe	9	5	5.7	1.1	12	14.9	13.4	15.6

Ripe	11	5	11.6	10.2	12	14.9	14.4	17.0

To register temperature, 2 temperature loggers (LogTag TRIX-8, LogTag Recorders Ltd) were added to the pallet with boxes between the fruits. In each RipeLocker 2 temperature loggers were added, 1 at the bottom layer and 1 at the top layer. In addition, to register room air temperature, 2 temperature loggers were placed on the lid of the RipeLockers. To register relative humidity, one additional logger (Escort RH iLog, www.cryopak.com) was placed on top of a RipeLocker lid.

To achieve an air temperature of approximately 10 °C inside the RipeLockers, the room temperature was initially set to 9 °C. However, the temperature-control of the room appeared to be difficult, leading to temporarily higher temperatures up to approximately 14 °C (see 4.2.3).

After 35 days storage and again after 2 days shelf-life, quality was assessed on several fruits according to Table 18.

Table 18 Overview of assessments for each of the 7 objects (control boxes plus 6 RipeLockers).

Days shelf-life	**Maturity**	**Size**	**#fruits external** Colour Fungus Dehydration	**#fruits internal** Firmness °Brix Flesh translucency
0 days	Standard	7	±16	±10
	Ripe	9	±10	± 5
	Ripe	11	±10	± 5
2 days	Standard	7	±16	±10
	Ripe	9	±10	± 5
	Ripe	11	±10	± 5

4.2.2 Storage

The storage time was 35 days under cooled conditions, followed by 2 days at higher temperature to simulate shelf-life (see next section, "realized conditions").

4.2.3 Realized conditions

The papayas of the various treatments were stored for 35 days in the temperature-controlled room with an initial set point air temperature of 9°C. Over the course of the trial, corrections to the temperature setpoint were made. Unfortunately, the temperature in the room was unstable and rose to values up to 14°C after an electrical problem on the farm on 15th November. Despite several attempts to correct this, the room temperature remained relatively high during the rest of the storage period, with an average of 12.5°C between 15th November and 30th November. (Figure 25). The temperature inside the RipeLockers followed this trend (data not shown).
The relative humidity in the room was not controlled and varied during the storage period between 50% and 85% (Figure 25). The humidity in the RipeLockers during the storage period was not measured but was expected to have been near 100% given the enclosed chambers.

The temperature during the 2 days shelf-life period was also not well controlled, with a realization of approximately 16°C during the first day and 19°C during the second day. The RH was between 60-65%.

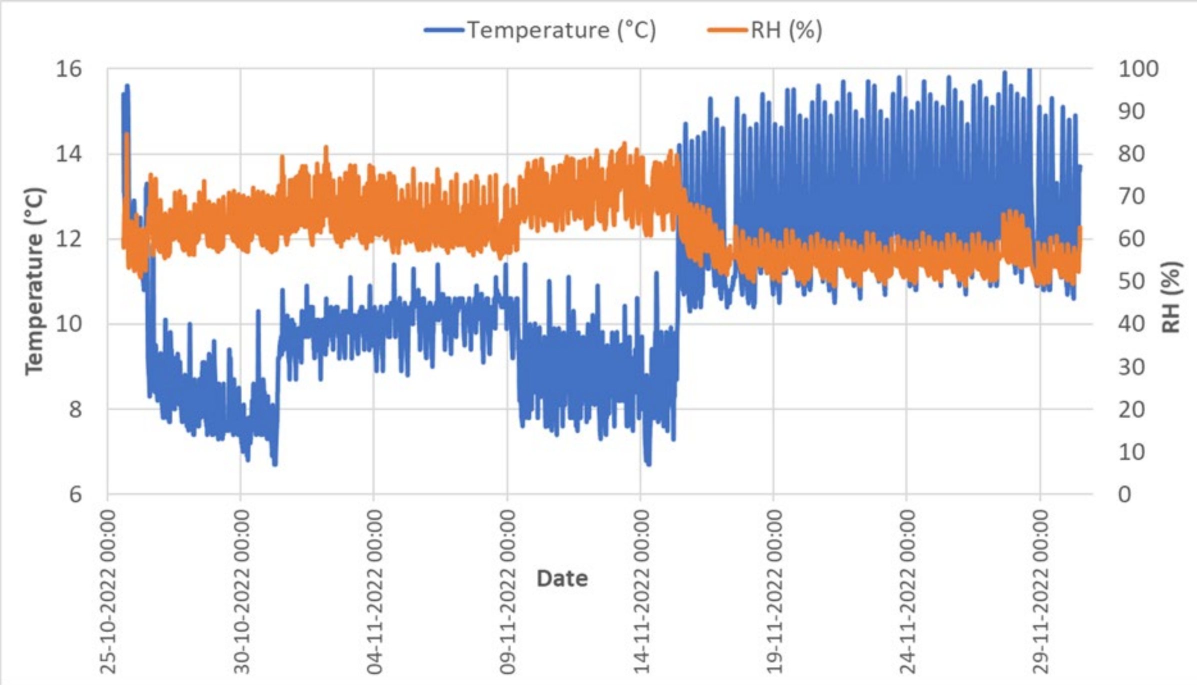

Figure 25. Room air temperature and RH during the storage period (logger placed on the lid of a RipeLocker).

The daily temperature inside the RipeLockers fluctuated less but was on average similar to the temperature in the storage room (data not shown).

After 34 days of storage, RipeLocker LLC started a venting program so that the RipeLockers were ready to be opened the next day (24 hours venting).
Quality assessments took place after 35 days of storage and after 2 days subsequent shelf-life at higher temperature (16°C during the first day and 19°C during the second day) and a relative humidity between 60-80%. Due to the high percentage of fruits with mould and flesh translucency, it was decided to limit the shelf-life period to 2 days.

The realized timetable is summarized in Table 19.

Table 19 Realized timetable.

Date	Activity
24 October 2022	Harvesting and sorting at Agricola Famosa (Macacos farm) Start of refrigerated storage
25 October 2022	Refrigerated transport to the Flamengo farm Continuation of refrigerated storage
26 October 2022	Filling boxes with control fruits and filling RipeLockers
29 November 2022	Start of venting RipeLockers (16 hours venting time + 8 hours to acclimate before opening)
30 November 2022	Quality assessments; slowly increasing room temperature for remaining papayas
2 December 2022	Quality assessments

4.2.4 Quality measurements

Papayas were scored individually on the parameters as shown in table 20.

Table 20 Measurement and methods used.

	Method / Classes
Weight loss (%)	Weight of individually numbered fruits was measured with a balance (provided by RipeLocker LCC).
Shrivelling (dehydration)	No = not clearly visible, Yes = clearly visible (commercially important)
°Brix	Juice squeezed by hand from a slice of papaya. Measured by digital refractometer (pocket refractometer, ATAGO).
Firmness	Spot measurement of pulp firmness after cutting papaya in half. Fruit Hardness Tester (Lutron FR-5120, automatic reading, with 1.0 cm plunger).  ***Figure 26. Fruit Hardness Tester with 1.0 cm plunger***
By Skin colour	Visual: 1= 0-25% yellow; 2=25-50% yellow; 3=>50% yellow
Flesh translucency	Yes/no. Resulting in % of fruits with flesh translucency.  ***Figure 27. Papaya cut longitudinally with flesh translucency (after 35 days storage)***
Mould (superficial): scored separately for stem-end, bottom-end (= nose-end / crown-end) and fruit body	Yes/No, resulting in % of fruits with mould on the stem-end, bottom-end and fruit body.
Decay (rot affecting the flesh)	Yes/No, resulting in % of fruits with decay.

4.2.5 Statistical analyses

The data are expressed in mean values with error bars corresponding to the 95% confidence interval (95% CI) and is presented in section 4.3.

4.3 Results

4.3.1 General observations

When removing the lids after 35 days storage, the interior of the RipeLockers was inspected. The lids were fully covered with water droplets and the fruits felt quite damp (see Figure 28). The temperature variations in the storage room may have contributed to this increased condensation.

Figure 28. Interior of a RipeLocker lid at opening with condensation droplets, and fruits with damp skin with mould growth (RipeLocker 2, upper layer).

4.3.2 Weight loss

The weight loss of papayas during storage in RipeLockers seemed significantly lower compared to the reference fruits kept in the control boxes (Table 21). During the subsequent shelf-life period, the weight loss seemed to remain lower by the papayas stored in the RipeLockers compared to the control boxes. When comparing the weight loss from day 0 (during transport) and day 2 (after 2 days shelf life) of each treatment, the amount of weight loss seemed similar for each treatment.

Regarding the maturity stage, there seemed to be no clear effect of the ripe and standard stage on the amount of weight loss. Also there seemed to be no effect of the narrow or wide span settings on weight loss.

Table 21 Weight loss (%), firmness and °brix for the different treatments. Data represent means ± 95% CI (n=amount), after 35 days storage (0 days shelf-life) and after additional 2 days shelf-life.

Days shelf-life	Treatment	Maturity and size	% weight loss avg ± 95% CI	Firmness (kg/cm^2) avg ± 95% CI	°Brix avg ± 95% CI
0	Control	Stand 7	5.7 ± 0.5 (n=15)	5.5 ± 2.5 (n=10)	12.6 ± 0.5 (n=10)
0	Control	Ripe 9	5.5 ± 0.4 (n=15)	2.9 ± 2.9 (n=5)	13.0 ± 0.6 (n=5)
0	Control	Ripe 11	5.8 ± 0.5 (n=15)	4.5 ± 5.7 (n=5)	12.8 ± 0.7 (n=5)
0	RL narrow	Stand 7	0.5 ± 0.2 (n=11)	7.8 ± 2.1 (n=30)	11.6 ± 0.3 (n=30)
0	RL narrow	Ripe 9	1.3 ± 0.2 (n=15)	4.7 ± 2.3 (n=15)	12.4 ± 0.4 (n=15)
0	RL narrow	Ripe 11	1.6 ± 0.3 (n=14)	8.4 ± 2.5 (n=15)	11.9 ± 0.6 (n=15)
0	RL wide	Stand 7	1.8 ± 0.3 (n=12)	7.7 ± 1.7 (n=30)	11.8 ± 0.3 (n=30)
0	RL wide	Ripe 9	1.5 ± 0.3 (n=15)	5.1 ± 2.7 (n=15)	12.5 ± 0.4 (n=15)
0	RL wide	Ripe 11	1.8 ± 0.4 (n=15)	7.5 ± 2.8 (n=15)	11.8 ± 0.4 (n=15)
2	Control	Stand 7	6.1 ± 0.5 (n=15)	3.4 ± 1.7 (n=10)	12.5 ± 0.3 (n=10)
2	Control	Ripe 9	5.9 ± 0.4 (n=14)	3.6 ± 3.6 (n=5)	12.7 ± 0.5 (n=5)
2	Control	Ripe 11	6.4 ± 0.5 (n=11)	2.8 ± 2.5 (n=5)	12.7 ± 0.6 (n=5)
2	RL narrow	Stand 7	2.5 ± 0.3 (n=12)	6.9 ± 1.7 (n=30)	11.5 ± 0.4 (n=30)
2	RL narrow	Ripe 9	2.0 ± 0.2 (n=15)	5.3 ± 2.4 (n=15)	11.7 ± 0.5 (n=15)
2	RL narrow	Ripe 11	2.6 ± 0.3 (n=15)	10.9 ± 2.8 (n=15)	10.9 ± 0.6 (n=15)
2	RL wide	Stand 7	2.5 ± 0.4 (n=12)	6.0 ± 1.8 (n=30)	11.5 ± 0.4 (n=30)
2	RL wide	Ripe 9	2.3 ± 0.3 (n=15)	5.9 ± 3.2 (n=15)	11.5 ± 0.6 (n=15)
2	RL wide	Ripe 11	2.8 ± 0.3 (n=15)	9.4 ± 3.2 (n=15)	11.6 ± 0.4 (n=15)

4.3.3 Quality

The average quality parameters for each treatment RipeLocker narrow and wide span and the control are summarised in table 22.

Table 22 Average % stem, bottom and belly mould ,% decay, % dehydration, firmness, °brix and % flesh translucency after 35 days storage (0 days shelf-life) and after additional 2 days shelf-life for each treatment (average between fruit maturity stage and size).

Time Point	Treatment	Count of Fruit #	Stem Mold (%)	Bottom Mold (%)	Belly Mold (%)	Decay (%)	Dehydration (%)	Count of Fruit #	Firmness (kg/cm2)	Brix (SSC)	Flesh Translucency (%)
Initial	Not relevant	23	0	0	0	0	0	23	9.2	15.3	0
Day 0	Control	35	17	0	0	11	57	20	4.6	12.8	35.0
Day 0	Narrow Span	104	75	97	92	14	0	60	7.2	11.9	25.0
Day 0	Wide Span	106	59	96	99	6	1	60	7.0	12.0	53.3
Day 2	Control	35	9	0	0	34	66	20	3.3	12.6	35.0
Day 2	Narrow Span	105	87	99	93	37	1	60	7.5	11.4	23.3
Day 2	Wide Span	103	81	98	97	27	17	60	6.8	11.5	53.3

The mould incidence after 35 days transport and after the shelf-life simulation, seemed higher in both RipeLockers treatments when compared with the control. On the opposite, much more dehydration (shrivelling) was observed in the control treatment than in the RipeLocker treatments. The same applied to the firmness, as the papayas kept in the Ripelockers seemed to be firmer than the controls, both at the end of the transport simulation as well as after the shelf life. It was interesting to note that the % decay (flesh rot) seemed to be similar for all treatment. It did however increase after the 2 days shelf life, as was expected.

After 35 days of storage, there seemed to be no clear differences in external colour between the treatments, on neither days (Figure 29 and photo on figure 30, after 2 days shelf-life). The colour development between 0 and 2 days of shelf-life was minimal.

As could be expected, the differences in brix level between the RipeLockers and the control seemed to be limited. Particularly compared to the decrease in brix level between the measurement done direct after harvest (level was 15.3 °Brix) and the ones carried out after the transport and shelf-life simulation.

Finally, the decrease in the firmness between harvest and after the 35 days transport simulation seemed more clear in the control papayas compared to in the papayas kept in the RipeLockers.

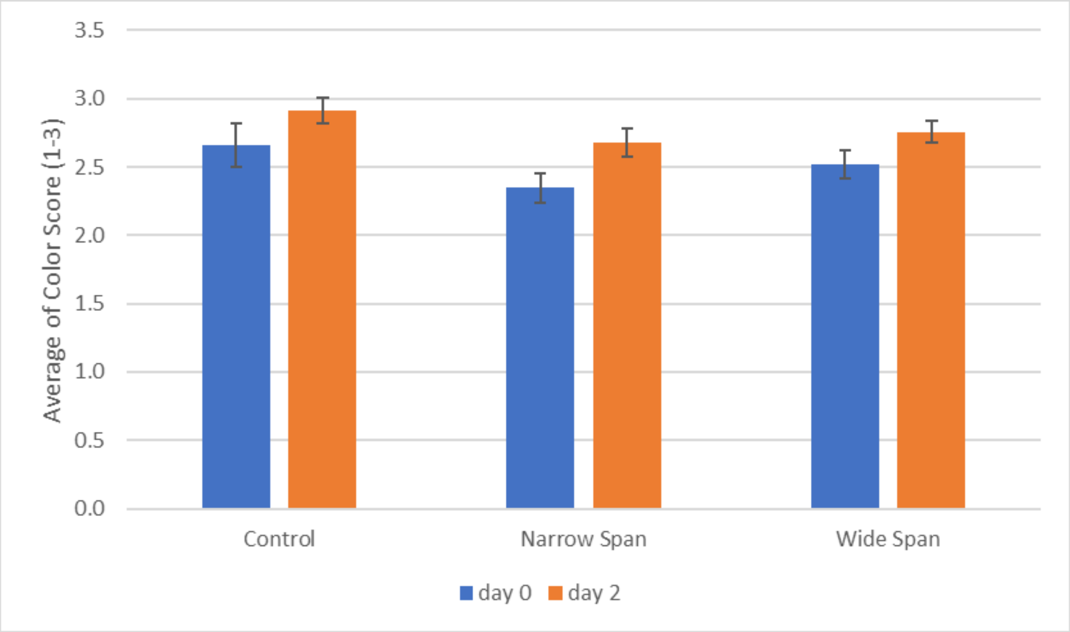

Figure 29. Average colour score ± 95% CI after 35 days storage 10-15 °C (day 0) and after 35 days storage + 2 days shelf-life (day 2).

In table 23, the results for colour, flesh translucency, mould for stem-end, bottom-end (= nose-end) and belly (fruit surface), decay (flesh rot), dehydration (shrivelling) are presented in more detail. Together with the detailed °Brix and firmness values presented in table 21, these two tables give insight in the papaya quality and interaction between the treatments.

Figure 30. Papayas after 35 days storage (10-15 °C) + 2 days shelf-life.
From left to right: RipeLockers No. 1, 2 and 3, Control, RipeLockers No. 4, 5 and 6.
From front to back row: 2 rows with Standard (size 7), 1 row with Ripe size 9 and last row with Ripe size 11.

The quality parameter % of fruits with translucency seemed to be affected by the RipeLockers settings: translucency seemed higher in the RipeLocker with wide span than narrow span, both at day 0 as well as after shelf life. Control and narrow span showed similar values. The % translucency did not increase over the shelf life. There seemed no clear effect of maturity stage in the fruits kept in the RipeLockers, neither after the transport simulation nor after the 2 days shelf life. However, in the control papayas there seemed to be more translucency in the riper fruits. A photo of the observed translucency is shown in figure 30.

Table 23 **Colour score, *% flesh translucency, %* stem, bottom and belly mould *,% decay and % dehydration after 35 days storage (0 days shelf-life) and after additional 2 days shelf-life.***

Days shelf-life	Treatment	Maturity and size	Count (# fruits)	Color Score (1-3) avg ± s.e.	% fruits with translucency	% Stem mold	% bottom mold	% belly mold	% decay	% dehy-dration
0	Control	Stand 7	16	2.8 ± 0.2	20	19	0	0	6	38
0	Control	Ripe 9	10	2.7 ± 0.3	60	0	0	0	20	80
0	Control	Ripe 11	9	2.4 ± 0.3	40	33	0	0	11	67
0	RL narrow	Stand 7	47	2.3 ± 0.2	30	77	100	89	15	0
0	RL narrow	Ripe 9	30	2.5 ± 0.2	20	83	97	100	20	0
0	RL narrow	Ripe 11	27	2.2 ± 0.2	20	63	93	89	7	0
0	RL wide	Stand 7	47	2.4 ± 0.2	53	53	98	100	2	0
0	RL wide	Ripe 9	29	2.7 ± 0.2	67	69	100	100	3	0
0	RL wide	Ripe 11	30	2.6 ± 0.2	40	60	90	97	13	3
2	Control	Stand 7	16	3.0 ± 0.0	20	6	0	0	38	69
2	Control	Ripe 9	10	2.7 ± 0.3	40	10	0	0	10	60
2	Control	Ripe 11	9	3.0 ± 0.0	60	11	0	0	56	67
2	RL narrow	Stand 7	48	2.7 ± 0.1	30	90	100	98	35	2
2	RL narrow	Ripe 9	30	2.9 ± 0.1	13	93	100	90	50	0
2	RL narrow	Ripe 11	27	2.4 ± 0.3	20	74	96	89	26	0
2	RL wide	Stand 7	48	2.8 ± 0.1	57	81	100	98	29	17
2	RL wide	Ripe 9	26	2.9 ± 0.1	47	92	100	96	27	12
2	RL wide	Ripe 11	29	2.7 ± 0.2	53	69	93	97	24	24

Regarding the % of decay, the lowest values were observed in the wide span settings but there was a large variation in the results. In addition, there seemed to be no clear effect of the maturity stage on the decay development. Except for the translucency %, the two different RipeLocker settings did not seem to have impact on the papaya quality.

Tasting some fruit from both controls and RipeLockers did not indicate off-flavour. In addition, the fruits from both controls and RipeLockers lacked a fresh taste and were judged as ‘towards senescent’.

Figure 31. Example of papayas with translucency in 4 out of 5 fruits.

4.4 Third trial RipeLockers. Discussion and conclusions

In accordance with earlier results, papayas from the RipeLockers seemed to be more firm on average and showed less shrivelling (dehydration) than papayas from the control treatment (kept in open boxes). On the other hand, the mould incidence after 35 days transport seemed higher in the papayas kept in the RipeLockers.
When opening the RipeLockers, moisture was dripping from the lid. Clearly indicating condensation and high Relative Humidity inside the chambers, leading to optimal conditions for mould development. To a certain extent, the temperature fluctuations in the storage cell may have induced extra condensation in the RipeLockers. The control fruit showed too much dehydration.

When cutting the papayas, translucency of the flesh was observed in this test. Also the control papayas showed several fruits with flesh translucency, meaning this phenomenon was not unique to the RipeLocker technology.
Nevertheless, there seemed to be more translucent papayas in the RipeLockers with wide span settings than in control and Ripelockers with narrow settings. This suggests that the technology has an effect on this disorder.

Moreover, in the control treatment there were more translucence fruits observed in the papayas of 'ripe' maturity at time of harvest. This indicates that the occurrence of translucency may be related to advanced (over)ripeness, also given the long storage time in combination with a temperature which was above optimal for about two weeks. However, there seemed to be no clear effect of maturity stage in the fruits kept in the RipeLockers, neither after the transport simulation nor after the 2 days shelf life. Once again this shows that there is an interaction between the RipeLocker technology and the development of this disorder.

The test was not carried out under optimal conditions due to the power failure. This issue probably had a larger impact on the fruits kept on the RipeLockers than on the control fruits. The sub-optimal conditions do give insight in the consequences of this kind of situations in future application.

5 General discussion and conclusion

The main points of attention for papaya quality are better control of the ripening, less water loss, and reduction of mould, particularly for the sea freight transportation of papaya from Brazil to the European market. Despite the mould growth issues, the results of the trials on site in Brazil carried out in 2022 seemed to show advantages of both Modified Atmosphere packaging (PerfoTec) and the use of hypobaric storage chambers (RipeLocker) relatively to the standard hot-needle packaging (reference).

The PerfoTec packaging seemed to reduce weight loss, decreased shrivelling and delayed colouring. This led to a fresher look, both after the transport and after 3 days shelf-life when compared with the papayas packed in hot-needle bags. The achieved gas conditions (average 12-13% O_2 and 7-8% CO_2) seem to be a good target for delayed colouring at a storage temperature of 11°C.
Keeping the papayas in the closed bags for 3 days at 20°C led to higher CO_2 levels. However no adverse effects of this higher concentration were seen or tasted.
Mould growth was a problem both in the PerfoTec as well as in the hot-needle reference packaging. The high microbiological load of the papayas upon harvest (to a large extent due to the weather conditions during the trials period) needs to be controlled to allow sea transport regardless of the technology applied during transport.
The positive and promising results of these trials give enough confidence now to plan pallet shipments in commercial transport. In this way this new application can be fully evaluated under practical conditions in commercial shipments.

Regarding the RipeLocker technology, the positive results compared to the hot-needle reference packaging are the seemingly reduced weight loss and associated reduced shrivelling and a better retention of green colour. Similar as described above, mould growth was a problem due to the high microbiological load of the papayas upon harvest (to a large extent due to the weather conditions during the trials period). However, the high Relative Humidity and moisture inside the RipeLockers aggravated the mould growth.
Some issues were observed in the application of the RipeLockers technology. The first one was the high moisture/condensation on the fruits and equipment, leading to excessive water droplets in the RipeLockers. The air circulation inside the chambers is limited and therefore the removal of papaya respiratory heat is less efficient when compared with papayas transported in boxes, stacked on a pallet. Higher temperatures and poor temperature control in the storage chamber, leading to temperature fluctuations might enhance the lower efficiency in removing respiratory heat and result in extra moisture/condensation in the RipeLockers. Moreover, these conditions stimulate the mould growth during transport.
The second issue is the occurrence of internal pulp disorders (reddish discolouration, translucency and associated softening). The reddish discolouration was only observed in the RipeLockers fruits and might be due to the venting settings (pressure release) applied upon opening the RipeLockers. The flesh translucency was also observed in the reference packaging. In addition, the % of flesh translucency differed between the two RipeLockers settings tested. This indicates that the disorder is not necessarily caused by the technology but the application of some specific settings increased the extension of the problem. The fact that riper papayas packed in the reference bags showed more translucency indicated that maturity (over ripening) may play a role in the disorder. This effect seems to be attenuated by the application of the pressure conditions in the RipeLockers, since there is no clear difference between the maturity stage and the observed amount of translucency.
During the course of this 4-year project, results have been obtained without the moisture/droplets issue or internal pulp disorders. This gives confidence that a solution can be found in future. Additional research is required to identify the optimal O_2, CO_2, and pressure settings before starting field tests in commercial shipments. RipeLocker LLC will investigate the settings for pressure build-up and pressure release of the RipeLockers.

A main problem for papaya quality is *anthracnose*, the infections with which originate in the field. In practice, this situation has worsened compared to previous years due to new restrictions on fungicide use. *Anthracnose* infections may decrease in the drier season, but remain a major concern. For successful commercial sea transport to Europe, first a solution to reduce *anthracnose* seems to be needed, regardless of the applied technology.

In conclusion, the success of PerfoTec (Modified Atmosphere packaging) or RipeLocker (hypobaric storage) depends on the quality at harvest, particularly regarding the microbial load and the risk for mould growth. If these conditions are controlled and met, both technologies show promise. Moreover, the current research has contributed to a better understanding of both technologies to optimize practical application.

6 References

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