Postharvest quality of different papaya cultivars

GreenCHAINge Vegetables & Fruits WP2
BO-29.03-001-010

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WAGENINGEN UNIVERSITY & RESEARCH

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Summary

The general objective in GreenCHAINge Vegetables & Fruits workpackage 2 (GreenCHAINge) is to obtain high quality and uniform melons and papayas on the shelf. This report focuses on the papayas, being one of the exotic products for the breeding company East-West Seed and enabling wholesaler Frankort & Koning to increase their market share of papayas in Europe. To obtain high quality and uniform papayas on the shelf in supermarkets, it is essential to transport papayas at optimal conditions.

For the European market, papayas are mainly transported from Brazil followed by Thailand and Ecuador (CBI 2018). Transport of papayas overseas takes approximately two to four weeks. Such long duration transport increases the challenge to obtain high quality papaya fruit on the shelf. European consumers have high demands, and appreciation for the papaya fruit will only increase in case of acceptable appearance, taste and smell. It is therefore essential to transport papayas at optimal conditions. To this end, within GreenCHAINge workpackage 2 we investigated postharvest quality of different papaya cultivars at a diverse range of circumstances: at different transport temperatures, after sea freight or after air freight, upon harvest at different maturity stages and upon storage at different time periods and temperatures. The first goal was to understand the traits which are important for post-harvest quality of papaya. Therefore we measured a range of traits such as weight, firmness, colour, Brix levels, respiration, ethylene production, mould growth and taste.

The aim of this study is to 1) study quality parameters related to shelf life and taste in order to optimize harvest stage, transport- and storage conditions, post-harvest treatments and allowing selection of cultivars suitable for long-distance transport to Europe, 2) investigate which treatments can reduce fungal infection and 3) study the taste profile of two well-known and one novel papaya cultivar.

We conclude that transport of papayas overseas, instead of by air transport, while maintaining quality levels, has both economic as well as environmental advantages. To maintain quality levels and increase consumer likeness it is important to take into account the effect of transport and storage temperatures, the harvesting stage and post-harvest treatments and finally the taste profile. This report summarizes the study, our observations and recommendations.

This document is the result of a study as part of GreenCHAINge Vegetables & Fruit workpackage 2. This study is executed from January 2015 till March 2019 by researchers of Wageningen Food & Biobased Research (WFBR), who performed an objective and independent study for East-West Seed and Frankort & Koning, who partly financed this project.
This report is confidential until November 2019 and intended only for East-West Seed, Frankort & Koning and WFBR. From November 2019 onwards the information is public.

1 Introduction

The worldwide commercial papaya (*Carica papaya* L.) production has met a significant increase during the last 50 years, in terms of yields and production volumes. Papaya is consumed fresh and is mainly produced in Asia and South America. Papaya produced in America account for over 37% of the worldwide production (Fuentes and Santamaría 2014, FAOSTAT 2018). After harvest, papayas are exported all over the world. Brazil and Mexico belong to the top 5 exporters of papaya. European imports of papaya have increased since 2013 to around 40 thousand tonnes in 2015 and 2016. In 2017, the volume reached 43 thousand tonnes, with a total value of € 103 million, indicating a growing interest for the papaya fruit in Europe (CBI 2018) and it is likely that future transport volumes of papaya to Europe will increase. It is therefore important to establish reliable transport practices to achieve high quality and good shelf life of papaya fruit.

Most papayas are transported to Europe by plane. Papayas are also transported per sea freight. Sea freight is cheaper, results in a lower carbon footprint and allows better temperature control compared to transportation by plane. However, sea transport from South America to Europe requires the ability to store papayas for prolonged periods of two to four weeks without quality losses. The challenge of storing papayas for prolonged periods lies in the fact that the fruits quickly soften after harvest due to the process of ripening. Fruit softening increases susceptibility to pathogen infection and mechanical damage, thereafter reducing the shelf life of the fruit (Jung Chen, Manenoi et al. 2007). It is therefore a challenge to pack and transport papayas while maintaining an acceptable shelf life. For most fruits, the quality is best when they are allowed to ripen on the plant (Kader 1999).

Growers and traders use peel colour to determine the ripening stage of the fruit. Depending on the cultivar, either the colour of the complete peel turns from green to yellow/red, or the colour changes gradually via so-called "yellow stripes" which appear on the green papaya peel. It is likely that loss of chlorophyll causes the production of carotenoids, lycopene and other pigments related to yellow and red peel colour, which in turn causes the peel colour to change (Aked 2002, Schweiggert, Steingass et al. 2011, Ong, Forney et al. 2013). Harvesting papaya at a stage in which the fruit is immature and firm, decreases the chance for mechanical damage and pathogen infection. However, harvesting at an immature stage results in either too immature or inadequately ripened fruits for the consumer. On the other hand, harvesting too late results in transport of mature and soft fruits and increases the chance of bad appearance, and thus quality loss due to mechanical damage. Bad appearance and inadequately ripened papayas increases postharvest losses and loss of consumer confidence, ultimately decreasing the value of papayas in the chain. Therefore it is important to find the optimal harvest moment to minimalize losses during transport and deliver papayas with good shelf life. Besides increased chances of mechanical damage during long distance sea transport, papayas are also subjected to various types of biotic and abiotic stresses which affect the ripening processes. In general, the temperature is kept as low as possible to decrease the metabolism of the fruits with a decreased ripening rate as a result. However, storage of fruits at too low temperatures can cause chilling injury. The optimal transport temperature for papaya depends on the ripening stage. Growers and traders determine the ripening stage of papayas based on the colour of the peel. Based on peel colour, recommendations for transport temperatures were proposed based on three classes: 1) 13°C for fruits with peel colour up to ¼ yellow, 2) 10°C for fruits with peel colour from ¼ to ½ yellow or 3) 7°C for fruits with peel colour is more than ½ yellow (Arpaia and Kader 1997). However, the recommended temperatures do not always hold, as different cultivars and growth conditions can lead to different outcomes.

Within GreenCHAINge workpackage 2, we aim to understand the behaviour of papaya fruits during transport and storage conditions. This to provide recommendations on the harvesting stage, post-harvest treatments and transport conditions suitable for sea freight of papayas.

The purpose of this research project on papayas in GreenCHAINge workpackage 2 is to obtain high quality and uniform papayas on the shelf. The main research questions are:

- What are the main quality traits to select papaya cultivars amenable for transport to the European market?
- What is the optimal harvest stage for sea-transport to Europe?
- What are the most effective post-harvest treatments to obtain high quality papayas upon arrival in Europe?
- Which treatments can reduce fungal infection on papayas?
- What is the taste profile of papayas after transport to Europe?

The main hypothesis is that optimised harvest moments, post-harvest treatments, transport- and storage conditions can increase quality and uniformity of papayas on the shelf. Improved appearance and taste of transported papayas will increase papaya appreciation by the European consumer, thereby increasing consumption of papayas. Moreover, improved quality of papayas at the end of the chain (at consumer stage) will decrease postharvest losses and increase the economic value of the papaya chain.

In this project, a range of quality traits is measured on several papaya cultivars harvested at different maturity stages and transported at different conditions. The results show that there is a potential to improve the intrinsic quality of papayas on the shelf by optimization storage temperature and by taking into account the effect of the harvesting stage on the quality. Furthermore, our results show that proper post-harvest treatments are essential, not only for quality in general, but also to reduce mould infection. Finally, the taste profile of three different cultivars indicate that selection for papaya cultivars with specific traits related to taste is crucial for consumer appreciation for papaya.

2 Postharvest quality

2.1 Introduction and objective

To determine which quality parameters are important for the papaya postharvest chain, several quality measurements were conducted to gain experience and understanding of the papaya fruit physiology. Thereafter, we investigated 1) which of the chosen cultivars is the most suitable for sea transport to Europe, 2) which maturity stage (green or mature) is the best to harvest papayas for export to Europe and 3) which of the following three postharvest treatments (T0; no treatment, T1: washing + fungicide treatment and T2: washing + fungicide + wax treatment) is the best to obtain high quality papayas on the shelf in Europe.

2.2 Material and Methods

2.2.1 Plant material and research approach for post sea or air freight test

Papaya fruits (*Carica papaya* L.) cv. Tainung No. 1 were grown at Agricola Famosa (Rio Grande do Norte, RN, Brazil). Papayas were harvested and shipped at the following periods and transport methods:

a) August 2015, transport by sea freight,
b) May 2016, transport by air freight and
c) December 2016, transport by sea freight.

Transport temperatures varied depending on the experiment between 10 and 13°C. Shipments were transported to Frankort & Koning (Venlo, the Netherlands), from where the papayas were transported by road to Wageningen Food & Biobased Research (WFBR, Wageningen, the Netherlands). Papayas transported by sea fright at August 2015 were either stored for 5 days at 18°C or 13 days at 10°C. Quality measurements were done at various time points during this storage (Figure 2.1a). Papayas transported by air freight (May 2016) were stored for 6 days at 10 or 15°C followed by a period of 9 days at 22°C (Figure 2.1b). Papayas transported by sea freight (Dec 2016) were transported at two different temperatures with an average of 10.5 or 12.6°C followed by storage for 7 days at 22°C (Figure 2.1c).

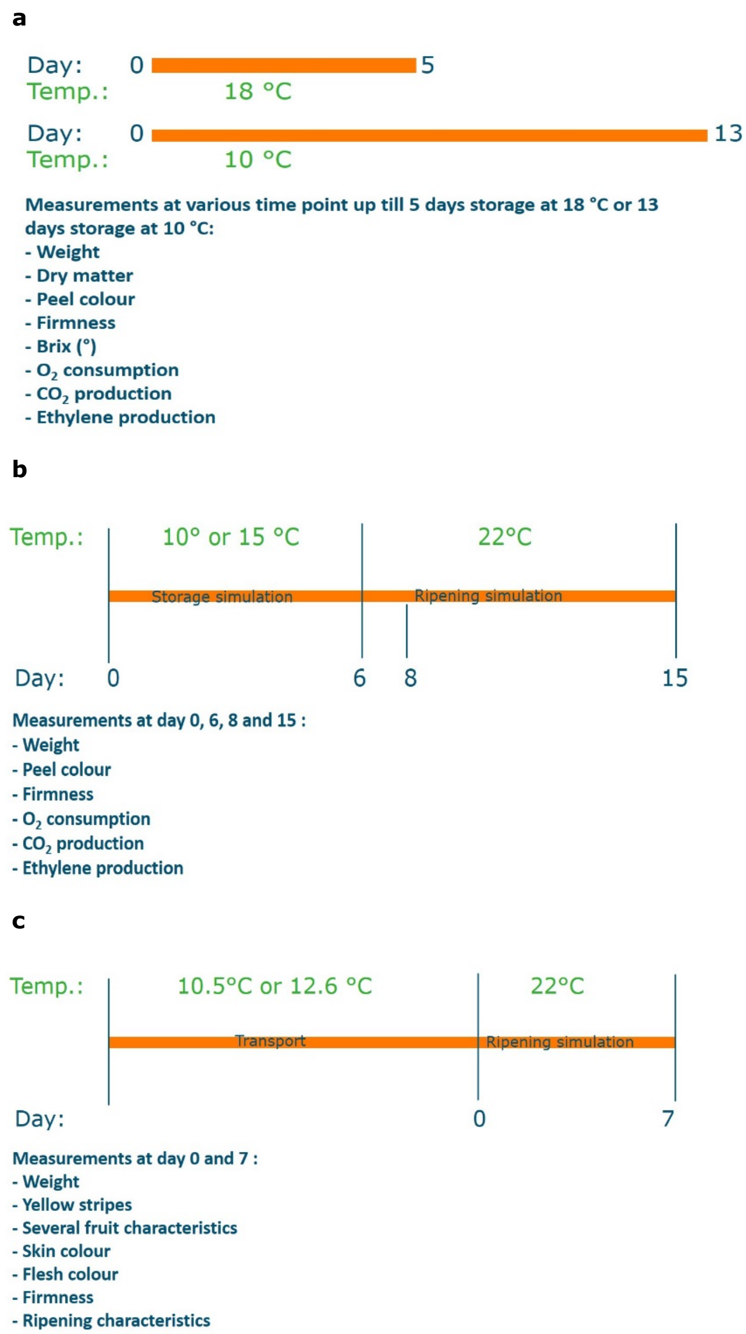

Figure 2.1: Research approach for testing papaya quality after sea transport in August 2015(a), after air transport May 2016(b), and after sea transport in December 2016(c).

2.2.2. Plant material and research approach for testing different cultivars, maturity stages and post-harvest treatments

Papaya fruits (*Carica papaya* L.) cv. Tainung, Bela Nova and Maradona were grown at Agricola Famosa (RN, Brazil). For comparison purposes, the Tainung variety is cultivated both at the same location as Bela Nova, called Tainung (BN) and at the same location as Maradona, called Tainung (M). Papayas were harvested, classified into green versus mature and either "not treated" (T0), treated by washing plus fungicide (T1) or by "washing plus fungicide plus adding a wax layer" (T2). All papayas were transported at commercial transport temperature of 12°C to Frankort & Koning (Venlo, the Netherlands), from where the papayas were transported by road to Wageningen Food & Biobased Research (WFBR, Wageningen, the Netherlands). Papayas were stored for 7 days at 10°C followed by a period of 8 days at 22°C. The research approach including measurement days and methods, is shown in Figure 2.2.

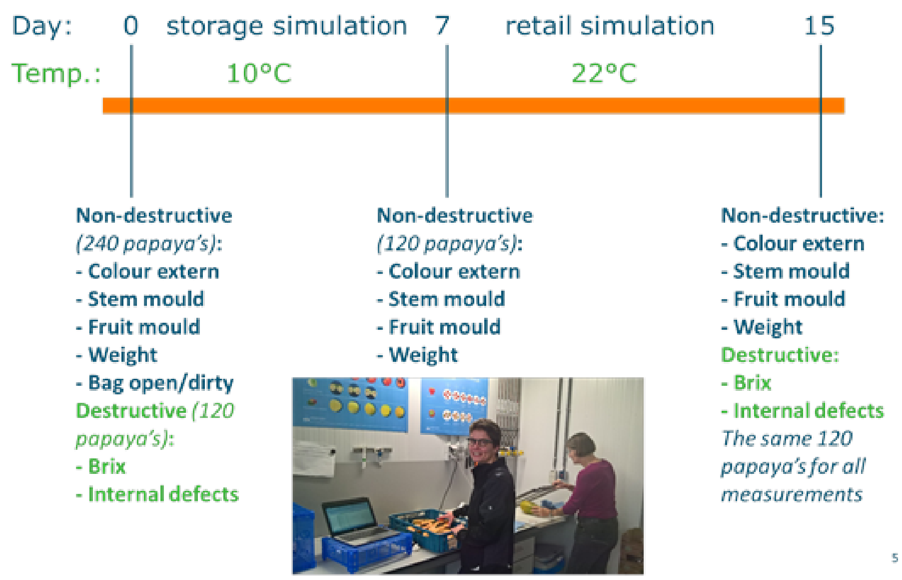

Figure 2.2: Research approach for testing different cultivars, maturity stages and post-harvest treatments.

Visual quality scoring

Visual quality was scored both externally and internally. Externally, fruits were judged for evenness, skin damage, pressure spots, bruises, rot, mould and clean stem-cut. Each quality aspect was evaluated as either "score 1" in case the quality aspect is present and observed or "score 0" in case the quality aspect was not observed. Furthermore, the number of yellow stripes on the calyx end of the fruit and the number of anthracnose-spots were recorded. Finally, the surface percentages of green freckling and brown spots were estimated. Internally, fruits were inspected for dry flesh, white spots in flesh, seed list browning, flesh browning, seed shrivel and seed germination and scored a 1 or 0 respectively if the quality aspect/defect was present or not. Additionally, the percentage of black seed-berries was estimated as the percentage of black seed compared to the total amount of seeds.

Weight

Weight of the papayas was recorded using a MS6002TS balance (Mettler-Toledo GmbH, Giessen, Germany).

Colour

In industry, papayas are divided in classes based on the number of yellow stripes on the skin; papayas with zero to one stripe are classified as "green" and papayas with two to three stripes are classified as "mature". Within GreenCHAINge WP2 we developed a 1-4 scale to determine papaya skin colour, with 1 indicating green skin with up to 25% yellow; 2 indicating up to 50% yellow; 3 indicating up to 75% yellow and 4 for up to 100% yellow (Figure 2.3).

Figure 2.3: Papaya skin colour scale. Scale determination: 1, green with up to 25% yellow; 2, up to 50% yellow; 3, up to 75% yellow; 4, up to100% yellow.

Later, papaya skin colour was assessed using image analysis of both sides of the fruit and flesh colour from a single half of a papaya cut over the stem-calyx axis. Images were acquired using a RGB camera (MAKO G-192C POE, Allied Vision, Stadtroda, Germany) positioned in a LED light cabinet (Designed by WFBR and build by IPSS Engineering, Wageningen, the Netherlands) and calibrated using a 24 patch colour checker card (Color checker classic, X-rite Europe GmbH, Regensdorf, Switzerland). Image analysis was done using multi-threshold colour image segmentation specific to either peel or flesh colours in the HSV colour space (in-house software tool developed at WFBR, Wageningen, The Netherlands). Colour was quantified as degrees in hue (Figure 2.4).

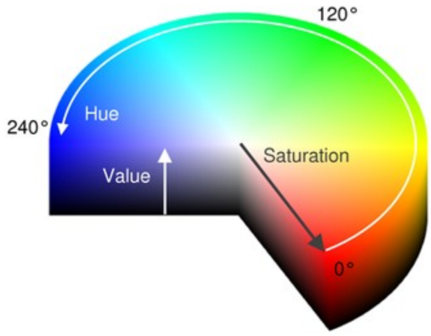

Figure 2.4: Colour scale in hue values: a lower hue value correlates with more yellow and less green. Source: Adapted from https://dsp.stackexchange.com/questions/30238/what-is-the-difference-between-the-terms-color-intensity-and-color-saturation.

Firmness

Papaya firmness was determined through limited compression; the force required to compress the fruit by 1.5 mm using a Texture Analyzer (TA-XT plus, Stable Micro Systems Ltd., Godalming, UK). Fruits were compressed at their thickest part, the "equatorial region", usually at 65-75 % distance from stem to flower.

Respiration and ethylene measurements

Papaya fruits were placed in individual 10 L high-density polyethylene drums (Engels Logistiek B.V., Eindhoven, the Netherlands) containing septa (Suba-Seal, Sigma-Aldrich) in the lids. The drums were closed for a recorded amount of time between 4 and 7 hours. After this time oxygen and carbon dioxide levels were assessed using a CheckMate 3 CO_2/O_2 headspace gas analyser (Dansensor A/S, Ringsted, Denmark) connected to a needle to sample the headspace. Following this, a 2.5 mL sample was taken from the headspace for ethylene analysis using gas chromatography (Packard model 437A equipped with a packed alumina column and a FID detector, Varian-Chrompack, Bergen op Zoom, The Netherlands).

Soluble sugar content and dry matter

Total Soluble Solids Content (SSC) in °Brix was assessed and dry matter was determined from two halves of a slice cut from the 'belly region' of the papaya. One half of the slice was gently squeezed to extrude the juice over a refractometer (GMK-701R, Nie-Co Products Nieuwkoop BV, Aalsmeer, the Netherlands) to determine the SSC. From the other half, a few dices of flesh were weighed prior to and after 3 days in an oven at 80°C to determine the percentage of dry matter content.

Mould growth

Mould growth of papaya was measured by division in four classes from class 0 (no growth) till class 4 (complete coverage by mould). This was done for both mould on the fruit (called fruit mould) and mould of the stem (called stem mould). Almost half of the papayas already had severe mould infection upon arrival at WFBR (see figure 2.5).

Figure 2.5: Pictures of papayas with mould infection upon arrival at WFBR.

2.3 Results and discussion

2.3.1a: Papaya behaviour during storage at 10 and 18°C post sea freight transport

While a decent amount of knowledge is available on papaya ripening directly after harvest, little has been published on papaya ripening after prolonged storage for more than three weeks. In order to monitor papaya ripening and storage after transport by sea freight from Brazil to The Netherlands, papayas were placed at 10 and 18°C and samples were taken at various times during this additional storage period.
After arrival at WFBR, the papayas were randomized, measured and placed at their respective storage temperature. Papaya weight averaged at 1025 g at the start of the experiment (Figure 2.6a). Weight loss after the respective storage periods of 5 days at 18°C and 13 days at 10°C were 2.2 and 2.0% (Figure 2.6b), indicating that at 18°C weight loss per day was significantly faster. Dry matter contents after these storage periods were 10.1 and 10.9% for 18 and 10°C, respectively (Figure 2.6c). Peel colour became darker yellow as storage progressed (Figure 2.6d). The colour level reached after 5 days of storage at 18°C was only reached after 13 days at 10°C. Firmness, as determined by limited compression, decreased over the storage times at both conditions (Figure 2.6e). While the firmness appeared to decrease faster at 18°C, the differences after 5 days at 18°C and 6 days at 10°C were no

longer significant (Figure 2.6e). Soluble sugar contents did not change over time and did not differ between the storage temperatures (Figure 2.6f). O_2 consumption started at 800 ppm kg^{-1} h^{-1} and had increased to 1000 ppm kg^{-1} h^{-1} after 13 days at 10°C (Figure 2.6g). At 18°C, O_2 consumption increased to around 1600 ppm kg^{-1} h^{-1} after the first day and remained similar after that. CO_2 production started below the detection limit on day 0, after which the headspace accumulation time in the drums was increased. At 10°C, CO_2 production increased from 250 to 350 ppm kg^{-1} h^{-1}, while at 18°C production had already reached 1000 ppm kg^{-1} h^{-1} (Figure 2.6h). Ethylene production at 10°C storage remained low at 10 ppb kg^{-1} h^{-1} throughout the storage period (Figure 2.6i). At 18°C storage, ethylene production increased to 20-30 ppb kg^{-1} h^{-1}, with a similar pattern as O_2 consumption and CO_2 production, albeit with a lot of variation between individual papayas.

Assuming that the papayas had the same average dry matter content prior to storage, these results suggest that part of the weight loss after the 18°C storage period was due to the loss of dry matter. The soluble solids contents did not show a significant drop, indicating that the assumed loss in dry matter was not due to respiration of sugars.

Overall, the results on O_2, CO_2, ethylene and colour indicate that papayas stored at 18°C are more metabolically active and ripen more quickly compared to storage at 10°C. Interestingly, the O_2 consumption and ethylene production follow the same pattern. Furthermore, storage temperature did not have a large effect on firmness; papayas softened at a similar rate at both 10 and 18°C (Figure 2.6e).

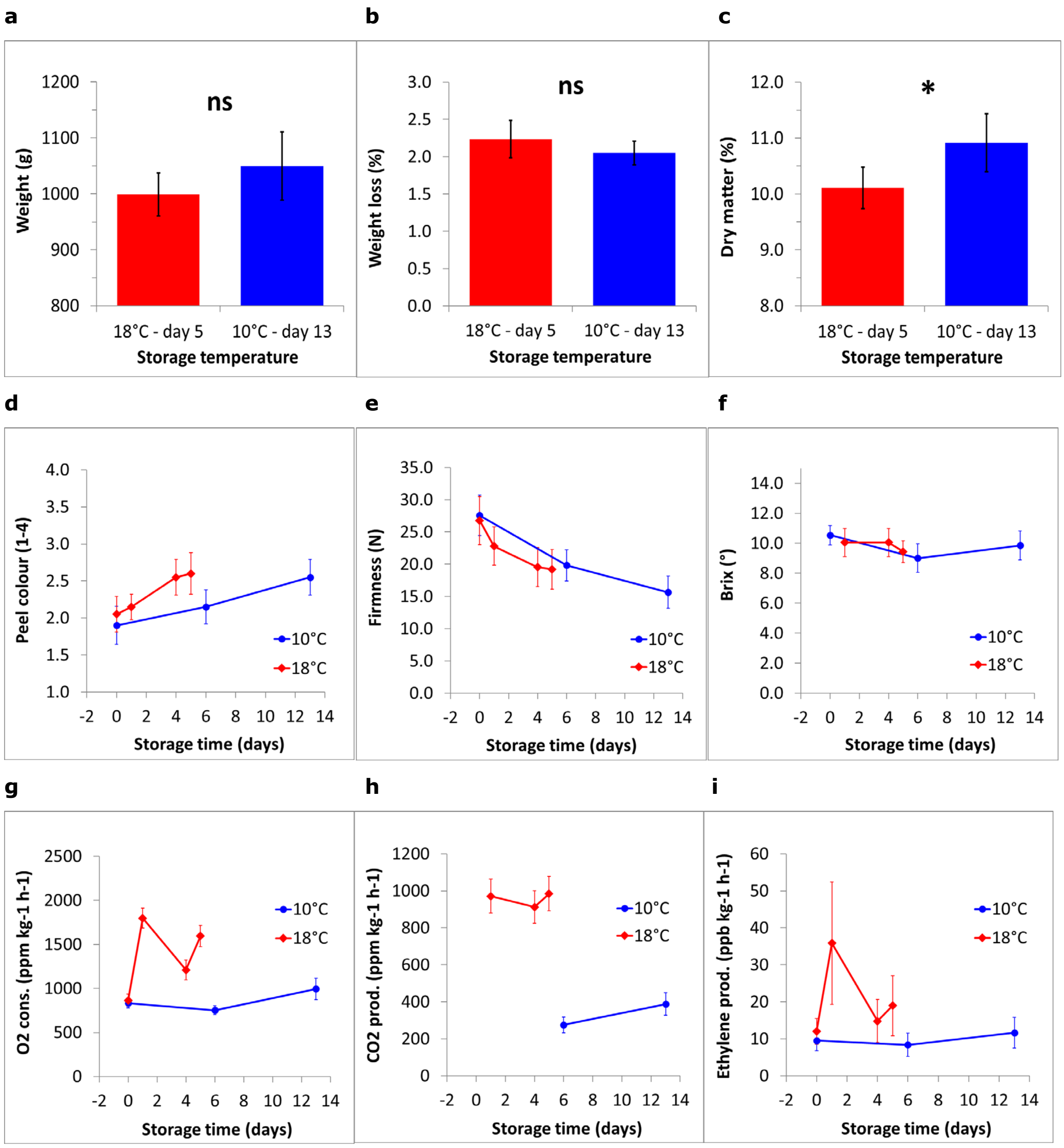

Figure 2.6: Physiological behaviour of sea freight transported papayas stored at 10 and 18°C. Papayas stored at 10 (blue) and 18°C (red) were monitored for up to 13 and 5 days, respectively. Physiological behaviour was monitored by weight (a), weight loss (b), dry matter (c), colour (d), limited compression (e), soluble sugar content (f), O_2 consumption (g), CO_2 production (h), ethylene production (i). Weight was measured at day 0. Weight loss was measured over a period of 5 days (18°C) or 13 days (10°C). Dry matter was measured at day 5 (18°C) or day 13 (10°C). The other data is shown over time (days). Data are means ± 95 % CI, n ≥ 20. * indicates significant difference ($p < 0.05$) and "ns" indicates not significant.

2.3.1b Influence of harvest maturity and storage temperature on papaya ripening speed post air freight transport

In the previous chapter we assessed the behaviour of papayas that had been transported overseas and subsequently stored. To better assess the behaviour of papayas during shipping in relation to maturity and transport temperature, we conducted a transport simulation using papayas that had been transported by air.

In Brazil, the papayas were harvested and sorted in two classes based on the number of yellow stripes; 0-1 stripe was classified as "green" and 2-3 stripes was classified as "mature". Shipment occurred directly after harvest, post-harvest treatment and packaging, and was done via air freight. However, upon arrival in Wageningen, the papayas had ripened more than could be expected based on their classification. It turned out that in Brazil the papayas had been stored at a local airport at temperatures over 30°C for one day, which conditions increase the ripening and the number of stripes on the peel. Nevertheless, at WFBR, the papayas were randomized per class, labelled and for each papaya the limited compression was assessed to determine the firmness. For gas headspace analysis only a limited amount of drums was available. Therefore just a subset of papayas, taken equally across their range of limited compression, was selected for these measurements.

The transport simulation consisted of a storage for 6 days at 10 or 15°C, followed by a period of 9 days at 22°C to simulate ripening ‘on the shelf’ (Figure 2.1b). Measurements were conducted at day 0, 6, 8 and 15.

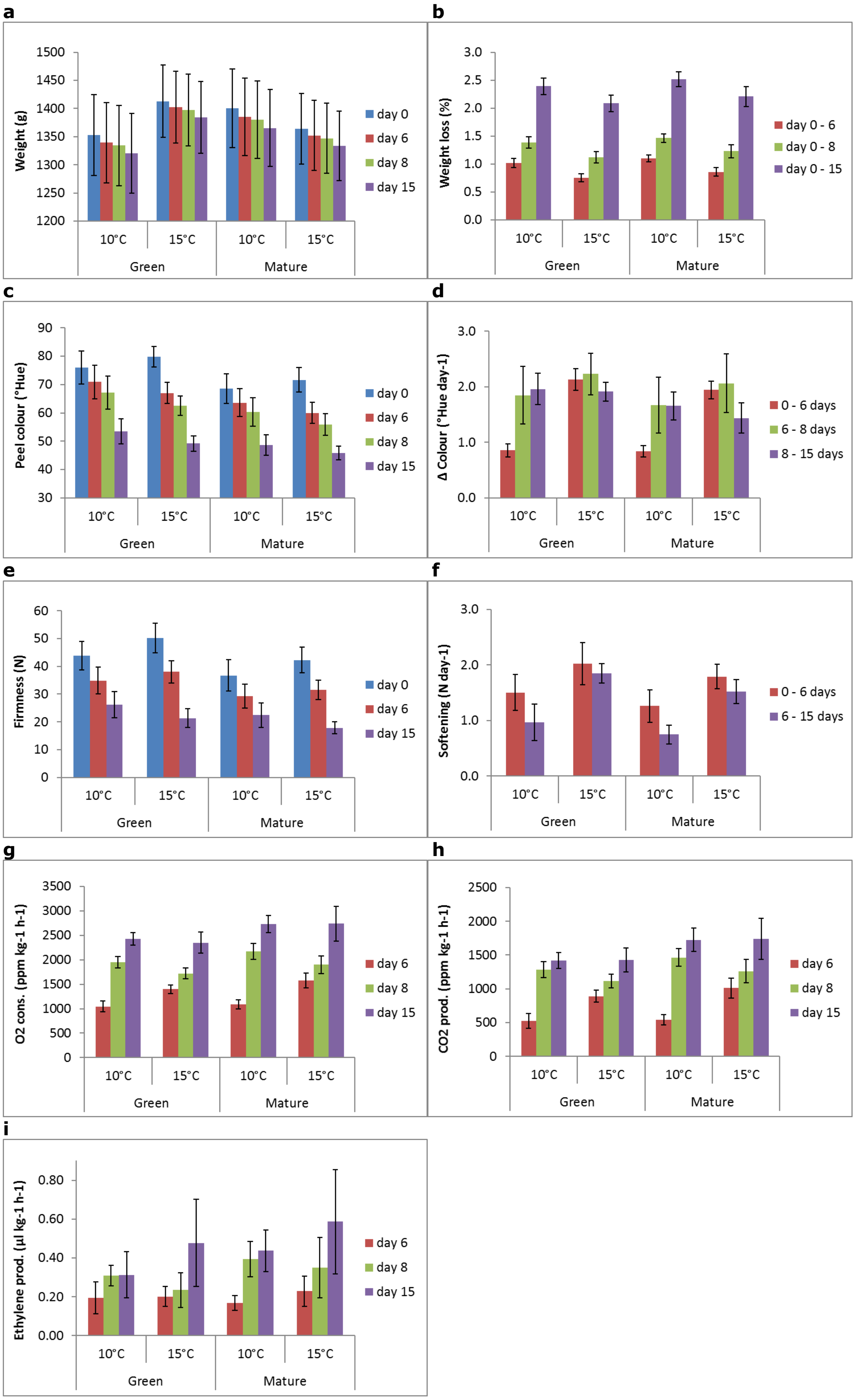

Figure 2.7: Physiological behaviour of air freight transported papayas stored at either 10 or 15°C during 6 days followed by a storage at 22°C during 9 days to further stimulate ripening. Two classes of papaya were determined at harvest: green and mature. Papayas were monitored over several days; 0 (blue), 6 (red), 8 (green) and 15 (purple). Physiological behaviour was monitored by weight (a), weight loss (b), peel colour (c), peel colour change rate (d), firmness (e), softening rate (f), O_2 consumption (g), CO_2 production (h) and ethylene production (i). Data are means ± 95% CI, n ≥ 13.

Papaya weight, averaged around 1400 g over all papayas, showed a large variation and declined steadily over time (Figure 2.7a). Weight loss increased over time and was similar for green and mature papayas at either storage condition (Figure 2.7b). The average peel colour started relatively green and changed to a dark yellow, starting in stripes developing from the floral end of the papayas (Figure 2.7c). Papayas classified as 'green' were more green than the 'mature' papayas and papayas stored at 10°C appeared to change colour less quickly than those stored at 15°C. The rate at which the papayas changed colour, quantified in degrees Hue per day, was the same in green and mature papayas, but doubled when stored at 15 instead of at 10°C from day 0 to 6 (Figure 2.7d). After day 6, when the papayas had been moved to 22°C, the rate was similar between papayas that had been stored at either 15°C or 10°C. See Figure 2.4 in materials and methods for explanation regarding Hue values.

Papaya firmness, as measured by the force to compress the papaya 1.5 mm, was similar for both storage temperatures and slightly lower in the mature papayas (Figure 2.7e). The rate at which the firmness changed was about 25 % higher in the papayas stored at 15°C and did not depend on the maturity of the papayas (Figure 2.7f). Interestingly, in the papayas stored at 10°C, the rate reduced markedly after placing the papayas at 22°C.

In summary, papayas from the two harvest maturities differed in absolute levels of colour and firmness, but there was no large difference in their behaviour during ripening. The rate at which peel colour changed and fruit softened was similar for both harvest maturities.

Storage temperature had a clear influence on the papaya metabolism and ripening. Papaya stored at 10°C showed a lower O_2 consumption, CO_2 and ethylene production compared to papayas stored at 15°C (Figure 2.7g,h and i), indicating decreased metabolism and ripening rates. The rates of peel colour development and fruit softening of papaya stored at 10°C were also lower compared to 15°C. These differences in metabolism and ripening rates disappeared when the fruits were moved to 22°C, except for the fruit softening. For both harvest maturities, the softening rate decreased after transfer to 22°C.

2.3.1c Influence of sea freight transport temperature on papaya quality

Based on the previous results, we wondered to what extent papayas could be transported by sea freight at 10°C. With this in mind we determined three classes of quality measurements to consider: external quality, ripening and internal quality. To this end, papayas were obtained from different containers of a single shipment that had different average transport temperatures, 10.5 and 12.6°C. Upon arrival of the papayas at WFBR, a range of quality measurements were performed. Subsequently the papayas were stored at 22°C for 7 days to simulate ripening 'on the shelf'. After seven days ripening at 22°C the papayas were subjected to quality measurements again.

External quality was judged based on weight, the number of yellow stripes, even fruit shape, skin damage, pressure spots, bruises, rot, mould and anthracnose. Papaya weight did not differ significantly between the two transport temperatures measured directly after transport, and neither when measured after 7 days of ripening (Figure 2.8a). In the field, yellow stripes on the papaya are a measure to estimate the progression of ripening. As papaya ripens, its colour changes from green to yellow and orange, starting with specific sections on the calyx-end of the papaya, which are visible as 'yellow stripes'. In this experiment, the number of yellow stripes was in most cases not visible, as almost all papayas already showed considerable yellowing between the stripes, which was scored as 4 (Figure 2.8b). Fruit shape was relatively symmetrical at 93%, with only a few papayas showing an uneven shape (Figure 2.8c). Skin damage, judged as sites where the skin was penetrated, was visible in 20 and 53% of the papayas transported at 10.5 and 12.6°C, respectively. Pressure spots, mainly visible on the stem end of the papaya and caused by pressure from box-stacking, were observed in 67% of the papayas transported at 10.5°C and 58 % of the papayas transported at 12.6°C. Bruises, visible as oval or round, dark green spots that change colour markedly slower than the rest of the papaya skin, were observed in 38 and 83 % of the papayas transported at 10.5 and 12.6°C, respectively. Rot, mould and anthracnose were not observed and as such not visualized. Overall, transport at 10.5°C resulted in less bruising and skin damage, compared to transport at 12.6°C.

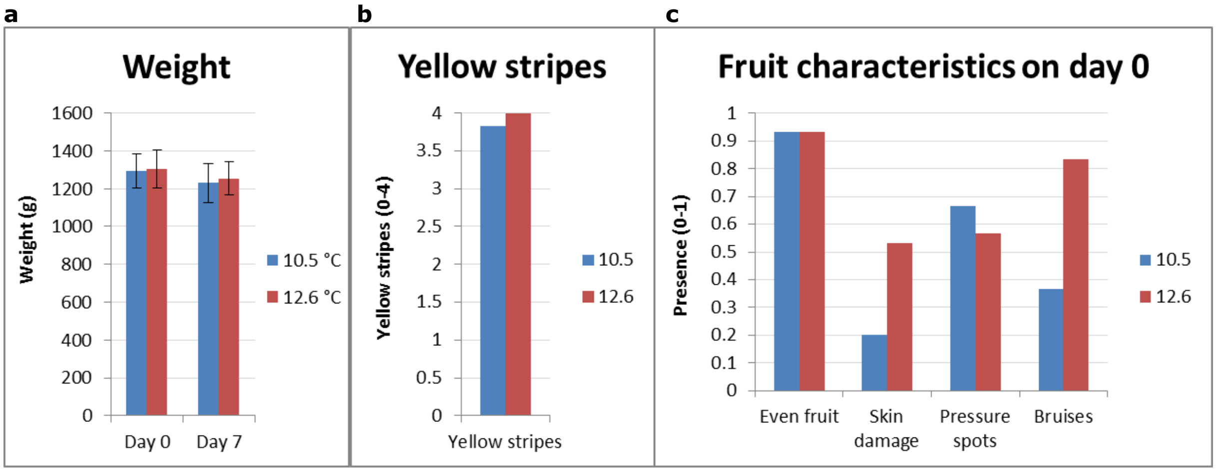

Figure 2.8: External quality of papaya fruit transported over sea at either 10.5 or 12.6°C. After arrival (day 0) papayas were ripened at 22°C for 7 days (day 7). External quality was determined at day 0 and 7, by measuring weight (a), number of yellow stripes (b) and presence of evenness, skin damage, pressure spots and bruises (c). Data represent means ± 95% CI (a) or means (b and c), n ≥ 10.

Papaya ripening was assessed based on papaya firmness, skin colour and flesh colour.
Skin colour after transport differed very significantly, with papayas transported at 10.5°C being greener than those transported at 12.6°C (Figure 2.9a). After ripening, the papayas had turned much more yellow and orange and the difference in skin colour was much reduced, though still significantly less orange in the papayas transported at 10.5°C. Flesh colour was significantly more red in the papayas transported at 10.5°C (Figure 2.9b). While this would suggest a faster ripening, a closer look showed this was due to internal damage in the flesh and as such the flesh colour should not be considered. Papaya firmness, the amount of force required to limitedly compress the papaya by 1.5 mm, changed from 18 to 11 N after 7 days of ripening (Figure 2.9c). No significant differences were observed between papayas transported at 10.5 and 12.6°C. Together, the results regarding limited compression and skin colour suggest that transport at 10.5°C results in greener papayas on arrival, although not firmer. Furthermore, after 7 days of ripening at 22°C papayas transported at both temperatures are almost equally coloured and soft.

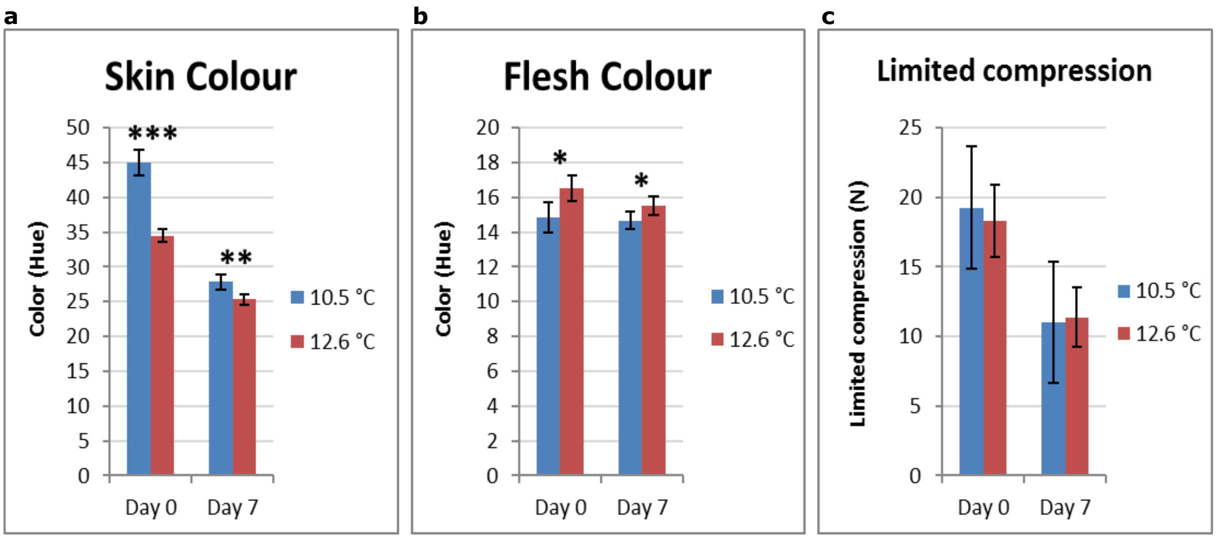

Figure 2.9: Ripening characteristics of papaya fruit transported over sea at either 10.5 or 12.6°C. After arrival (day 0) papayas were ripened at 22°C for 7 days (day 7). Ripening was determined based on skin colour (a), flesh colour (b) and limited compression (c). Data represent means ± 95% CI, n ≥ 10. Statistical abbreviations (student's t-test): *, p < 0.05; **, p < 0.01; ***, p < 0.001; else, not significant.

Internal quality was scored based on the occurrence of white spots, percentage of black seed berries, dry flesh, white spots in flesh, seedlist browning and flesh browning. Between the transport conditions there were no marked differences in the occurrence of white spots (Figure 2.10a). The percentage of black seed berries was about 23 and 47 % in papayas transported at 10.5 and 12.6°C respectively, and these percentages did not change during ripening (Figure 2.10b). Dry patches in the flesh occurred only in the papayas transported at 10.5°C and had increased after ripening (Figure 2.10c). Seedlist browning was observed after ripening and was with 90% significantly higher in the papayas transported at 10.5°C, compared to 20% of seedlist browning observed in papayas transported at 12.6°C (Figure 2.10d). Flesh browning, detectable as a change in colour and a toughening of the tissue, was observed only in papayas transported at 10.5°C (Figure 2.10e). Figure 2.10f provides visual examples of the observed seedlist and flesh browning, and also illustrates the earlier noted darker flesh colour due to tissue damage.

Overall, the papayas transported at 10.5°C showed considerable tissue browning and damage. Seedlist browning was severe in all papayas in which flesh browning was observed. In papayas with less severe seedlist browning no flesh browning was observed. These observations would suggest that the cause of the browning originates within the seedlist. Also interesting was that the percentage of black seeds was markedly lower after transport at 10.5°C. Whether this is related to the seedlist browning is unknown.

Looking into the transport temperature data, we can see that the papayas transported at set point 10.5°C reached a minimum temperature of 9.5°C, and the papayas transported at set point 12.6°C reached a minimum temperature of 10.2°C. The optimum temperature for papayas that are 0-25% or 25-50% yellow is 13 and 10°C, respectively (Arpaia and Kader, 1997). In this experiment, the papayas transported at set point 10.5°C stayed below 10°C for 36 hours. The period of time below 10°C may have been the trigger for the browning.

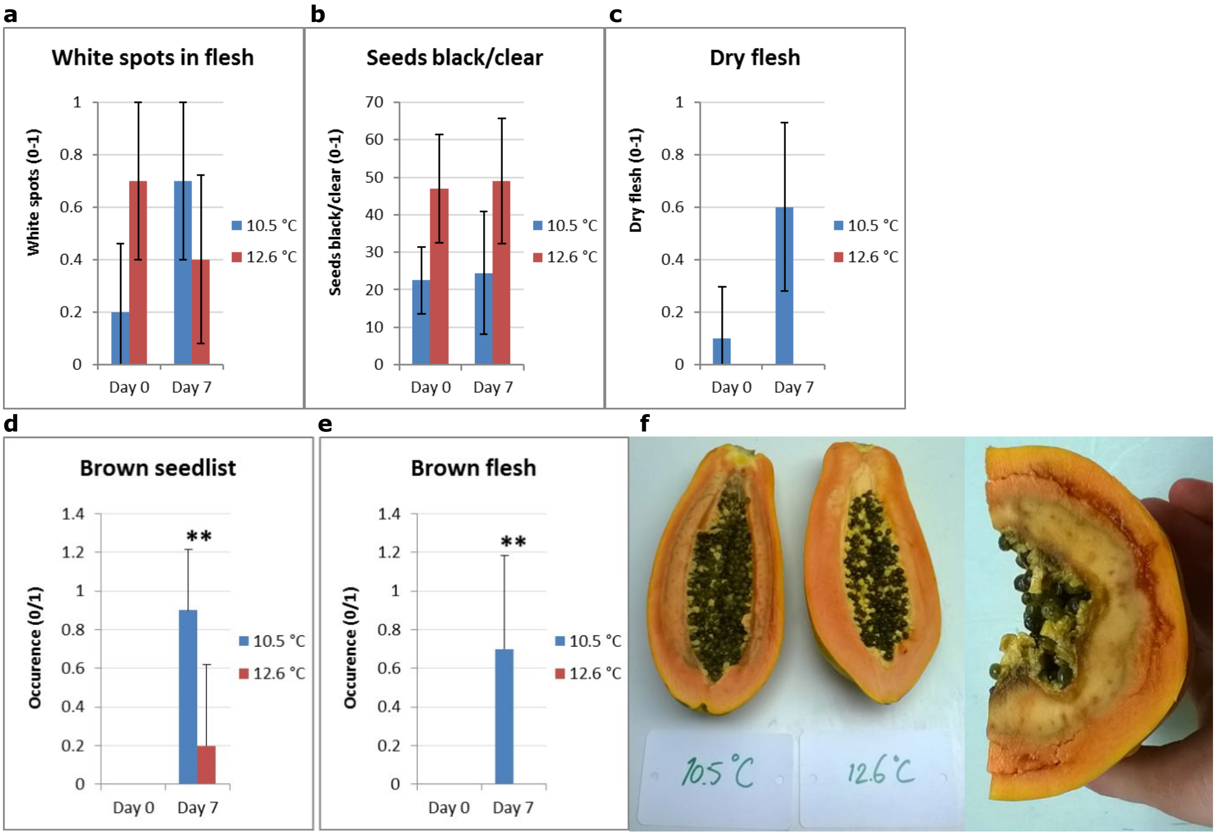

Figure 2.10: Internal quality of papaya fruit transported over sea at either 10.5 or 12.6°C. After arrival (day 0) papayas were ripened at 22°C for 7 days (day 7). Shown are occurrence of white spots in flesh (a), black seed berry percentage (b), dry flesh (c), seedlist browning (d), flesh browning (e) and further examples of flesh browning (f). Data represent means ± 95% CI, n = 10. Statistical abbreviations (two-tailed Pearson's chi-squared test): **, $p < 0.01$.

2.3.2 Testing of different papaya cultivars, harvest stages and post-harvest treatments

The following papaya cultivars have been tested for long-distance transport: Tainung, Bela Nova and Maradona. Tainung as the main variety for export from Brazil to Europe. Bela Nova as a potential variety for export to Europe and Maradona as main variety exported from Mexico to the US and currently also being exported to Europe. In this experiment we investigated I) which of the three cultivars is the most suitable for sea transport to Europe II) which maturity stage (green or mature) is the best to harvest papayas for export to Europe and III) which of the following three postharvest treatments (T0; no treatment, T1: washing + fungicide treatment and T2: washing + fungicide + wax treatment) is the best to obtain high quality papayas on the shelf in Europe. For comparison purposes, the Tainung variety is cultivated both at the same location as Bela Nova, called Tainung (BN) and at the same location as Maradona, called Tainung (M).

Soluble Solids Contents, peel colour analysis and mould growth
Soluble Solid Content (SSC in °Brix) is a measure for the sugar %. The SSC at day 0 was highest for Tainung (BN) and Tainung (M), both at day of arrival at WFBR (day 0) and after storage plus ripening (day 15). Even Tainung classified as green shows higher Brix values compared to the mature Bela Nova and Maradona cultivars. Overall, the results regarding SSC show a decreasing trend at day 15 compared to day 0, irrespectively of the maturity stage, although the differences are not statistically significant (Figure 2.11).

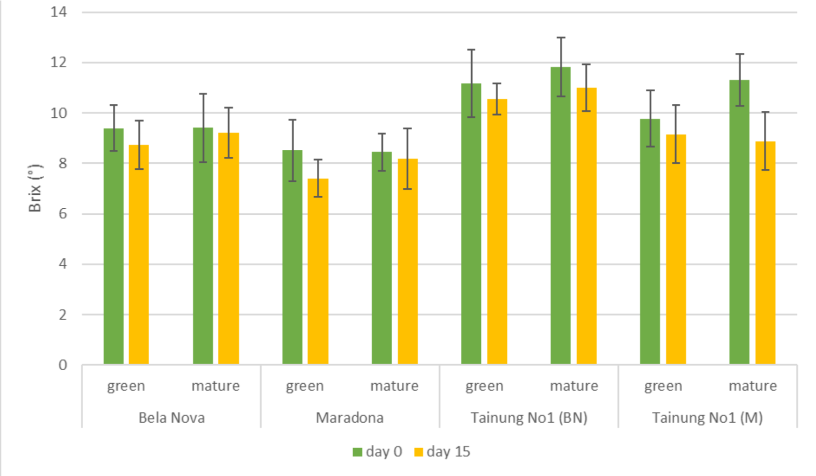

Figure 2.11: Mean (±sd) Soluble Solid Contents (SSC in °Brix) of different papaya cultivars harvested at either green or mature stage, measured at day 0 and 15.

Papaya skin colour was measured using image analysis. Mature fruits have lower hue values (indicating more yellow and less green) compared to fruits classified as green (Figure 2.12). Besides maturity, higher occurrence of fruit mould corresponds to papayas with a lower hue value and thus an increased area of yellow colour on the peel (Figure 2.13). A possible explanation is that fruit susceptibility for fungal infection changes during the developmental stages of the fruit due to ripening and senescence. In general, mature fruit are more susceptible for fungal infection compared to greener fruits. The postharvest treatments did not affect the peel colour (data not shown).

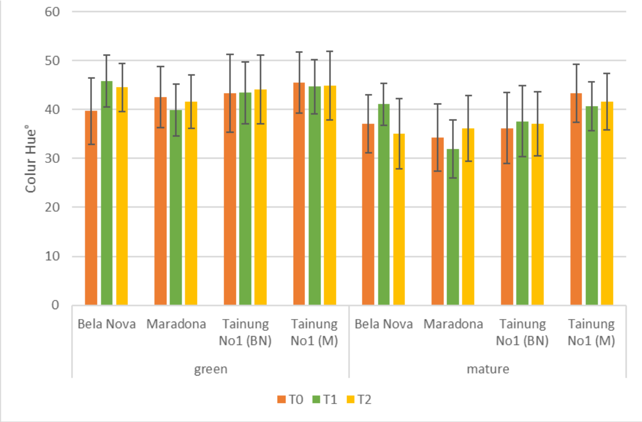

Figure 2.12: Mean (±sd) colour (Hue°) measured at day 0 for cultivars harvested at either green or mature stage.

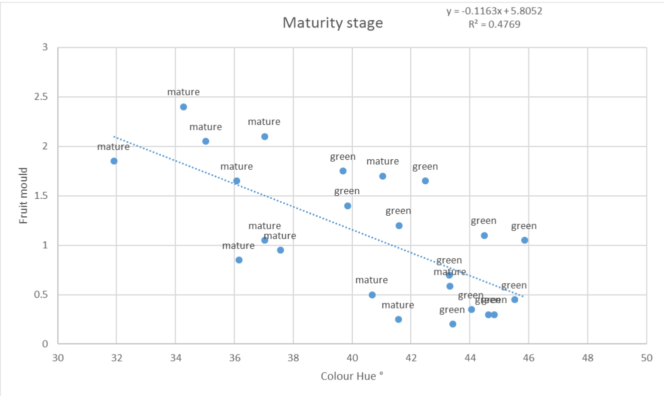

Figure 2.13: Effect mould growth on papaya peel colour (Hue°).

Internal defects

Overall, looking at the results of fruit internal defects like seed shrivel, seed germination and white spots, Tainung (M) showed the least internal defects compared to Bela Nova and Maradona (Figure 2.14 - Figure 2.16). Bela Nova showed the most internal defects.

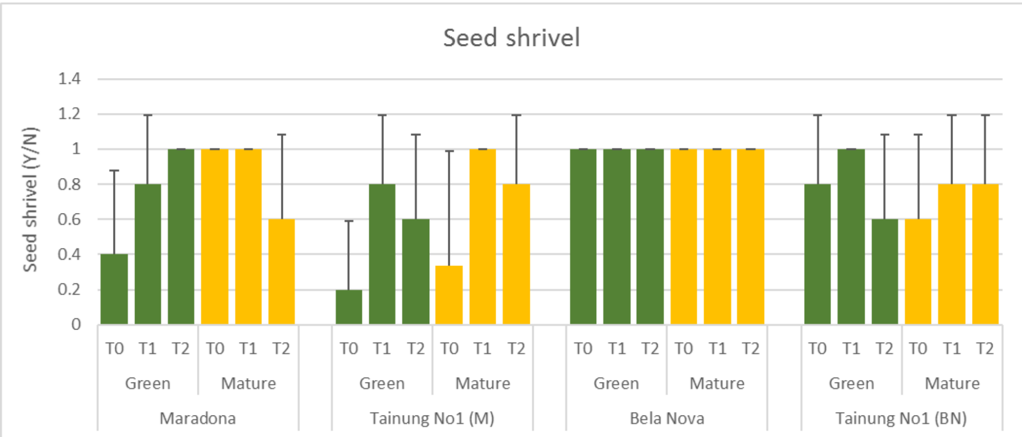

Figure 2.14: Mean (+SD) seed shrivel determined by scoring Y=Yes(1) or N=No(0), of the indicated cultivars harvested in either the green or mature stage.

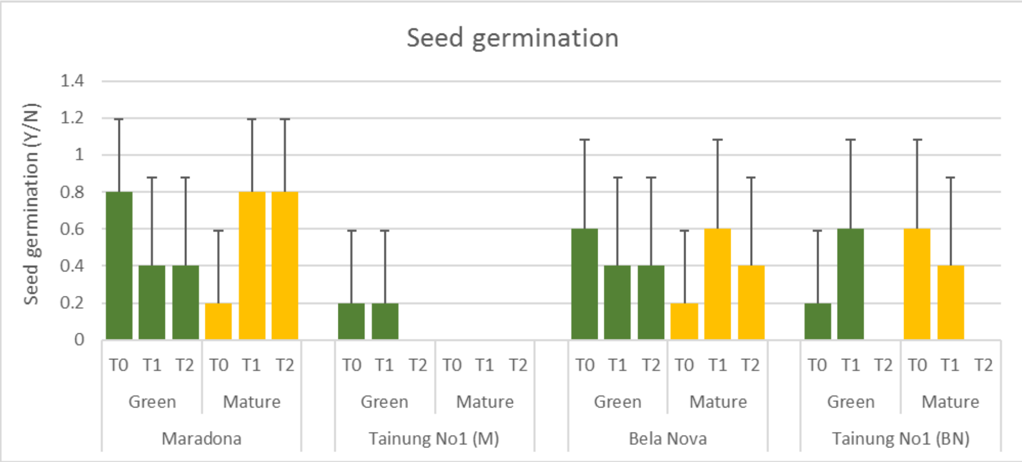

Figure 2.15: Mean (+SD) seed germination determined by scoring Y=Yes(1) or N=No(0), of the indicated cultivars harvested in either the green or mature stage.

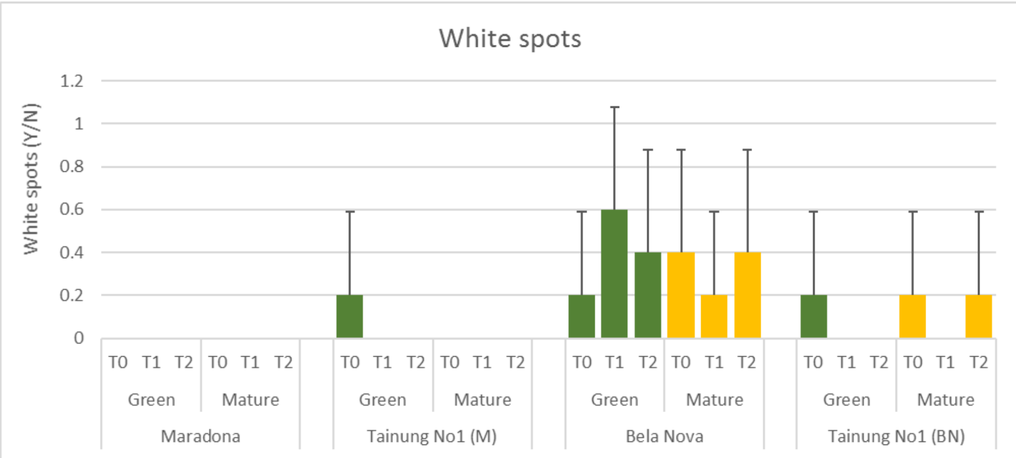

Figure 2.16: Mean (+SD) white spots determined by scoring Y=Yes(1) or N=No(0), of the indicated cultivars harvested in either the green or mature stage.

Regarding the effect of the post-harvest treatments, treatment T1 and T2 decreased the average stem mould infection (Figure 2.17), indicating that application of an anti-fungal treatment (perhaps combined with a wax layer) minimizes mould infection on papaya.

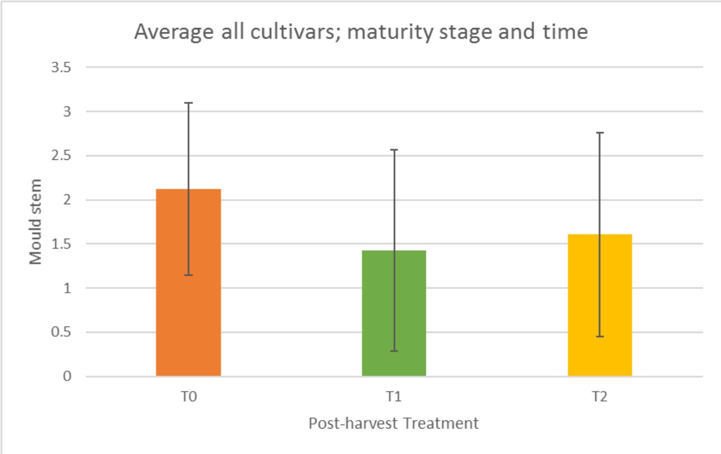

Figure 2.17: Mean (±sd) stem mould for papayas subjected to different post-harvest treatments: T0 (no treatment), T1 (washing and fungicide treatment) and T2 (washing, fungicide treatment and wax treatment).

2.4 Conclusions and recommendations

During the first three experiments described in chapter 2.3.1 we have monitored a large number of fruit characteristics and established objective and accurate measurement techniques for a number of them, e.g. skin colour, flesh colour and non-destructive firmness and their respective rates.
Based on the results obtained from these measurements, we have seen that transport temperatures close to 10°C are very important to reduce the ripening speed, decrease weight loss and maintain a higher firmness. We have also shown that a higher firmness is important as it increases the resistance of the peel to bruising and skin damage and thereby to fungal attack. However, transport at low temperatures may provide a risk, as could be seen when papayas were transported for a period below 10°C. Whether the observed browning was related only to the low temperature or to an interaction between temperature and growing conditions would require further investigation.
Papaya maturity does not influence the rates of colour and softening, but can offset the ripening level. For example, harvesting papayas earlier will provide more firm papayas that are more resistant to bruising and fungal attack. However, harvesting papayas too early (when they are too unripe) may cause problems with ripening and development of sweetness. The extent to which this would influence papayas that are transported for multiple weeks overseas would require further investigation.

Regarding the experiment described in chapter 2.3.2 (testing different papaya cultivars, harvest stages and post-harvest treatments), we can conclude that Tainung appeared the best cultivar of the three, based on the levels of measured SSC (°Brix), mould and internal defects. Regarding the maturity stage at harvest, no quality differences between papayas harvested at a green versus mature stage were observed. However, on the day of arrival at Wageningen the colour and mould levels were lower in papayas harvested at the green stage. From the comparison between the three post-harvest treatments the results indicate that applying an anti-fungal treatment (combined with a wax layer) minimized weight loss and mould compared to no treatment. In general, papayas can be harvested at both the green or mature stages but, after washing, an anti-fungal treatment is necessary.

3 Postharvest treatments against mould growth

3.1 Introduction and objective

Mould growth is one of the most important postharvest issues in the production and distribution of papayas. Mould growth is a serious problem in the export and import of papayas, particularly for the long distance transportation from South America to Europe. The relevance of this issue has been increased since the application of Sportak in Brazil (one of the largest production countries) has been forbidden. Therefore alternatives are necessary to avoid product losses. There are several postharvest treatments that may contribute to control fungal growth. The objective of this part of the project is to study the potential of postharvest strategies to control mould growth in the chain. From a broad range of postharvest treatments two have been selected for a first screening of the possibilities:
1) application of specific gas conditions and 2) application of a short heat treatment.

The following hypothesis were formulated and tested:

1) Currently papayas are transported in bags (Modified Atmosphere Packaging or needle-perforated) and sometimes without bag. At the moment it is not clear if the bags reduce mould growth. The use of bags may increase the relative humidity in direct vicinity of the fruits, stimulating the growth of moulds. Hypothesis 1: The use of bags during transportation of papayas increases mould growth.
2) Hypothesis 2: The application of specific gas conditions (increased CO_2 concentration) and a short heat treatment reduces fungal growth within the distribution chain.

3.2 Material and Methods

Papayas were harvested in Brazil and transported by ship to The Netherlands: 96 papayas were packed in a macro-perforated bag and 96 were transported without bag. All fruits were from the same cultivar (Tainung), grown at the same location, harvested at the same time and the same postharvest handling was applied.

3.2.1 Insight in effect of plastic bag (test 1)

This part of the test was carried out directly after arrival of the fruits in Wageningen. Upon arrival at WFBR, the fruits were measured and scored according to the following procedure:
- Measure O_2 and CO_2 inside bag of the 96 bagged fruits (Dan Sensor)
- Record if the bag was open and/or dirty (visual assessment)
- Measure the amount of fruit dehydration: weight (on all fruits) and moisture content (on 36 bagged and 36 unbagged papayas)
- Measure the amount of mould growth on all fruits: mould stem, mould fruit (visual assessment)

3.2.2 Study alternative anti-fungal growth methods (test 2)

The remaining 60 unbagged papayas (Tainung) from test 1 were stored in Controlled Atmosphere (CA) containers. The next gas conditions were applied:
- Ambient (20.6% O_2, 0% CO_2)
- Low O_2 (3%), high CO_2 (8%)
- Low O_2 (3%), very high CO_2 (15%)

The papayas were stored at 12°C and 100% Relative Humidity (RH). After 8 and 16 days, the fruits were measured and scored for:

- Amount of fruit dehydration: weight loss
- Amount of mould growth: mould stem, mould fruit (visual assessment)

Figure 3.1: Experimental setup for applying gas conditions.

The remaining 60 bagged papayas were used to test the heat treatment. The following heat treatment conditions were applied:

- Untreated
- Water bath (5 min at 49°C)
- Hot forced air (30 min at 49°C and 90%RH)

The hot forced air treatment was applied as follows: papayas were laid on a grid (20 papayas at once) without touching each other. The door of the climate chamber was closed and the papayas were heated at 49°C during 30 minutes (see upper right Figure 3.2). The fruits were subsequently cooled down to 12°C in 30 minutes (in a cold room). Afterwards the fruits were kept for extra 30 minutes at 12°C. The fruits were processed in batches of 20 papayas.

The water bath heat treatment was applied as follows: 6 papayas were placed in a water bath at 49°C for 5 minutes. A grid was put on top of the papaya to prevent floating (see upper left Figure 3.2). Directly after the heat treatment the papayas were cooled down in large containers with tap water for 5 minutes (lower photo Figure 3.2). The batch of 6 papayas was repeated until all fruits were processed. After the heat treatment and cooling down the papayas were placed in carton boxes and stored at 12°C until day 16. After 8 and 16 days, fruits were measured and scored for:

- Amount of fruit dehydration: weight loss
- Amount of mould growth: mould stem, mould fruit (visual assessment)

3.2.3 Stem and fruit mould visual assessment and dry matter determination

Papayas were visually assessed for mould on the stem on a four-point scale: 0, no mould infection, 1, 0-25% of the area covered with mould, 2, 25-50% of the area covered with mould, 3, more than 50% of the area is covered with mould. Papayas were likewise visually assessed for mould on the fruit on a four-point scale: 0, no mould infection, 1, 0-15% of the area covered with mould, 2, 15-30% of the area covered with mould, 3, more than 30% of the area is covered with mould. Dry matter was determined by weighing a few dices of flesh prior to and after 3 days in an oven at 80°C to determine the percentage of dry matter content.

Figure 3.2: Upper pictures: Papayas put in the heat water bath or hot forced air. Lower picture: Papayas in container for cooling-down.

3.3 Results and discussion

3.3.1 Test 1: Insight in the effect of plastic bag during transportation

Since the needle-perforated bags were used, the atmosphere measured inside the bags upon arrival was normal air (no modified atmosphere conditions). All bags showed signs of condensation and were dirty. Figure 3.3 shows the weight and moisture content of the papayas with and without bag upon arrival.

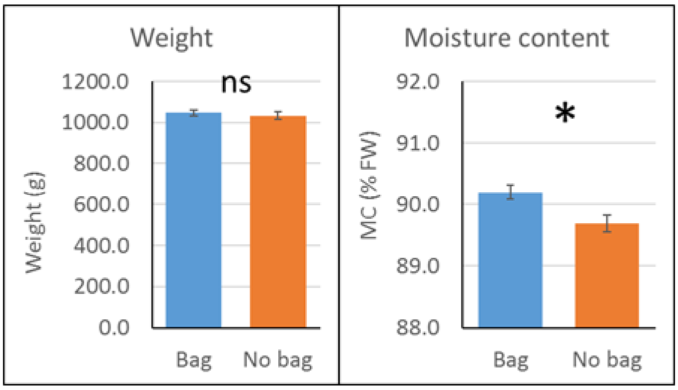

Figure 3.3: Average weight (left) and average moisture content (right) of papayas transported with and without bag (n=96). Statistical abbreviations (student's t-test): *, $p < 0.05$; ns, not significant.

Statistical analysis showed that there was no significant difference in the average weight of the bagged and unbagged papayas. On the other hand, the moisture content of the papayas in bags was significantly higher than the papayas transported without bag. This may indicate that papayas transported in bags lose less moisture than the papayas transported without bags.

Figure 3.4 shows the average scores for stem mould and fruit mould. The papayas transported in bags had significant less stem mould and fruit mould (lower scores) than the ones without bag. The reason for this difference cannot be identified in this study. One possible reason is that the natural peel coating of the fruits is protected better in the bags (where the water vapour seems to be higher) than in the situation without bags.

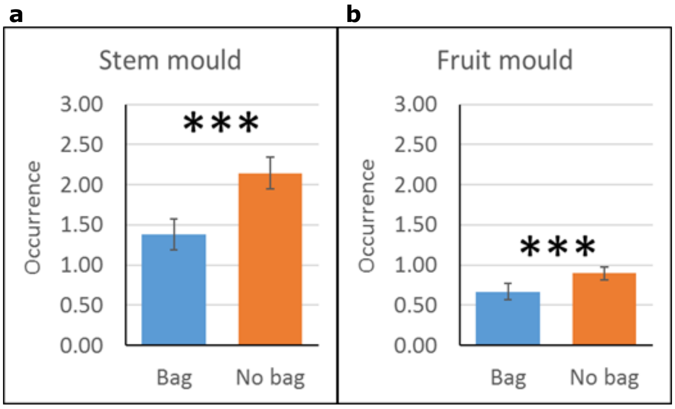

Figure 3.4: Average scores for mould stem (a) and mould fruit (b). Statistical abbreviations (student's t-test): ***, $p < 0.001$.

3.3.2 Test 2: Study alternative anti-fungal growth methods

<u>Results of the application of Controlled Atmosphere (CA)</u>

The weight loss and mould growth of the papayas stored at different gas conditions is respectively presented in Figure 3.5 and Figure 3.6.

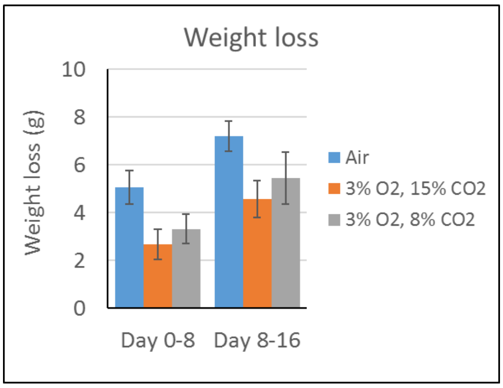

Figure 3.5: Average weight loss in grams (±sd) for papayas subjected to normal air, 3% O_2 and 15% CO_2 or 3% O_2 and 8% CO_2.

a b

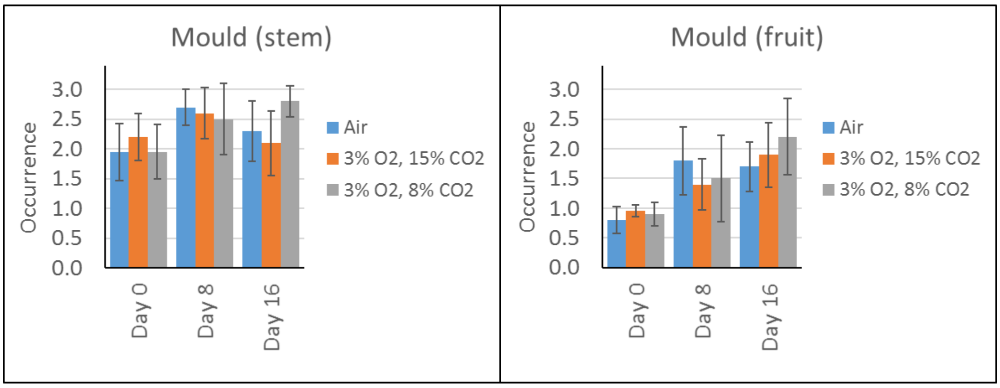

Figure 3.6: Mean (±sd) occurence of mould on the stem (a) and the mean occurence of mould on the fruit (b) on day 0, 8 and 16.

Papayas stored under normal atmospheric gas conditions showed more weight loss than the fruits stored under Controlled Atmosphere (CA). No difference in weight loss was measured between the two CA conditions. The application of CA conditions is generally known to reduce the metabolism of fruits resulting in a decrease of moisture loss (Wells 1962, Kader 1993).

Regarding the amount of mould growth, no clear effect of the applied gas conditions was measured. It is interesting to notice that the amount of fruit mould increased over time, particularly between the moment of arrival and the first week of storage. The increase in stem mould over time is however less evident. The amount of stem mould is larger than the amount of fruit mould, especially at arrival. Therefore, it seems that fruit moulds have more chance to develop and increase than stem moulds.

<u>Results of the application of heat treatment</u>
During the heat treatment in the water bath, the temperature in the core and under the skin was measured as illustrated in Figure 3.7.

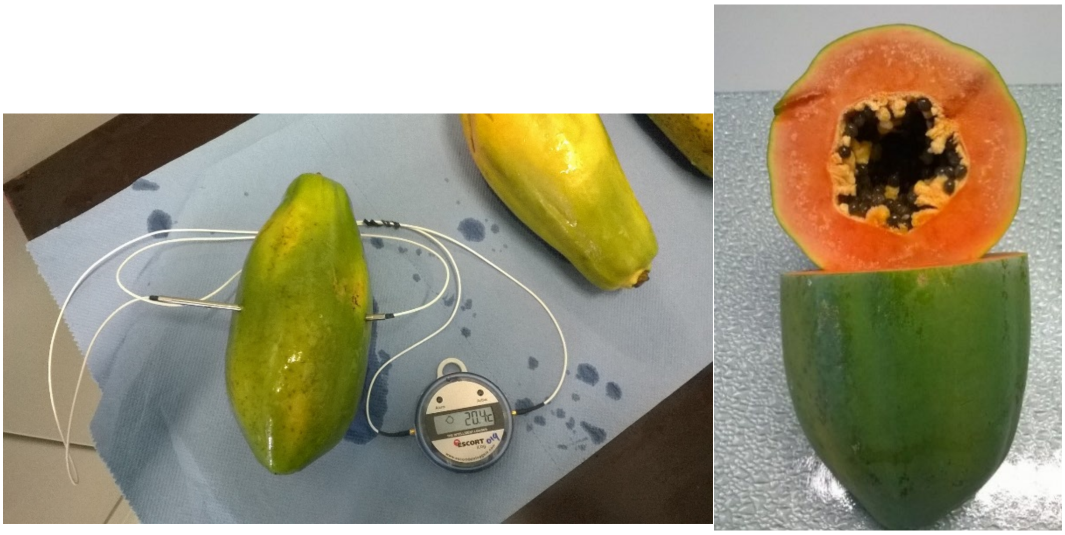

Figure 3.7*:* Demonstration temperature measurement of the core and under the skin of the papaya fruit.

The measured temperatures during the heat treatment are plotted in Figure 3.8. The temperature under the skin reached around 28°C and the core reached 18°C.

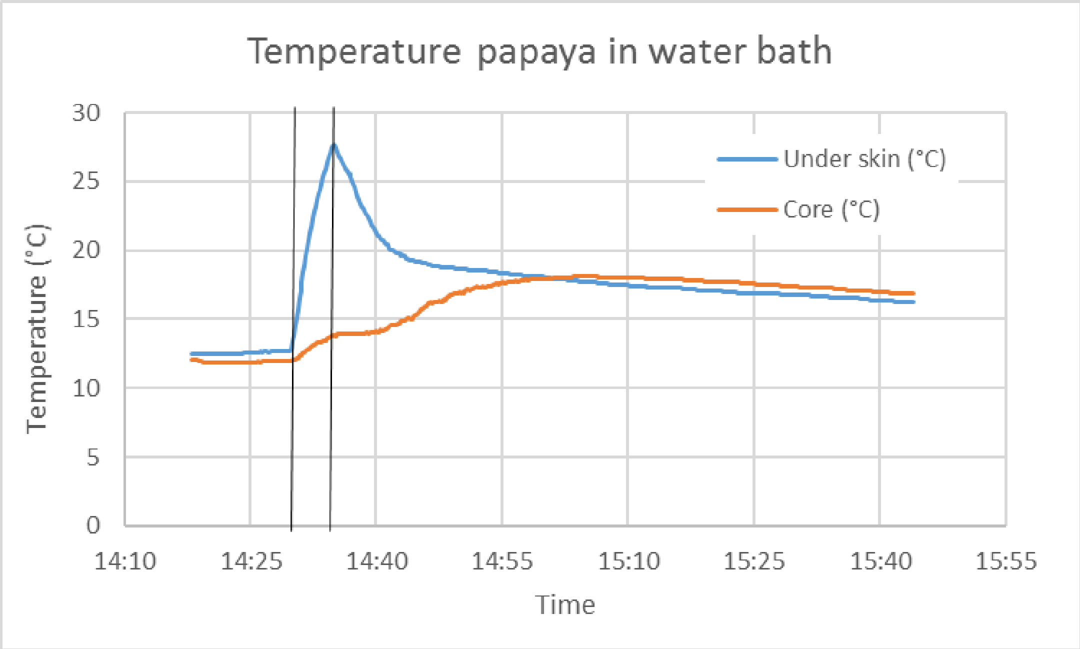

Figure 3.8: Temperature of a papaya during the heat treatment. The two black bars show the period that the papayas were kept in the water bath.

The weight loss and mould growth of the papayas from the different heat treatments is respectively presented in Figure 3.9 and Figure 3.10. As expected the weight loss increases over storage. There does not seem to be a relation between the weight loss and the application of a heat treatment. Concerning stem mould, the application of the heat treatments (both water bath and hot air) reduced the amount compared to the untreated fruits. This effect was less clear for fruit mould, after 8 days there was no significant difference between the heat treated and the untreated papayas. However after 16 days the papayas treated in the water bath showed less fruit mould than the control/untreated papayas.

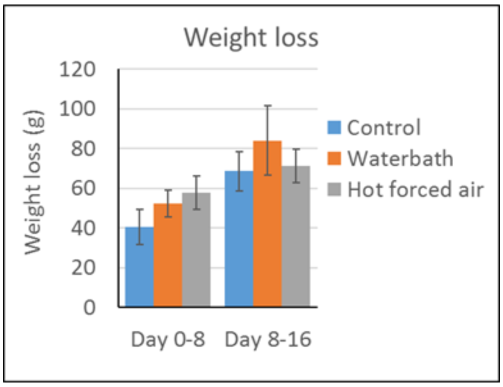

Figure 3.9: Mean (±sd) weight loss in grams of papayas subjected to one of the three treatments: Control; no treatment, water bath; papayas subjected to heat treatment and hot forced air; papayas subjected to hot forced air treatment.

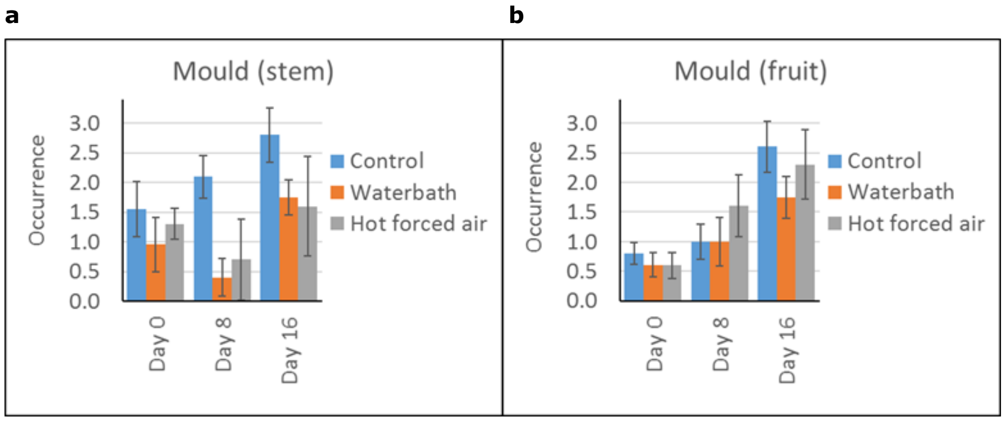

Figure 3.10: Mean (±sd) occurrence mould on the stem (a) and fruit (b) of papayas subjected to the stated treatments at day 0, 8 and 16.

3.4 Conclusions and recommendations

One of the objectives of this research was to compare the effect of transporting papayas with and without bags. This study shows that the use of macro pierced bags during transportation reduces mould growth and seems to avoid moisture loss. Based on this research the reduction of mould growth when using bags has been proven and quantified.

The other objective of this work was to test the potential of two postharvest strategies to reduce mould growth: application of CA conditions and a heat treatment.

The application of CA conditions reduced moisture loss but had no effect of mould growth. It should however be pointed out that the CA storage is applied after a long distribution chain period of more than 1 month after harvest. There was already much mould present on the fruits at the start of the CA storage. Under these conditions the impact of the CA gas conditions may be more limited, whereas if applied directly from the start of the distribution chain it can reduce the development of mould growth.

The heat treatment seems to have potential in reducing the development of moulds, particularly the application of the water bath. It can be expected that this effect can be even larger upon optimisation of the applied process conditions. The temperatures reached during this test were relatively low (just 28°C). Further optimisation is therefore required. Also the application of the heat treatment in the production location, thus before transportation, should inhibit mould growth. The effect of the treatment on moisture loss should be further investigated.

It should be emphasised that these results are valid for the cultivar Tainung No.1 and for the moulds that were present on the tested batch. One of the major challenges in mould control is the different sensitivity of several types of mould infections to different postharvest strategies. Therefore a method that is effective for one kind of infections may have a much lower impact for other kind of moulds. Moreover the type of mould infection depends on a large number of factors. A successful mould reduction strategy requires therefore a full chain approach from the farm to the transportation and further distribution in the import countries. The first step to set up this strategy is to get insight in the potential infection moments and in the type of mould infections that may be expected by different growing and harvesting conditions for different papaya cultivars. The interaction between mould and cultivar is also a relevant aspect is this approach.

4 Taste research

4.1 Introduction and objective

Transport overseas from South America to Europe can take up to four weeks. Delivering papaya at a ripeness and flavour meeting European consumer demand is rather a challenge since the papaya fruit quickly soften after harvest. To prevent softening and damage, papayas are harvested immature (based on amount of yellow stripes on the peel), however this could affect flavour. Flavour is becoming more important for European consumers. Europeans consumers prefer papayas to be ripe at purchase, the flavour should be sweet and firm of texture (CBI 2018). The goal of this research is to compare the taste profile of three papaya cultivars.

4.2 Material and Methods

4.2.1 Products

The following three cultivars were selected and delivered to Wageningen Food & Biobased Research (WFBR, Wageningen, the Netherlands): Tainung, Maradona and a novel cultivar which will be named cultivar X.

Upon arrival, the papayas were checked on quantity. All of the papayas belonging to the Maradona and cultivar X were subjected for the taste experiment, which will be further explained in paragraph 4.2.2. Papayas of the Tainung cultivar were divided into two groups. One group was used for the experiment as described in chapter 3, and the other group was subjected to the taste experiment.

4.2.2 Taste experiment

The taste experiment consists of two parts and the main aim is 1) to distinguish the cultivars from each other and 2) to map the differences for certain quality aspects related to taste.
Two taste experiments were performed with cultivar Tainung, Maradona and cultivar X:

- **Tetrad test**, to test if the cultivars can be distinguished from each other,
- **Profiling test**, to test the differences in odour, taste, texture and other taste related attributes.

Both tests were performed in sensory boots with daylight lighting and slight overpressure to minimize carry-over effects of odour residuals. All samples (at room temperature) were put in cups with a three digit code and tasted at room temperature.

Data acquisition was carried out with Eyequestion (version 3.13.1, 2014). The panellists evaluated the samples at their own individual speed. Data analysis was performed with EyeOpenR®.

4.2.2.1 Tetrad test

For the tetrad test, four samples are offered for tasting to panellists: two from one cultivar and two from another cultivar. Subsequently, the panellists were asked to form two groups out of the offered samples based on taste similarity (for illustration see Figure 4.1). In general, panellists will better distinguish the taste of the different cultivars in case of large taste differences between the cultivars. The other way around, panellists will be less likely to correctly form groups of the offered samples if the taste of the two different cultivars are similar. Twenty-one panellists of different nationalities participated for both Tetrad tests. One group started with the test in which Tainung was tested against the Maradona cultivar, while the other group started the test in which Tainung was tested against the X cultivar. Subsequently, the two groups switched from tests. The four offered samples within the tetrad test were presented according to a balanced random order design to level out order and carry-over effects.

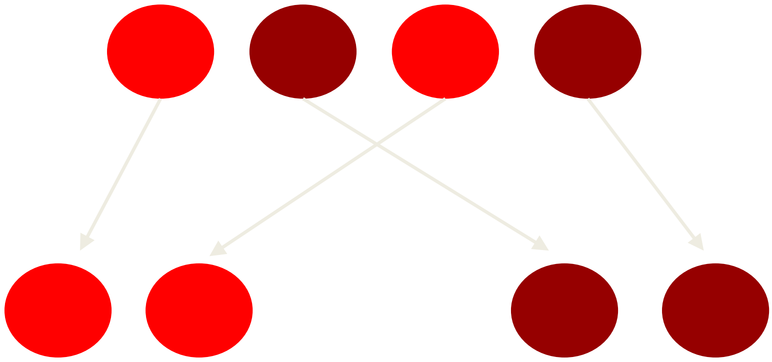

Figure 4.1: Design of the Tetrad test.

4.2.2.2 Profiling test

The following cultivars were tested in the profiling test:

- Tainung
- Maradona
- Cultivar X

For the profiling test, eighteen papaya consumers of different nationalities participated. Each panellist began with tasting a Tainung sample. Subsequently, the panellists were offered a sample for tasting for each of the three cultivars in duplicate. This was done according to a balanced random order design to level out order and carry-over effects. Next the panellists were asked to score the intensity between 0 and 100 on a line-scale, the so called Visual Analogue Scale (VAS) (see Figure 4.2). Distinction was made between sensory attributes related to odour, taste, hardness texture (from soft to hard), aftertaste and enjoyability (Table *4.1*). For statistical analysis, ANOVA and Tukey's HSD were used.

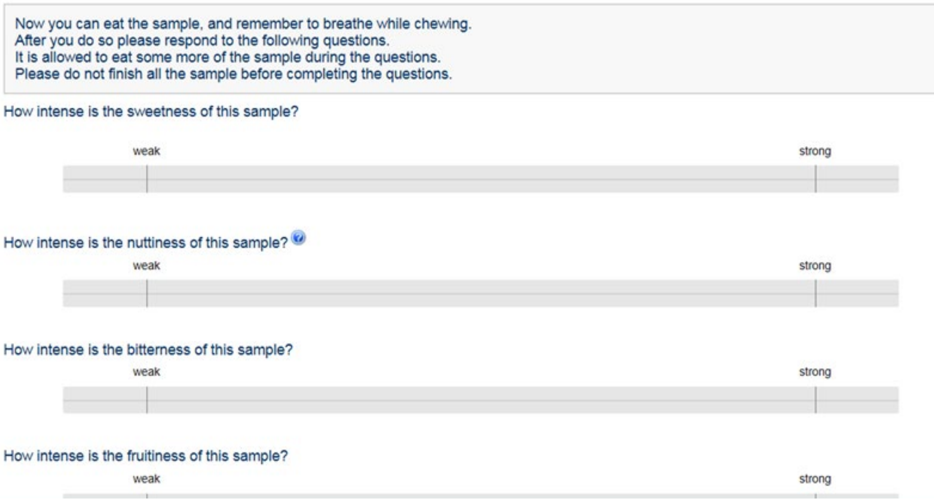

Figure 4.2: Illustration Visual Analogue Scale (VAS) used for the profiling test.

Table 4.1: List of sensory categories and attributes used for the profiling test.

Category and Attributes	Description
Odour	
Fruity	
Flowery	
Earthy-underbush	
Off smell	
If off smell, intensity and description	
Taste	
Sweetness	
Nuttiness	All nuts can be associated with the perceived taste
Bitterness	
Fruitiness	
Hardness (texture)	
Aftertaste	
Intensity	
Description	
Enjoyability (overall liking)	

4.3 Results and discussion

4.3.1 Tetrad test

Papaya consumers (n = 21) tested Tainung versus Maradona and Tainung versus cultivar X in a tetrad test to determine whether there were taste differences between the cultivars. The results are shown in Table *4.2*.

Table 4.2: Results Tetrad test papayas.

Test	Consumers (N)	Correct answers	P-value
Tainung vs Maradona	21	11	0.056
Tainung vs X	21	14	0.002 **

From the results we observe that the panellists are able to distinguish Tainung from the culitvar X based on tasting. There seems to be a trend that panellists were able to distinguish Tainung from the Maradona, however the results were not significant.

4.3.2 Profiling test

For the papaya taste profile, 18 panellists were asked to score for 10 attributes and for two attributes a description (off-smell and aftertaste). In Table *4.3* and Figure 4.3 the results are shown of the profiling test.

Table 4.3: Results of the profiling test of the papaya cultivar Tainung, Maradona and cultivar X. Data represent means with n= 18 and statistical notations (ANOVA with Tukey's HSD posthoc tests) represent significant differences ($p < 0.05$) between A and B.

	Tainung no1	Maradonna	X	F-value	p-value
Odour					
Fruity	34.99 ^{B}	49.78 ^{A}	45.50 ^{A}	7.09	0.003
Flowery	34.29	43.36	42.78	2.43	0.103
Earthy-Underbush	35.43	34.96	37.97	0.30	0.746
Taste					
Sweetness	36.81 ^{A}	37.17 ^{A}	29.03 ^{B}	4.73	0.015
Nuttiness	32.96 ^{AB}	38.35 ^{A}	29.94 ^{B}	6.61	0.004
Bitterness	32.59 ^{B}	56.72 ^{A}	53.60 ^{A}	19.93	<0.001
Fruitiness	39.64	41.78	33.57	2.24	0.122
Texture (Hardness)	43.59	39.08	42.58	0.87	0.427
Aftertaste					
After-taste	39.52 ^{B}	53.32 ^{A}	47.69 ^{AB}	7.64	0.002
Enjoyability	39.34 ^{A}	30.92 ^{AB}	26.81 ^{B}	4.02	0.027

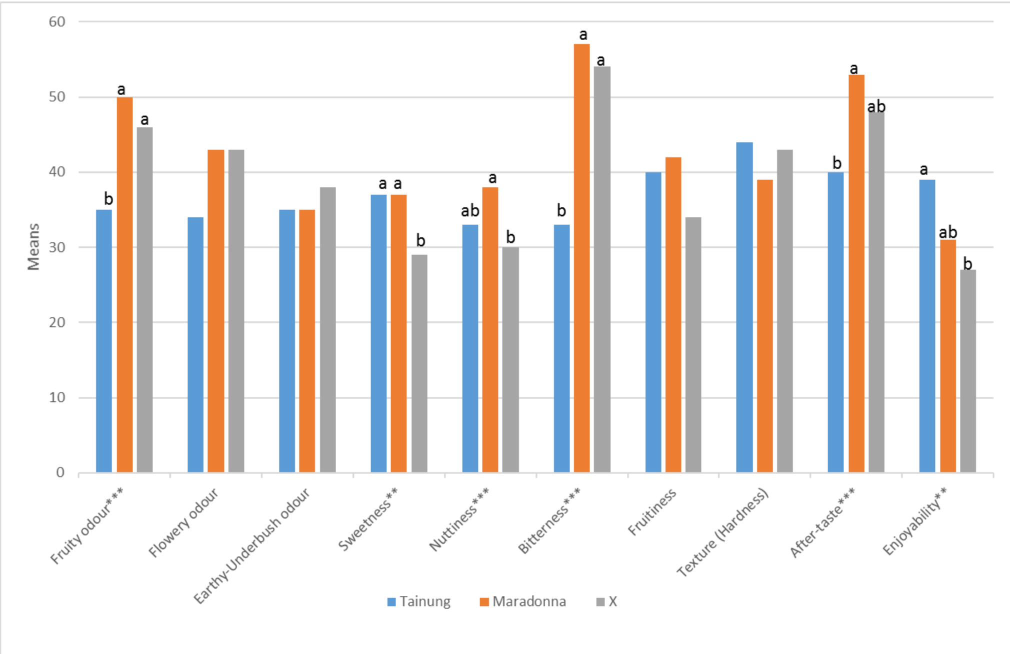

Figure 4.3: Results of the profiling test of the papaya cultivar Tainung, Maradona and X. Data represent means with n= 18 and statistical notations represent significant differences (ANOVA, ***: $p \leq 0.01$; **: $p \leq 0.05$; *: $p \leq 0.1$ and Tukey's HSD post hoc test, $p < 0.05$ for a and b).

Looking at the determined profiles (Table 4.3, Figure 4.3 and Figure *4.4*), we observe that papayas belonging to Maradona and X have quite similar sensory profiles. Maradona and X only differed in sweetness and nuttiness. X is perceived as less sweet and less nutty compared to cultivar Maradona. Tainung showed rather a different profile compared to the Maradona and X. Tainung is perceived as less bitter compared to Maradona and X. Additionally, Tainung is perceived with a decreased fruity odour and sweeter compared to X. Compared to Maradona, Tainung scores lower on fruity odour and aftertaste. It should be noted that all three varieties scored remarkably low on enjoyability, even though Tainung scored higher on enjoyability compared to cultivar X (39.34 and 26.81 respectively on a scale of 0 – 100).

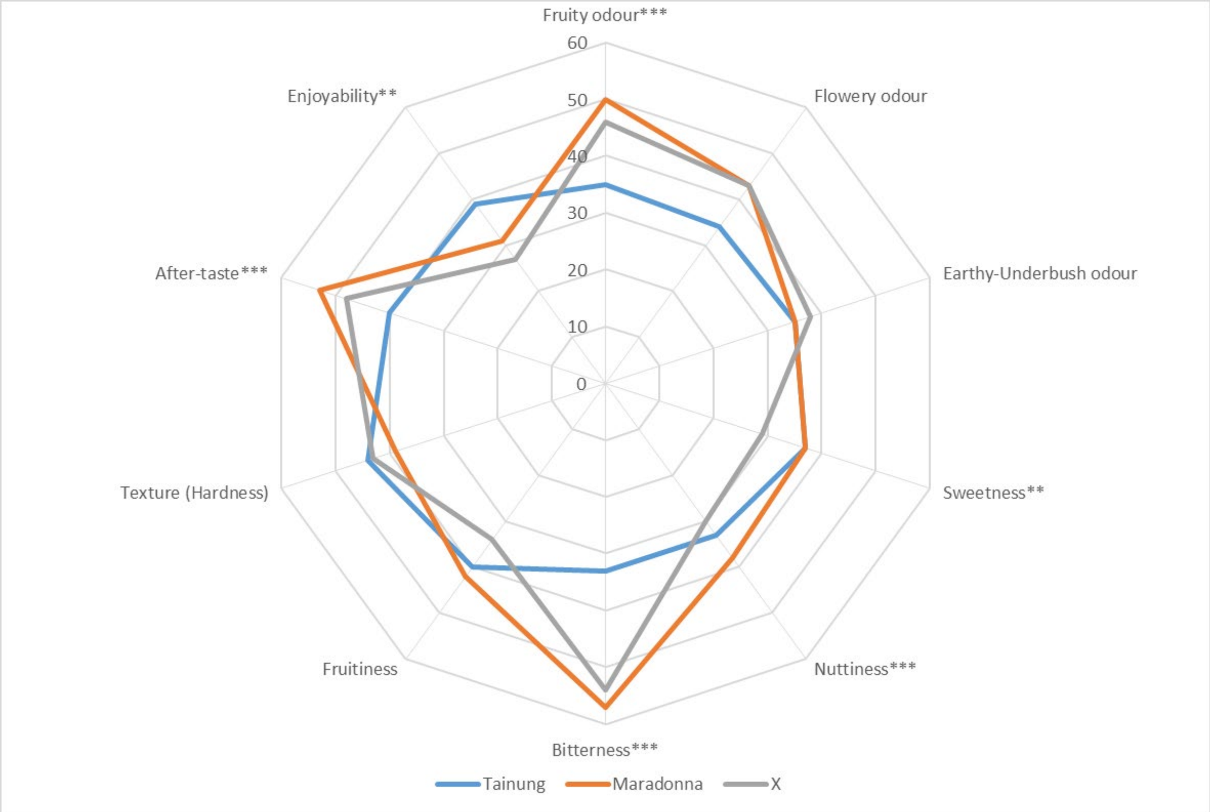

Figure 4.4: Spiderplot taste profile of papayas belonging to the cultivar Tainung, Maradona and X. Data represent means with n= 18 and statistical notations represent significant differences (ANOVA, ***: p ≤ 0.01; **: p ≤0.05; *: p ≤0.1.

Off-smell

The panellists were also asked whether they perceived an off-smell. From the panellists, approximately 80-90% answered they did not detect an off-smell (Figure 4.5a). Panellists who answered yes were asked to score the intensity of the off-smell on a scale of 0 – 100. The results are shown in Figure **4.5**b. In the few times that an off-smell was noticed, the intensity score was 40-50 on a scale of 0-100.

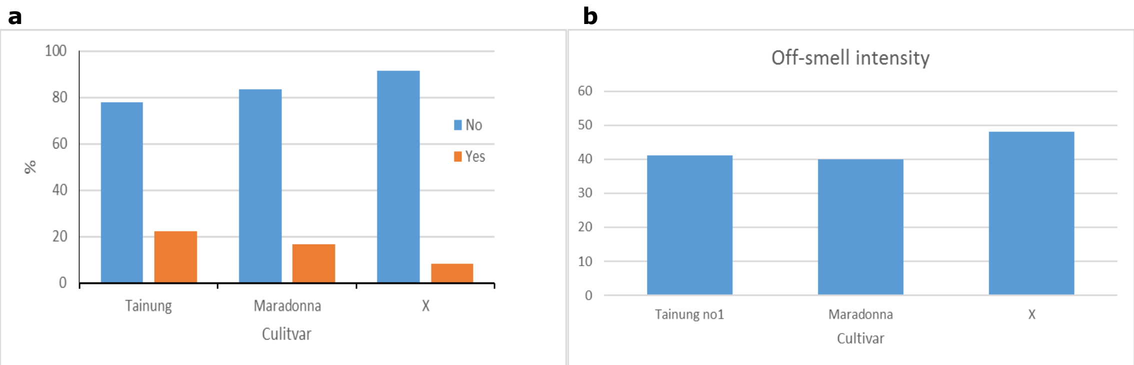

Figure 4.5: Results of the perceived off-smell detection expressed as percentage(a). Panellists were asked whether they detected an off-smell (Yes) or not (No). Perceived intensity of the off-smell on a scale of 0 – 100(b).

Aftertaste
Regarding aftertaste, panellists were asked to score for the intensity of the aftertaste and give a description of the aftertaste. From the descriptions, wordles were generated per variety (Figure 4.6). Big sized words within a wordle is mentioned more often by panellists compared to small sized words. From the generated wordles, we observe that a bitter aftertaste is most often described for cultivar X. For Tainung, besides having a bitter aftertaste, sweet and nutty were also mentioned often although to a lesser extent than bitter. For Maradona, (very) bitter aftertaste was also the most distinctive aftertaste.

Figure 4.6*:* Wordle aftertaste descriptions: left:Tainung, middle: Maradona and right: X.

4.3.3 Correlation taste and physiological attributes

Finding a correlation between certain physiological attributes and the determined taste profile could provide a more in-depth insight in the interaction between different taste related attributes and fruit physiological attributes. To this end, the following physiological attributes were measured and investigated on correlation with the attributes form the taste profile:

- Weight
- Brix
- pH
- Moisture Content (MC)
- Mould on the stem
- Mould on the fruit

Table *4.4* shows the determined correlations between physiological attributes of papaya and the determined attributes from the taste profile. From the results we see that brix is negatively correlated with moisture content of the fruit. Remarkably, mould on the stem is negatively correlated with the earthy underbush smell. No, clear explanation can be found for this, as mould could increase the earthy under bush smell. It could be that the mould is only on the surface and not in the flesh yet, which the panellists were scoring. pH is positively correlated for both bitterness and aftertaste. Bitterness is likewise positively correlated to aftertaste. Looking at enjoyability, this attribute is positively correlated for sweetness and fruitiness and negative for bitterness, aftertaste and pH.

Table 4.4: Correlation taste attributes and physiological attributes

	Weight (g)	Brix	[illegible]	MC	Mould (stem)	Mould (fruit)		Fruity odour	Flowery odour	Earthy-Underbush	Sweetness	[illegible]iness	Bitterness	Fruitiness	[illegible]ure (Hardness)	After-taste	Enjoyability
Weight (g)	1.00	-0.41	0.01	[illegible]	0.21	0.55		0.01	0.34	-0.06	-0.30	[illegible]	[illegible]	-0.14	[illegible]	[illegible]	-0.21
Brix	-0.41	1.00	-0.04	-0.92	0.27	-0.40		0.43	[illegible]	-0.49	0.28	-0.11	[illegible]	0.22	0.30	[illegible]	-0.10
pH	0.01	-0.04	1.00	-0.08	0.26	0.18		0.48	[illegible]	[illegible]	-0.43	0.06	0.82	-0.48	0.44	0.70	-0.61
MC	0.54	-0.92	-0.08	1.00	-0.15	0.38		-0.33	[illegible]	[illegible]	-0.17	0.19	-0.15	-0.08	-0.23	-0.32	0.17
Mould (stem)	0.21	0.27	0.26	-0.15	1.00	0.26		0.47	0.26	-0.65	0.08	0.08	0.37	0.18	0.35	0.41	-0.11
Mould (fruit)	0.55	-0.40	0.18	0.38	0.26	1.00		0.11	0.27	0.08	-0.27	0.12	0.24	-0.10	0.30	0.21	-0.11
Fruity odour	0.01	0.43	0.48	-0.33	0.47	0.11		1.00	0.72	-0.43	0.18	0.08	0.46	0.23	0.14	0.40	-0.18
Flowery odur	0.34	0.13	0.14	0.04	0.26	0.27		0.72	1.00	-0.25	0.01	0.09	0.21	0.33	0.03	0.13	-0.10
Earthy-Underbush	-0.06	-0.49	-0.49	0.36	-0.65	0.08		-0.43	-0.25	1.00	0.19	0.10	-0.54	0.12	[illegible]	-0.53	0.39
Sweetness	-0.30	0.28	-0.43	-0.17	0.08	-0.27		0.18	0.01	0.19	1.00	0.29	-0.63	0.84	[illegible]	[illegible]	0.78
Nuttiness	0.16	-0.11	0.06	0.19	0.08	0.12		0.08	0.09	0.10	0.29	1.00	-0.05	0.16	[illegible]	[illegible]	0.03
Bitterness	0.26	0.08	0.82	-0.15	0.37	0.24		0.46	0.21	-0.54	-0.63	-0.05	1.00	-0.66	0.48	0.89	-0.87
Fruitiness	-0.14	[illegible]	-0.48	-0.08	0.18	-0.10		0.23	0.33	[illegible]	0.84	[illegible]	[illegible]	1.00	[illegible]	-0.53	0.82
Texture (Hardness)	0.08	[illegible]	[illegible]	-0.23	0.35	0.30		0.14	0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.54
After-taste	0.15	[illegible]	[illegible]	-0.32	0.41	0.21		0.40	0.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.77
Enjoyability	-0.21	-0.10	-0.61	0.17	-0.11	-0.11		-0.18	-0.10	0.39	0.78	0.03	-0.87	0.82	-0.54	-0.77	1.00

4.4 Conclusions and recommendations

One of the objectives of this research was to determine taste profiles of the three papaya cultivars after transport to Europe from South America. This study determined the taste profiles of the cultivar Tainung, Maradona and cultivar X. From the profiling test the differences were revealed. Cultivar X was less enjoyable probably due to increased bitter taste and decreased sweet taste compared to Tainung. Cultivar X and Maradona showed quite similar taste profiles. Based on the results we have seen from the Tetrad test, papayas of the cultivar Tainung are distinguishable from cultivar X based on taste. Also, for the Tetrad test no clear taste distinction was made by panellists for Tainung versus Maradona. This was not reflected in the taste profiles of Tainung and Maradona, as both showed quite different taste profiles. The profiling test reveals that Maradona is more bitter, less sweet and had an increased aftertaste and flowery odour compared to Tainung. All three varieties scored remarkably low on enjoyability. Although only three cultivars were measured, the correlation summary from Table *4.4* shows that enjoyability seems to increase by increasing the sweetness and fruitiness of the fruit and decreasing pH, bitterness and aftertaste. This could lead to European consumer appreciation for the papaya fruit. The correlation between the attributes shows that bitterness, aftertaste and pH seems to have a negative effect on the enjoyability and sweetness and fruitiness seems to have a positive effect. Bitterness was highly correlated with aftertaste and pH. Bitter taste is known to last, so it may well be that the aftertaste is due to the bitterness. It would be interesting to study which compounds causes the bitterness. It is essential to gain insight in the interaction between different taste related attributes and fruit physiological attributes for obtaining papaya on the shelf, which will be highly appreciated by European consumers.

5 General conclusion and discussion

In GreenCHAINge workpackage 2 we investigated postharvest quality of different papaya cultivars at a diverse range of circumstances: At different transport temperatures, after sea freight or after air freight, upon harvest at different maturity stages and upon storage at different time periods and temperatures. The first goal was to understand the traits which are important for post-harvest quality of papaya. Therefore we measured a range of traits like weight, firmness, colour, Brix levels, respiration, ethylene production, mould growth and taste. We observed that:

- Weight loss after storage for 5 days at 18°C is faster compared to storage for 13 days at 10°C.
- In all our experiments firmness decreases during storage. Interestingly, storage temperature did not have a large effect on firmness; papayas softened at a similar rate at both 10 and 18°C
- Dry matter content remains similar upon storage for 5 days at 18°C or 13 days at 10°C.
- Respiration and ethylene production patterns indicate that papayas stored at 18°C are more metabolically active and ripen more quickly compared to storage at 10°C.
- The colour level reached after 5 days of storage at 18°C was only reached after 13 days at 10°C. Also in the experiment comparing storage at 10 versus 15°C, the rate of peel colour development was remarkably lower at 10 compared to 15°C.
- Fruit softening of papaya stored at 10°C was also remarkably lower compared to 15°C**. This indicates that storage temperature affects not only colour development but also softening of the fruit and can be used to adjust the ripening speed.**
- Transport at 10.5°C resulted in less bruising and skin damage, compared to transport at 12.6°C. **Together, the firmness and skin colour data suggest that transport at 10.5°C results in greener papayas on arrival, although not firmer. However it is important to realize that a period of time below 10°C may trigger browning.**
- Mature harvested papayas have lower hue values compared to fruits harvested at a green stage, however the rate at which the peel colour changed was similar.
- Green harvested papayas have lower mould levels compared to fruits harvested at mature stage.
- Firmness of papayas harvested at green stage is higher compared to papayas harvested at mature stage. Similar to the change in colour, also the rate at which fruit softening occurred is similar in papayas harvested at a green or mature stage. **The advantage of harvesting papayas earlier is that they will be more firm and more resistant to bruising and fungal attack. However, harvesting papayas too early may cause problems with ripening and development of sweetness.**
- Based on the levels of measured SSC (°Brix), mould and internal defects cultivar Tainung seems to be the best cultivar for export to Europe compared to Maradona or Bela Nova.
- **The combined effects of washing, applying a wax layer and giving an anti-fungal treatment minimized weight loss and mould compared to no treatment, or just washing and/or applying a wax layer.**
- To treat mould in papaya, avoiding the use of fungicides, heat treatment seems to have potential. Particularly the application of a water bath, which is already in use to export papayas from Brazil to the US to destroy insects, could be applied relatively easy. Packed papayas had a 0.5% higher moisture content, and reduced mould on both stem and fruit compared to unpacked papayas.
- Papayas stored for 16 days in CA were less dehydrated, but had similar levels of mould, compared to papayas that had not been stored in CA. Heat-treated papayas showed less fruit mould when treated at 49°C for 5 minutes, and less stem mould when treated at 49°C for 30 minutes.

In general we can conclude that, packaging papayas prior to transport, and heat treatment upon arrival at the wholesaler, reduces post-harvest fungal infection.

Last but not least, papaya taste is important for consumers. We compared the taste profile of cultivars Tainung, Maradona and the novel cultivar x. We observed that:

- The taste of Tainung was more appreciated compared to the taste of cultivar x, probably due to its low scores on bitterness and aftertaste.
- The taste profile of cultivar x was similar to the profile of cultivar Maradona, except that Maradona was experienced as sweeter and more-nutty.
- In general, the scores on enjoyability seems to be positively correlated to the scores on sweetness and fruitiness, and negatively correlated to bitterness and aftertaste. As expected, bitter papayas with a strong probably bitter aftertaste are less preferred by consumers.

Transport of papayas oversees, instead of by air transport, while maintaining quality levels, has both economic as well as environmental advantages. To maintain quality levels and increase consumer likeness it is important to take into account the effect of transport and storage temperatures, the harvesting stage and post-harvest treatments and finally the taste profile. This report summarizes our observations and recommendations.

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To explore the potential of nature to improve the quality of life

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Report 1916

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