Ripening of plum fruit

GreenCHAINge Fruit & Vegetables WP6 (BO-29-03-001-010

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Contents

Summary

Ripening of plums, from South Africa (SA), was studied following reefer transportation. In experiment 1, plum cultivars 'Pioneer' and 'African Rose' were ripened using different temperature scenarios. Both cultivars showed increased coloration during ripening, but this was much more pronounced in 'Pioneer' compared to 'African Rose'. In 'Pioneer' there was a clear decrease in firmness during ripening; this was correlated with the temperature sum. At a temperature sum of 100-120 degree-days, the fruit had soften completely and reached the "ready–to-eat" stage. Increasing the temperature sum did not further soften the fruit. Irrespective the temperature scenario, 'African Rose' showed no softening and did not become "ready-to-eat".
In experiment 2, plum cultivars 'Songold' and 'Southern Belle' were harvested three times during their production season, transported to the Netherlands (NL), and ripening was studied at three temperatures (16, 20 and 24°C for 2 days). 'Songold' was always less firm at arrival compared to 'Southern Belle'. The applied temperatures did not have a clear effect on the speed of ripening. Fruit firmness at arrival was similar for the different batches of each cultivar; fruit from later harvest batches showed slightly more softening during storage and shelf life than fruit from first harvest batch. Ethylene treatment (100 ppm, 24h) had effect on firmness loss in 'Southern Belle' when plums were ripened at higher temperature (ethylene effect was not tested in 'Songold'). Ethylene production in 'Songold' was about ten times higher than in 'Southern Belle' and increased during ripening in both cultivars. No clear effect of ripening temperature on ethylene production was observed.

This document is the result of a study as part of GreenCHAINge project. This study was executed from January 2015 until March 2019 by researchers of Wageningen Food & Biobased Research (WFBR), who performed an objective and independent study for Total Produce BV. and STEMS FRUIT, who partly financed this project.

1 Introduction

The GreenCHAINge project is a project financially supported by the industry and the Dutch government (Topsector horticulture public private partnership) comprising different sub-projects (work packages) focussing on different fruit and vegetable products. One of the sub-projects, work package 6, is dedicated to avocado and stone fruit (plums) and is carried out with and by Total Produce BV, STEMS fruit and Wageningen Food and Biobased Research (WFBR).

Transport of plums takes place in reefer containers from e.g. South Africa to Europe, especially in winter time. There are a great many different cultivars on the market, often divided into three groups according to skin colour: yellow, black and red. To enable continuous delivery of plums, fruit traders may handle over 30 - 50 cultivars during the year, with each cultivar only being available during a couple of weeks. Currently there are no specific, cultivar dependent, protocols for storage and ripening. Transportation in reefers mostly follows a sequence of specific temperature settings, called dual temperature treatment. This treatment is applied on plums that are chilling sensitive. Container is loaded with plums already pre-cooled at -0.5°C. After 5 days, the set point is changed to 7.5°C for a period of maximum 10 days. Thereafter, the set point is put back at -0.5°C for the remaining transport time. In some cases, prior to shipment, fruit are treated with the ethylene sensitivity blocker 1-MCP to delay ripening during transport.
Following transport fruit are marketed but quality is not always acceptable. Common disorders are lack of proper ripening and symptoms of low temperature damage, also called chilling injury symptoms (e.g. wooliness, internal browning, heterogeneity of ripeness).
The aim of this investigation was to gain more insight in the ripening behaviour of some different plum cultivars following transport from South African to Rotterdam and to test the effect of different ripening temperatures and ethylene on ripening behaviour and quality of the fruit.

2 Materials and methods

2.1 Fruit material and experimental design

Two experiments were performed. Imported plums were received from Total Produce BV, Rotterdam, immediately after arrival. Fruit was transported to Wageningen for experimental treatments. One experiment, referred in the present document as experiment 1, was done to study the ripening of two different cultivars (‘Pioneer’ and ‘African Rose’) under different temperature profiles and to study the dynamics of different ripening markers (colour, firmness, brix, pH, ethylene production, etc.) during ripening. In another experiment (experiment 2), the ripening behaviour of two plum cultivars (‘Songold’ and ‘Southern Belle) was studied 2 or 3 times during their harvest season (comprises about 4 to 5 weeks) to investigate the effect of the harvest time on ripening. In addition in this experiment the ripening was done at different temperatures and the effect of ethylene on ripening was determined.
On the last ‘Southern Belle’ batch, an ethylene treatment was applied during ripening and compared to the standard ripening protocol. Exogenous ethylene (100ppm) was applied in the first 24 hours of the ripening protocol.

2.2 Fruit ripening parameters

Texture was measured in different ways: non-destructively using limited compression methodology; destructively (at the end of the experiment) using a penetrometer. Brix was measured in fruit juice using a digital refractometer and pH of the sap was measured with pH indicator paper. Titratable acidity (TA) was determined by titration with 0.1N NaOH solution and expressed in percentage equivalent malic acid. Skin colour was measured using a colour box and digital camera. From the images, the L, a and b values were determined for each individual fruit. The overall colour variation during the complete treatment was expressed via the ΔE and calculated according to equation 1.

$$\Delta \boldsymbol{E} = \sqrt{(\boldsymbol{L}_{21} - \boldsymbol{L}_0)^2 + (\boldsymbol{a}_{21} - \boldsymbol{a}_0)^2 + (\boldsymbol{b}_{21} - \boldsymbol{b}_0)^2} \qquad (1)$$

For respiration rate and ethylene measurements, individual fruit were overnight enclosed in a 0.5L plastic cup. The accumulation of CO_2 and ethylene, and the depletion of oxygen in the headspace were determined. O_2 and CO_2 were measured with Checkmate-3 (Dansensor, Ringsted, DK); ethylene was measured by gas chromatography with flame ionization detector (Interscience, Breda, NL).
Dry matter (DM) was determined in fruit quarters, including peel, but not the pit. Fresh weight and weight following 48 hours of oven drying at 80°C were determined to calculate % dry matter.

More detailed information on experimental methods and procedures is available on request.

3 Results

3.1 Experiment 1

Plums of cultivars ‘Pioneer’ and ‘African Rose’ were ripened under 4 different temperature scenarios with different temperature sums:

- Path I: 11 days at 0.5°C, followed by 3 days to 8°C and 7 days at 12°C = 113.5 °C·day
- Path II: 21 days at 12°C = 252 °C·day
- Path III: 3 days at 8°C followed by 18 days at 12°C = 240 °C·day
- Path IV: 21 days at 20°C = 420 °C·day

3.1.1 Colour development

In all ripening scenarios and in both cultivars, the skin colour becomes darker red as the fruit ripens; this is reflected in the changing values of ΔL, Δa, Δb and ΔE. Figure 1 shows the change in colour parameters between the start (day 0) and end of the experiment (day 21). The colour changes increase with the increasing temperature sum. The colour changes are more pronounced in ‘Pioneer’ than in ‘African Rose’ (Figure 2). This indicates that ‘Pioneer’ shows better ripening than ‘African Rose’.

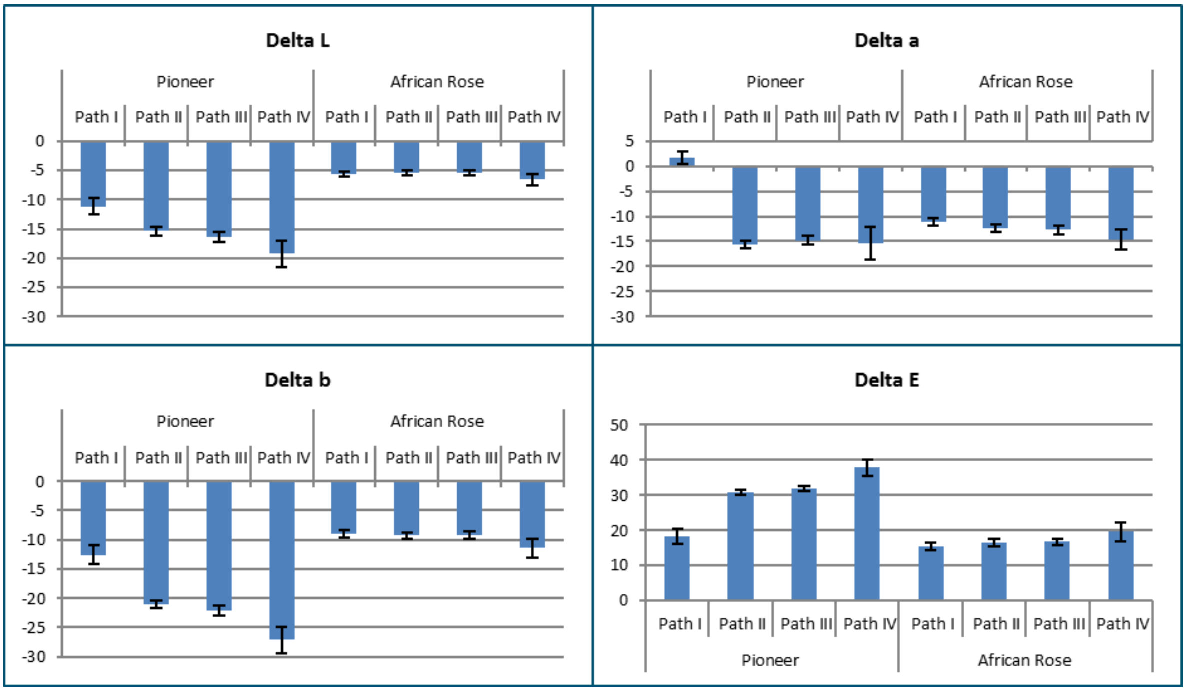


Figure 1: Difference in colour parameters (ΔL, Δa, Δb and ΔE) between day 0 and day 21 of storage/ripening under different temperature scenarios (n=20).

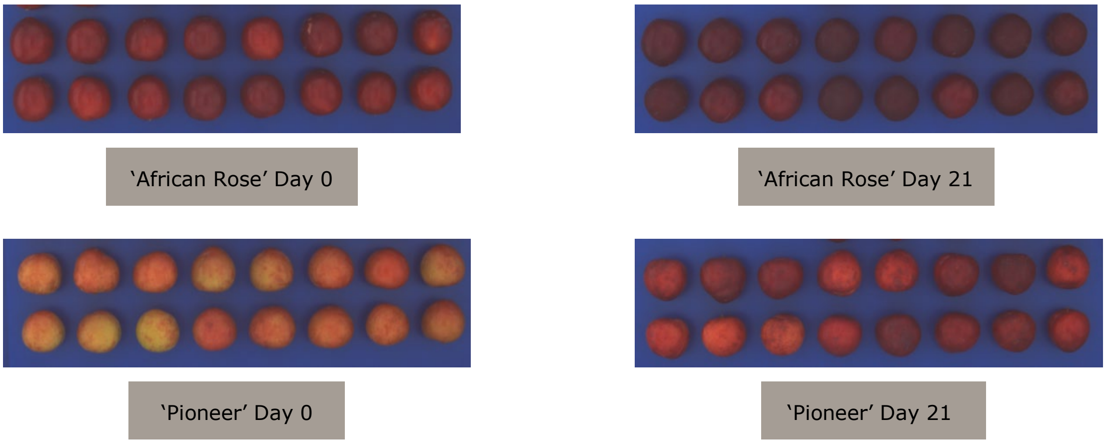


Figure 2: Pictures of 'African Rose' and 'Pioneer' plum cultivars taken on day 0 and 21 of storage period. These pictures were used for the colour analysis (proportion of dark and light colour and determination of ΔL, Δa, Δb and ΔE values.

3.1.2 Dry matter (DM), Brix and pH

DM, Brix and pH were measured at the end of the storage period. The % dry matter was about 10% in 'Pioneer' and 12.5% in 'African Rose'. DM was not influenced by the different storage scenarios. Brix of the fruit juice was about 10.5 for 'Pioneer' and 13 for 'African Rose' and was not affected by the different storage scenarios. pH was around 3 in 'African Rose' and was not affected by the storage scenarios. pH in 'Pioneer' depended on the storage: it increased with increasing temperature sum from 3 at 10.5 degree-days to 5 at 420 degree-days. This indicates that the plums are getting less acid when they are getting ripe.

Table 1: Brix and pH values of 'African Rose' and 'Pioneer' plum varieties measured after 18 days storage at 0.5, 12 and 20°C, ± standard deviation (n=8).

	Storage temperature	Temperature sum (° days)	Brix	pH
'African Rose'	0.5 °C	10.5	13.6 ± 0.5	3.0 ± 0.0
	12 °C	216	12.8 ± 0.3	2.8 ± 0.3
	20 °C	420	12.7 ± 0.4	3.5 ± 0.3
'Pioneer'	0.5 °C	10.5	11.6 ± 0.9	3.3 ± 0.6
	12 °C	216	10.5 ± 0.3	4.5 ± 0.3
	20 °C	420	10.3 ± 0.3	5.0 ± 0.0

3.1.3 Firmness

Firmness as measured by limited compression and by penetrometer showed a clear relationship with the temperature-sum in 'Pioneer'. At a temperature-sum of 100-120 degree-days the fruit have soften completely. Increasing the temperature-sum does not further soften the fruit. In 'African Rose', there was little or no softening, independent of the storage scenario (Figure 3).

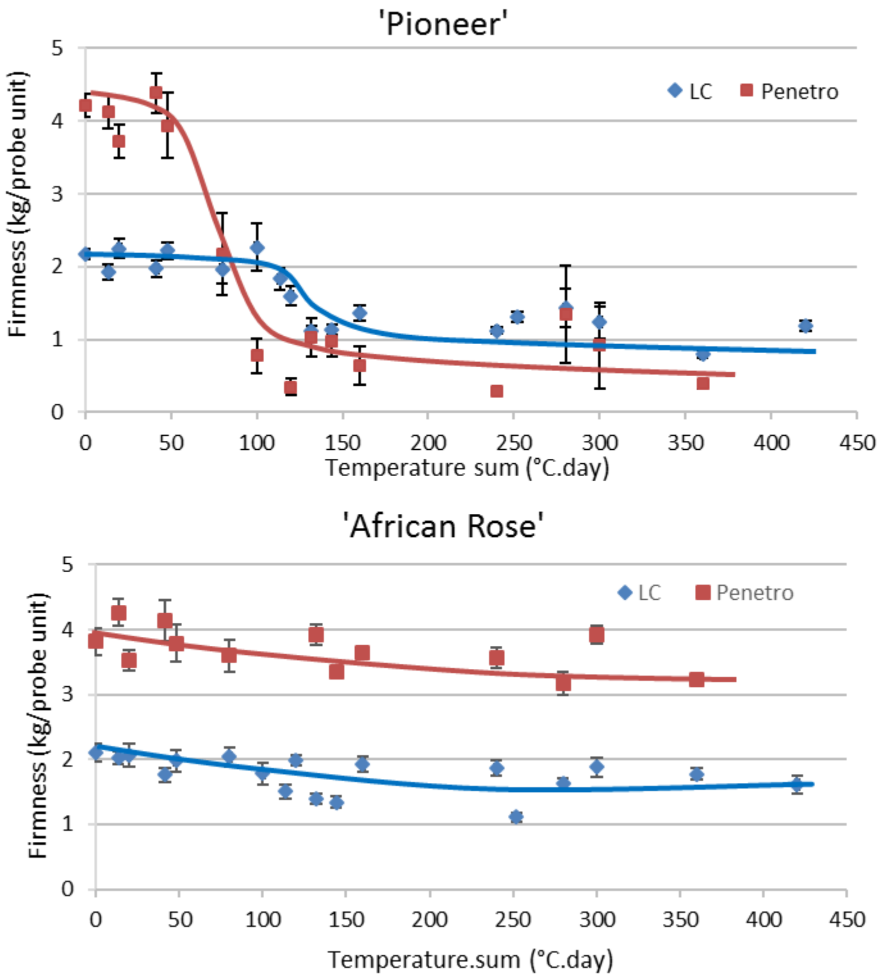


Figure 3: Firmness of 'Pioneer' (upper panel) and 'African Rose' (lower panel) measured with limited compression (blue dots) and penetrometer (red dots) plotted against the temperature-sum during the four ripening scenarios. Error bars represent the standard error (n=20).

3.2 Experiment 2

Ripening behaviour of two cultivars ('Songold' and 'Southern Belle') was studied at different times during their production season. For the ripening, different protocols were applied. At arrival, fruit were placed for 2 days at either 16, 20 or 24°C (and 85% RH). Thereafter fruit were placed for 3 days at 8°C (85% RH) and thereafter fruit was placed at display conditions, 18°C (60% RH). In 'Southern Belle', the effect of ethylene applied during the ripening at three different temperatures was tested (100ppm ethylene applied in the first 24 hours of ripening protocol) on the late harvest batch.
At arrival, plums of 'Songold' were already quite soft (between 1.5 and 2 kg) and almost ready–to-eat (Figure 4-A). Cultivar 'Southern Belle' was much more firm.
The different ripening temperatures (applied for 2 days) did not have a clear effect on the ripening speed. Although firmness at arrival was not different through the production season for both cultivars, the softening was slightly faster in fruit from late harvest compared to fruit from early harvest. This was especially clear in 'Southern Belle' (Figure 4-B).

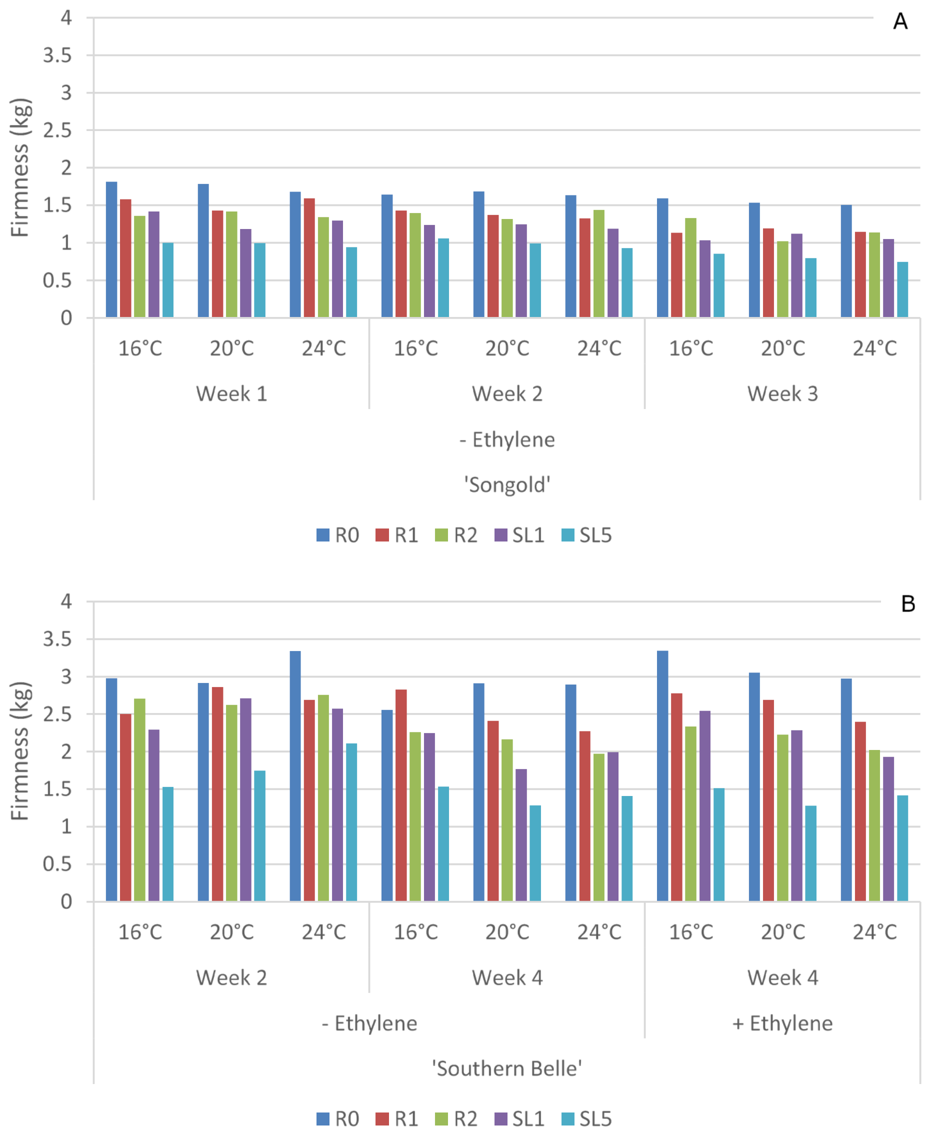


Figure 4: Firmness of cultivars 'Songold' (A) and 'Southern Belle' (B) measured with limited compression at regular intervals prior ripening (R0), during the ripening (R1 and R2; on first and second ripening day respectively) and shelf life period (SL1 and SL5; on first and fifth day respectively). Ripening consisted on three different temperature treatments (16, 20 and 24°C). 'Songold' was ripened without adding exogenous ethylene (- ethylene). 'Southern Belle' was ripened without adding exogenous ethylene (- ethylene) and with flushing 100ppm ethylene in the first 24 hours of ripening (+ ethylene) (n=20).

The effect of application of ethylene on ripening was tested in 'Southern Belle', late harvest batch. Ethylene (100 ppm) was applied during the first day of ripening at either 16, 20 or 24°C. Ethylene treatment did affect the softening speed (measured as loss of firmness) of the fruit when combined with high ripening temperature scenario (Figure 5). In this experiment, the ripening speed was slightly higher at 20 and 24°C compared to 16°C and it can be seen that softening stops as soon as the fruit are transferred to 8°C.

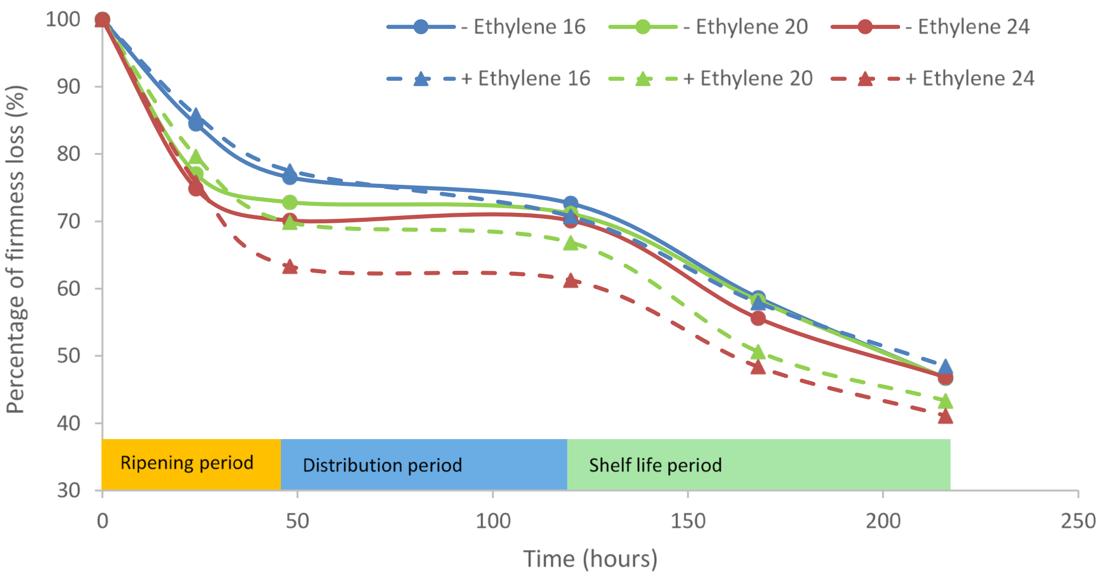


Figure 5: Loss of firmness of 'Southern Belle' ripened for two days at 16, 20 and 24°C with (+ ethylene) or without (- ethylene) addition of 100ppm ethylene during the first 24 hours of ripening. Firmness at the start of ripening was between 3 and 4 kg and designated as 100%. Boxes on the bottom of the figure schematize the storage profile: ripening period at three different temperature profiles, distribution period at 8°C; shelf life period at 18°C and 60% relative humidity (n=20).

Respiration rate was measured at arrival and after 2 days of ripening at 16, 20 and 24°C (data not shown). There was no clear effect of the ripening temperature on respiration rate in 'Songold' and 'Southern Belle'. The harvest time also did not have a clear effect on respiration. The treatment with ethylene of 'Southern Belle' fruit from late season did not affect the respiration rate.
Ethylene production of fruit was measured at arrival (measurement was done at 8°C) and after 2 days of ripening at 16, 20 and 24°C (fruit were first cooled down to 8°C before starting ethylene production rate measurement). In both cultivars, there was no consistent difference in ethylene production with respect to ripening temperatures. Ethylene production of 'Songold' was very high (around 100 – 140 µL/kg·h during ripening); production was lower in the late harvest than in the earlier harvests (Figure 6-A). Ethylene production in 'Southern Belle' was much lower (5-25 µL/kg·h during ripening) than in 'Songold'. Ethylene production in 'Southern Belle' was higher in late harvest compared to early harvest (Figure 6-B).

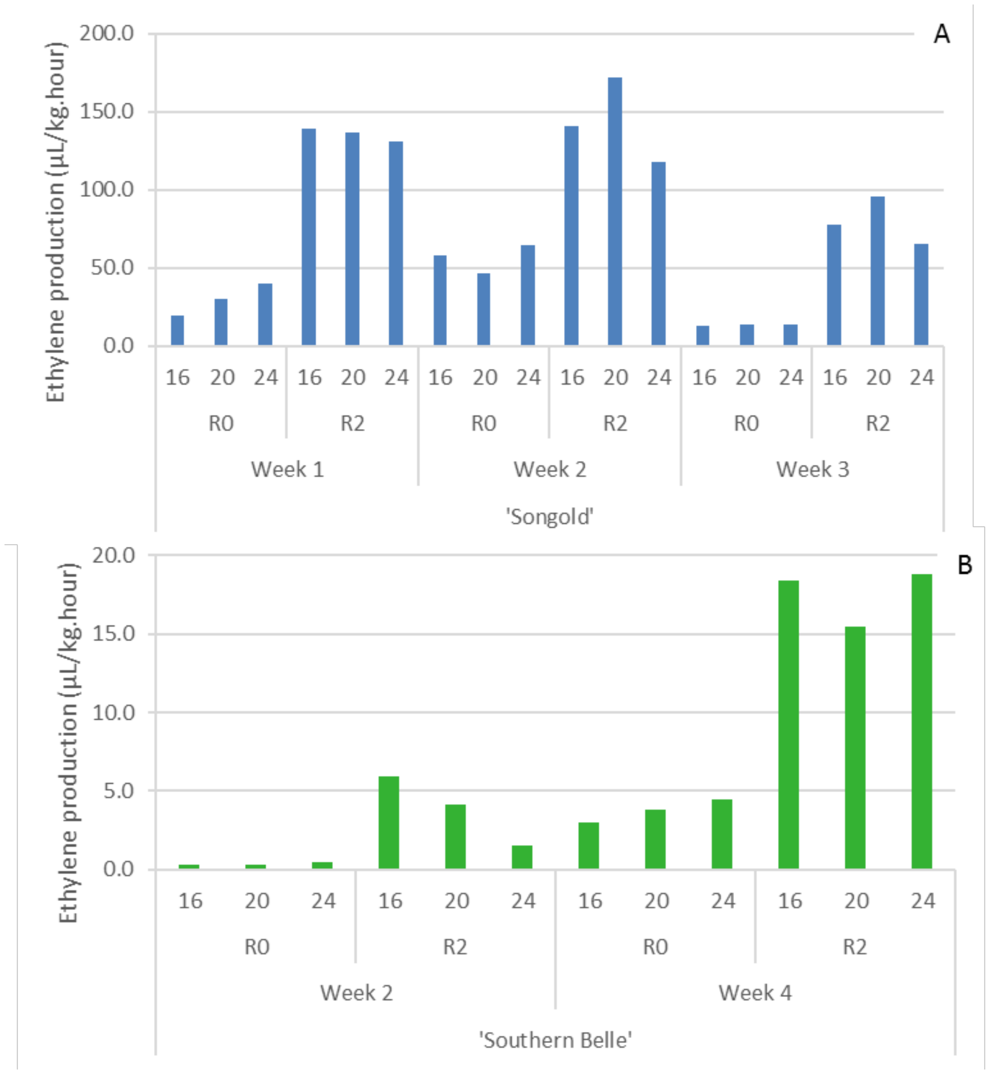
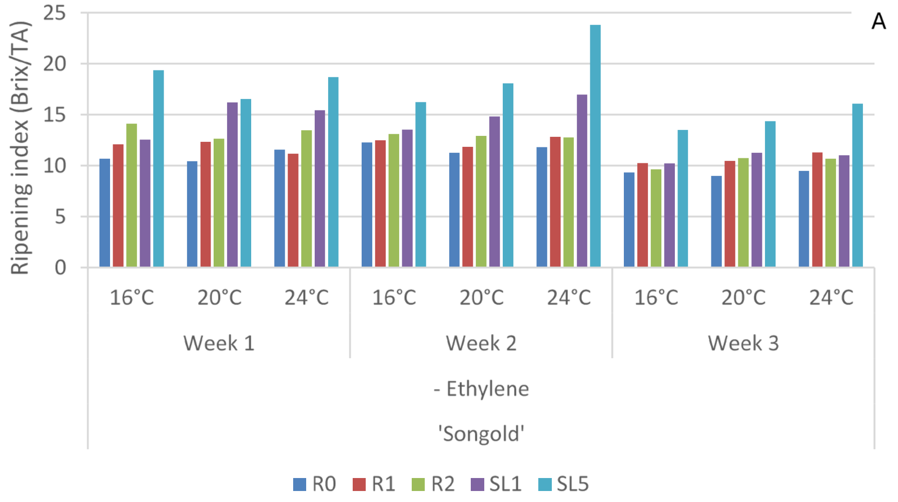


Figure 6: Ethylene production at arrival (R0, measured at 8°C) and ethylene production after 2 days (R2) of ripening at different temperatures (measured at 8°C) in 'Songold' at 3 harvest times (upper figure: A) and in 'Southern Belle' at 2 harvest times (lower figure: B)(n=5).

At different times during the ripening, storage and shelf life, the ripening index (RI) was calculated (= °brix/TA%). A ripening index of about 13 and up is considered acceptable as ready-to-eat. All fruit of 'Songold' arrived with RI around 10 and reached RI values over 13 already after 1 day of shelf life for the two early batches (Figure 7-A). The latest batch showed slower ripening and reached acceptable RI values later during the shelf life. Higher ripening temperature generally resulted in higher RI values.
In 'Southern Belle' RI was well below 10 in the early batch, indicating unripe fruit (Figure 7-B). These fruit did not further ripen. The later batch showed some ripening; at day 5 of the shelf life RI reached an acceptable value. Ethylene treatment did not affect the RI.



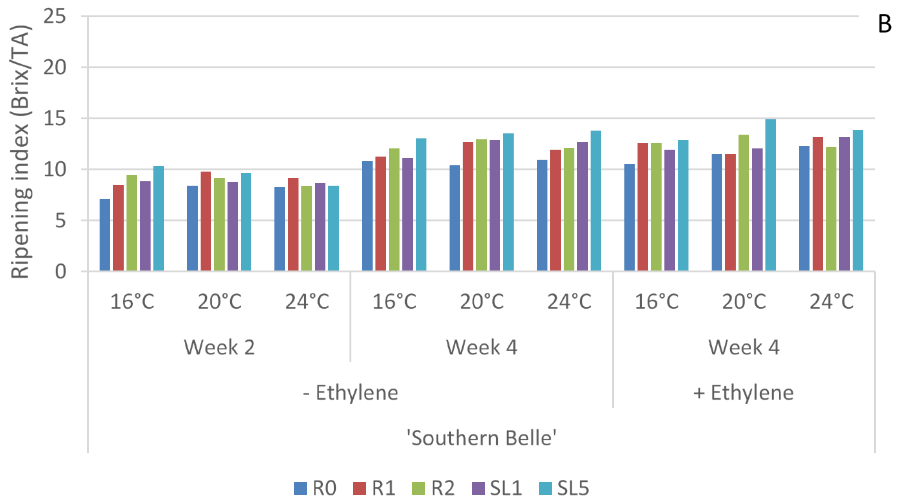


Figure 7: Changes in ripening index of 'Songold' (upper figure: A) and 'Southern Belle' (lower figure: B) during ripening at three temperatures (16, 20 and 24°C) and subsequent shelf life, repeated over 3 ('Songold') or 2 weeks ('Southern Belle'). In week 4, part of the 'Southern Belle' plums were treated with 100ppm ethylene (+ Ethylene) during the first 24 hours of ripening (n=10).

4 Discussion

In experiment 1, plum cultivars ‘Pioneer’ and ‘African Rose’ following reefer transportation were ripened using different temperature scenarios. In ‘Pioneer’ there was a clear decrease in firmness during ripening; this was correlated with the temperature-sum. At a temperature-sum of 100-120 degree-days the fruit had soften completely. Irrespective the temperature scenario, cultivar ‘African Rose’ showed no softening and did not reached a good eating quality. The reason for this different behaviour is not clear. Both cultivars arrived with a firmness of about 4 kg (penetrometer). Either ‘African Rose’ was picked too immature, or the conditions during transport were unfavourable resulting in lack of ripening. It would be advisable to develop better protocols for harvest maturity for different cultivars and to compare the ripening potential of harvested fruit before and after transportation.

In experiment 2, plum cultivars ‘Songold’ and ‘Southern Belle’ were harvested 3 times during their production season, transported to NL, and ripening was studied at 3 temperatures (16, 20 and 24°C for 2 days). Cultivar ‘Songold’ was always less firm at arrival compared to ‘Southern Belle’. This indicated that the fruit were picked at different maturity stages or that ‘Songold’ shows more softening during the transport period. The ethylene production of ‘Songold’ was much higher than of ‘Southern Belle’. This may also indicate that ‘Songold’ may show ripening during transport. Especially in this cultivar, and others with high ethylene production, it may be useful to treat with ethylene blocker, like 1-MCP, before transport. The applied temperatures did not have a clear effect on the speed of ripening. This may be caused by the short ripening period that we applied (only 2 days). In each cultivar, fruit firmness at arrival was similar for the different batches; fruit from later harvests showed some more softening during storage and shelf life (lower firmness values at end of shelf life) than fruit from first harvest. This indicates that fruit from the later harvest were more mature. Ethylene treatment (100 ppm, 24h) was tested in ‘Southern Belle’ but had little effect on firmness loss; only at the higher ripening temperature softening was stimulated by ethylene). In all batches of ‘Songold’, the ripening index was well over 10 at the end of shelf life, indicating that the fruit were acceptable. In ‘Southern Belle’, especially from the first harvest, the ripening index was lower, indicating that the fruit should be picked more mature to support good quality at the consumer. At the end of the shelf life period, plums were tasted during an informal tasting session. ‘Southern Belle’ plums showed quality issues such as mealy texture, low juiciness. These quality issues were not scored during this experiment but should be taken into account when evaluating the effect of ripening protocols and harvesting batch on the ready-to-eat quality of plums.

5 Conclusion

The present study was applied over only four cultivar of plums and over a short period during the export season 2016-2017. Depending of the production location and the exporter portfolio, a wide range of plum cultivars are cultivated over the world. Not all the cultivars are suitable for long transport under low temperature. Although exporters had screened their main cultivars, it was clear in this study that not all cultivars react on the same way to ripening protocols after transport to Europe.

- In general the temperature-sum theory can be applied for some of the cultivars ('Pioneer' and 'Sungold' (result not shown)) in order to predict the ripening behaviour of the plums and the Ready-to-eat stage. Knowing the temperature-sum behaviour of plum cultivar, allow the importer to apply the optimal ripening protocol (high temperature and duration) to deliver plums at the best ready-to-eat stage to consumer.
- Overall the results showed huge differences between the cultivars in ripening behaviour; the exact background of the differences is not clear and there are no straightforward methodologies at hand to improve the ripening.
- Huge differences were also observed within the harvesting windows of the cultivar 'Southern Belle'. The softening speed, the ethylene production and the ripening index behaved differently according to the harvest batch. These indicate that post-harvest quality is strongly correlated with the maturity stage of the plums at the harvesting moment. A cultivar-specific protocol for picking stage, based on e.g. firmness and ripening index, would be a first important step to improve quality. It would be also advisable to develop better protocols for harvest maturity per cultivars and to compare the ripening potential of harvested fruit before and after transportation.
- In addition, the effect of the long cold storage and the impact of temperature and ethylene in ripening needs further attention. Indeed several chilling injury symptoms were observed on plums during the ripening protocols. The chilling injury symptoms were responsible for heterogeneous ripening of the plums or outbreak of internal quality disorders such mealy texture, low juiciness. The ethylene treatment during ripening did not cure the chilling injury symptoms, but at the contrary enhanced them. No clear conclusion about the effective effect of the ethylene treatment during the ripening protocol can be drawn as the plums used for this test suffered from chilling injury.

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

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The mission of Wageningen University and Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 5,000 employees and 10,000 students, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.