Validation of Australian food quality traceability technology (Smart-r-tag)

Quality development of two perishable fruits; Strawberry and Avocado

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WAGENINGEN
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Preface

Producers, end-customers and regulators alike are requiring more information about products that are brought to market, especially for perishable food produce. Detailed comprehensive handling and condition information of those goods throughout the supply chain will become expected by all stakeholders. Existing solutions to achieve this, comprising a growing global market exceeding USD 3B, are costly, labour-intensive and bulky.

SensaData is a Melbourne based start-up developing a next-generation data logger called Smart-r-tag for use in food cold/cool supply chains (and other applications) to track and report on produce condition for increased safety and reduced waste etc. SensaData partnered with La Trobe University to develop the technology. The SensaData technical development program will finalise soon, including in-field trials with major Australian food producers.

Wageningen University & Research (WUR) in the Netherlands (see www.wur.nl) is a leading international agri/food institution including leadership in post-harvest technology and application of food quality decay models. This collaborative project with SensaData seeks to establish further evidence that Smart-r-tag capability provides real value to food supply chain participants, through lab tests and field trials using WUR expertise, systems and facilities. The present work could yield further opportunities leveraging Smart-r-tag capabilities to address WUR's global research and industry profile to improve food supply chains.

Summary

Food quality is influenced by abiotic conditions such as: temperature, relative humidity, gasses (oxygen, carbon dioxide, etc.). These were monitored in experiments with strawberry and avocado by Smart-r-tag sensors manufactured by SensaData and provided to WUR. The data from the sensors were used as input for prediction of fruit quality and shelf life with a quality loss model.

The objective of this research is to test if SensaDatas sensor tags are able to capture abiotic conditions as input for quality prediction for strawberry and avocado. The study did not include developing new quality models based on the acquired data. Models described in literature and developed by WUR are used for quality prediction. The sensors used in the study are the Smart-r-tag Ver1, capturing temperature and relative humidity information and the Smart-r-tag Ver2, recording temperature, relative humidity, oxygen - and carbon dioxide concentration.

In two experiments, one with strawberry and one with avocado, the quality of the produce was evaluated and the abiotic storage conditions were monitored using the Smart-r-tags. During storage the strawberries showed different levels of decay depending on the storage temperature, especially the storage condition at 20 °C affected the fruit severely.
Avocados stored at different temperatures showed different levels of firmness loss. During the periods in which temperature was high (22 °C and 18 °C) the decrease in firmness was the highest.

The Smart-r-tags are able to measure and log the abiotic conditions (temperature, oxygen and carbon dioxide) in which the produce was stored. However, for relative humidity there are also some non-realistic readings, readings above 100%. Furthermore concerning the monitoring of oxygen and carbon dioxide contents (inside modified atmosphere packaging), the carbon dioxide measurements are inaccurate when the actual carbon dioxide contents are higher than 10% and/or when relative humidity in the packaging headspace is saturated.

For quality modelling purpose, the parameter temperature was used as input variable. This data was as input useful for quality prediction. The quality prediction did not exactly match the observed quality, as the quality models were not optimised for these specific produces and abiotic conditions. The models can be adapted or other models could be used to fit the data better.

The following recommendations can be given based on the work that was performed:

1. Validate relative humidity sensors when measuring at high humidity. In supply chains with perishable product like fruit and vegetables humidity is commonly above 90% RH and often higher than 95 % RH. It is important that the sensors operate well in this RH range for them to be useful in practice. Certainly a humidity cannot be higher than 100% RH.
2. Validate if the carbon dioxide sensor is measuring the correct concentration when measuring under high humidity. We found a discrepancy between our reference and the output of the Smart-r-tag ver2 sensor.
3. Select and use a quality prediction model that fits the need and support the decision making of the intended customer for the tags. There are many models described in literature, but they serve a certain purpose. Generic models are relatively easy to use, but might be too general for the case on hand. This has to be evaluated in a follow-up project, with practical pilots.

In a possible follow-up WUR is willing to assist SensaData with selecting and setting up the best quality prediction models in combination with the needs of the customer.

1 Introduction

Food quality is influenced by abiotic conditions such as: temperature, relative humidity, impact, gasses (oxygen, carbon dioxide, etc.). These will be monitored by sensors manufactured by SensaData and provided to WUR. This information will be used as input for prediction of food quality via a quality loss model. The Q-loss calculation provides a view on the history of the monitored products in terms of quality loss (% of initial quality) and gives a prediction of remaining quality or shelf life which can provide options to optimise stock management strategies. Together with monitored data by the SensaData tags, the calculated quality information (Q-loss) can be reported via a future web based information exchange platform.

SensaData obtained a grant from the Australian academy of technology and engineering to fund research of Wageningen Food & Biobased Research to independently test the tags for gathering input for food quality prediction for 2 fruits: strawberry and avocado

1.1 Research question

The research question in this study is:

Do SensaDatas sensor tags capture abiotic conditions as input for good quality prediction for strawberry and avocado?

For this research no new models were developed but of-the-shelf models made by WFBR were used. This report is intended for SensaData and the funding agency.

2 Material and methods

The trials have addressed the condition monitoring requirement for 2 different produce types: strawberries and avocadoes and include:

- Different temperature conditions
- Different packaging types to test gas sensor and relative humidity sensors
- Observed quality decay of samples
- Comparison with WFBR models of predicted quality decay

2.1 Sensors

Two sensor platforms were used for obtaining abiotic conditions:

1. Smart-r-tags ver1: capable of recording temperature and relative humidity measurements

Figure 1 ***Smart-r-tag ver1*** ***(photo: SensaData)***

2. Smart-r-tags ver2: capable of recording temperature, relative humidity, oxygen and carbon dioxide measurements. According to SensaData, the gas sensors used in the Smart-r-tags ver2 have an accuracy of ±1% absolute. The carbon dioxide sensor ranges from 0 to 25%. The relative humidity sensor has an accuracy of ± 5%.

Figure 2 ***Smart-r-tag ver2*** ***(Photo: SensaData)***

Data is extracted via a handheld RFID-reader and exported to a database after reading. The data are then later downloaded in an Excel format.

For reference measurements in the avocado experiment at regular basis, oxygen and carbon dioxide content in the packaging headspace was measured with Checkmate 2 (Dansensor, Ringsted, DK). The accuracy of the gas sensors are ±0.1% for the oxygen, ±0.5% absolute and ± 1.5% relative for the carbon dioxide sensor. The Checkmate 2 is yearly calibrated by the company Gullimex (Borne, NL).

2.2 Fruit

The fruit used for the testing is:

- Strawberry: Dutch grown Elsanta. Harvested on May 15th 2018.
- Avocado: Peruvian Hass Avocado. Harvest April 2018.

2.3 Model

2.3.1 Strawberry

The quality development of strawberry is modelled using Hertog et al (1999) by calculating the increase of effected strawberries by decay with:

$$\frac{dN}{dt} = k_s N \frac{N_{\max} - N}{N_{\max}} \quad (1)$$

With N the percentage of effected strawberries [0-100]. N_{max}=100%, k_s growth factor (/day), with

$$k_s = k_{s,ref} e^{\frac{E_a}{R_{gas}}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)} \quad (2)$$

R_{gas} the universal gas constant, equal to 8.314 J/mol/K, E_a equal to 70000 J/moll, $k_{s,ref}$ is 0.6 /day, T the temperature (K), T_{ref} = 283K. E_a and $K_{s,ref}$ are commonly used to adapt the model for other strawberry varieties and to get a better fit with the raw data.

2.3.2 Avocado

The shelf life (SL) of avocado's is determined by the quality attributes firmness, the colour and any internal disorders. The SL is limited by the quality state ready-to-eat, which corresponds to a certain firmness. Experiments have shown that colour development precedes loss of firmness. From practice it is known that produce becomes unacceptable during the distribution if a certain colour limit has been reached, even though the firmness limit is not reached at that moment. Based on this, one can conclude that it would be sufficient to predict the colour. However, the ready-to-eat limit is given in terms of the firmness and not all varieties of avocado have a change in colour upon ripening. Therefore, the generic keeping quality model for avocado will predict the shelf life based on both characteristics. It is based on the generic keeping quality model as developed by Tijskens and Polderdijk 1996 and extended to dynamic environmental conditions by Tijskens and Evelo (1994) and Hertog (2004).
The quality acceptance limits depend on quality inspection moment in the distribution chain.

The keeping quality (KQ) is defined as the time that a product will remain acceptable during storage or distribution. The shelf life (SL) is defined as the keeping quality at standard conditions.

2.3.2.1 Constant environmental conditions

If the quality is determined as the sum of several quality attributes (*n*) degrading by non-interfering processes, then the keeping quality at constant temperature can be written as

$$KQ = \frac{f\left(Q_0, Q_{\lim}\right)}{\sum_{i=1}^{n} k_i} \quad (3)$$

with k_i the rate constant of quality attribute *i* and $f\left(Q_0, Q_{\lim}\right)$ the function describing the underlying quality decay mechanism as function of the initial quality Q_0 and the acceptance limit Q_{lim}. Equation (3) assumes that if all quality attributes have the same order of reaction kinetics, then the rate constants can be summed. Often *k* follows Arrhenius equation (2). The rate constants are such way that $\sum_{i=i}^{n} k_i^{\text{ref}} = 1$ d^{-1}. The keeping quality at T^{ref} is

$$KQ\left(T^{\text{ref}}\right) = \frac{f\left(Q_0, Q_{\lim}\right)}{\sum_{i=1}^{n} k_i^{\text{ref}}} \quad (4)$$

Combining (3) and (4) gives KQ independent of the actual decay mechanism, under the assumption that the initial quality and quality limits do not change for different temperatures, as

$$KQ = \frac{KQ(T^{\text{ref}})\sum_{i=1}^{n} k_i^{\text{ref}}}{\sum_{i=1}^{n} k_i} \tag{5}$$

2.3.2.2 Dynamic environmental conditions

In normal distribution chains the conditions are not constant and the impact of every constant temperature period must be considered. For infinitely small time steps the change in quality Q is given by

$$\frac{dQ}{dt} = -\sum_{i=i}^{n} k_i Q^m \tag{6}$$

with m the order of quality decay. With this equation the remaining KQ at certain standard conditions, or the SL, is

$$KQ = \frac{Q_s^{1-m} - Q_{\lim}^{1-m}}{(1-m)\sum_{i=1}^{n} k_i} \quad \text{for } m \neq 1$$
$$KQ = \frac{\ln(Q_s / Q_{\lim})}{\sum_{i=i}^{n} k_i} \quad \text{for } m = 1 \tag{7}$$

with Q_s the value of the quality at the time during the distribution chain at which the SL is calculated.

2.4 Experimental set up

2.4.1 Strawberry

2.4.1.1 Storage facility

For normal air (NA) storage the fruit was stored in a room equipped with temperature and relative humidity control. For the controlled atmosphere storage the fruit was stored in a flow through system where oxygen and carbon dioxide is controlled actively via mass flow control and gas chromatographs. In the flow through system temperature is also controlled.

2.4.1.2 Planning and abiotic conditions

For strawberry the start of the experiment is May 16th 2018 and quality has been assessed via the quality evaluation according to paragraph 2.4.1.3. End quality has been evaluated 6 days later on May 22nd. The abiotic conditions are according to Table 1:

Table 1 Abiotic settings for strawberry storage

Condition no.	Temperature [°C]	RH	O_2	CO_2
1	6	90	NA[1]	NA
2	6	100	NA	NA
3	0	90	NA	NA
4	20	90	NA	NA
5	6	90	5	15
6	6	90	1	20

For condition 2 the fruit was packed in plastic bags to have a high humidity. The packed punnets were stored in the same room as condition 1.

[1] NA: Normal Air

5 punnets containing approximately 24 strawberries (~500 gr.) were used per conditions together with the reference measurement on the starting day.

Figure 3 ***Strawberries in flow through system with Smart-r-tag ver2 sensors before start of storage period*** ***(Photo: Eelke Westra)***

2.4.1.3 Quality evaluation

The strawberries were assessed for calyx and decay using a hedonic scale (Table 2):

Table 2 Hedonic scale for strawberry quality assessment

Calyx (per berry)	Decay (per berry)
0: Fresh green	0: Perfect
1: Yellow and/or 1 leaf brown	1: Dry damage
2: Multiple leaves brown	2: Wet damage spots or multiple dry spots
3: > 50% brown	3: Multiple wet damage spots
	4: Rot or Microbial spots
	5: Severe rot or microbial damage (> 50% of strawberry)

2.4.2 Avocado

2.4.2.1 Storage facility

For normal air (NA) storage, the fruit was stored in a room equipped with temperature and relative humidity control. For the controlled atmosphere storage, the fruit was packed in modified atmosphere packaging after ripening.

2.4.2.2 Planning and abiotic conditions

For avocado the start of the experiment is May 8th 2018 and quality has been assessed via the quality evaluation according to paragraph 2.4.2.3. In the first phase, the fruit has been ripened in cell with 85% relative humidity and controlled temperature (22°C) for at least 3 days. During the ripening period, the texture of the avocado will be analysed several times with limited compression (LC) method using a Guss fruit texture analyser. The ripening period ended when at least 80% of the avocado batch had reached the RTE 2 stadium (acoustic AWETA LC values< 22$Hz^2.g^{2/3}$). After ripening, a maximum 3 day transport period was simulated at 5°C. Just after the transport period, the avocado will be transferred to the shelf life room. The shelf life simulation will consist to dispose the avocado in room at 18°C and 60% RH. The texture, via AWETA measurement, and the ripening stadium will be followed on day 0 and daily from day 3 of the shelf life period. The shelf life period will end when at least 60% of the avocado batch has reached ready-to-eat stadium 3 (acoustic AWETA texture < 18.3 $Hz^2.g^{2/3}$).

In the second additional test, the Smart-r-tag with oxygen and carbon dioxide logger were used to record the packaging headspace gas composition in time. Four different packaging bags material/characteristics were used to pack ripened avocados. Bags were made of bi-oriented propylene or low density polyethylene and with laser micro-perforations. In each bag (20*22 cm), two avocados were packed together with one Smart r-tag, flushed with a gas mixture made of 5% O2 and 10% CO2 and stored at 18 °C for 17 days. Quality of avocado was assessed on day 17.

***Figure 4 Avocados packed in different MAP films** (Photo: Maxence Paillart)*

2.4.2.3 Quality evaluation

After shelf life all avocados are tested for quality following the hedonic scale:

- Vascular browning 1 -5 (5 = severe)
- Pulp decay 1 – 5 (5 = severe)
- Stem rot 1- 3 (3 = severe)

At the end of the shelf life period, all individual avocados are manually scored according to the ready-to-eat scale (see Table 3) and opened to score any internal disorders.

Table 3 ready-to-eat scale for avocados

RTE class	Description	Texture (AWETA) ($Hz^2.g^{2/3}$)
1	RTE not OK – too hard	>22
2	RTE OK, but still hard	18.3-22
3	RTE OK	11.3-18.3
4	RTE OK, but getting too soft	9-11.3
5	RTE not OK – too soft	<9

Four batches were consisting of 80 avocados were used to go through the simulated supply chain.

For the test involving the modified atmosphere packaging and the Smart-r-tag sensor, each batch consisted of one bag with two avocados. The quality evaluation as well as the firmness measurement were performed on the last day of the shelf life period.

3 Fruit testing

3.1 Strawberry

3.1.1 Quality

The strawberries stored for 6 day showed visible signs of decay. Compared to the reference batch evaluated on moment of storage all stored fruit had lost quality. The fruit with the most temperature abuse (20°C in storage condition 4) no quality was left since all fruit had decayed, decay score of 5 (Figure 5).

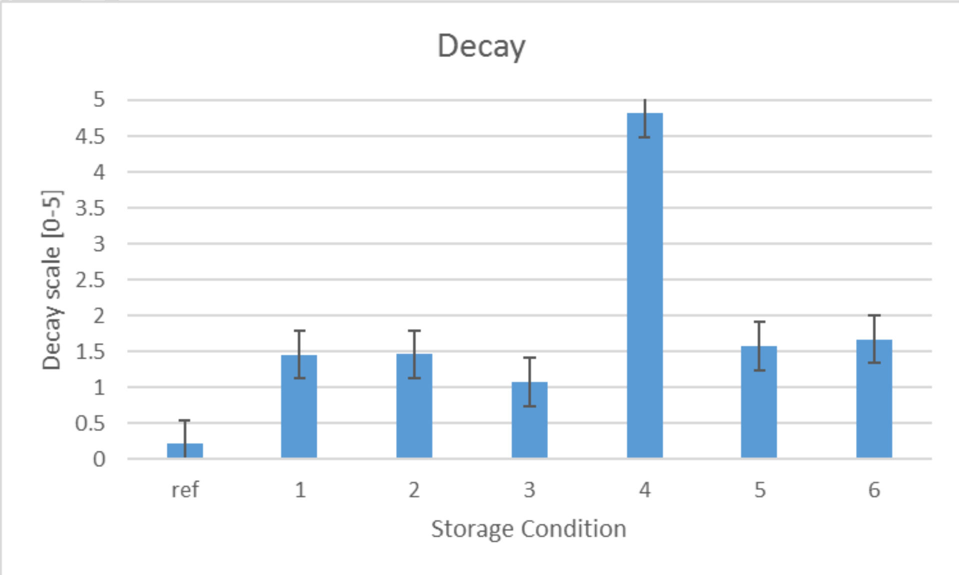

Figure 5 Decay of (un)stored strawberries. Error bars represent the least significance difference

Storing at 0°C (storage condition 3) showed least decay (score of 1) over a period of 6 days. The calyx of all cold stored fruit was unaffected. Storing at 20°C resulted in all leafs completely brown and a severity score of 3.

3.1.2 Sensor output

In the normal air, 6 Smart-r-tags were installed to monitor the abiotic conditions. All 6 were able to measure the set conditions for the temperature (Figure 6). The peaks in storage condition 3 represent the defrost cycle of the refrigeration system.

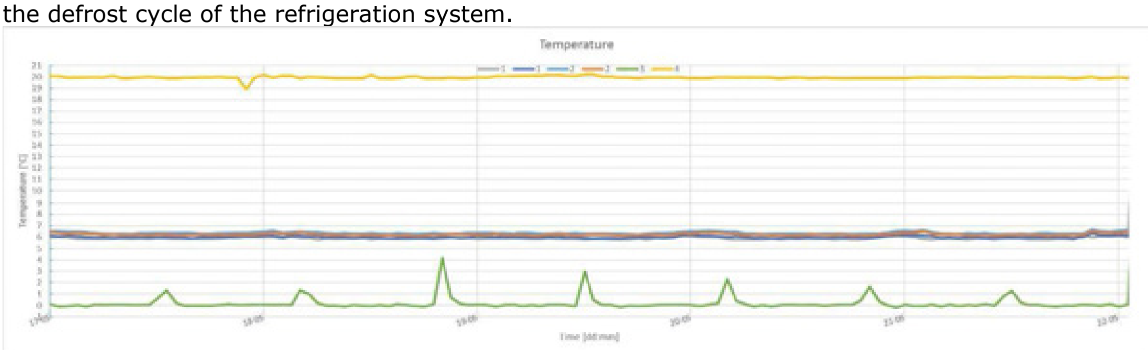

Figure 6 Temperature during the storage period for condition 1 (grey, dark blue lines), condition 2 (light blue, orange lines), condition 3 (green line) and condition 4 (yellow line)

The measured relative humidity is given in Figure 7.

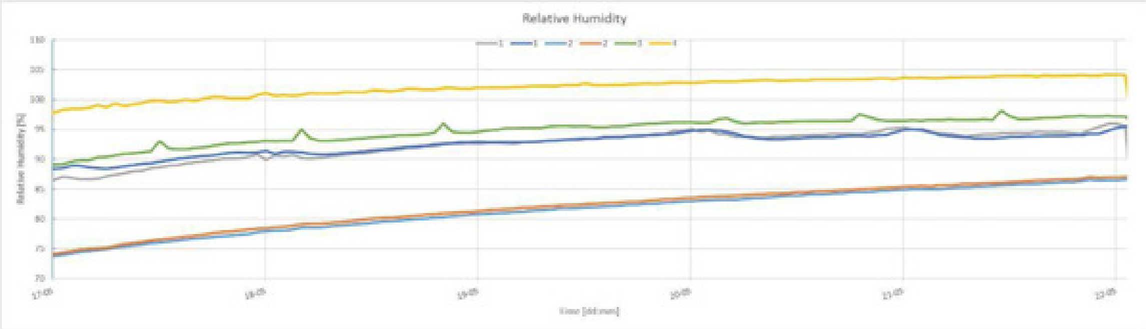

Figure 7 ***Relative humidity during the storage period for condition 1 (grey, dark blue lines), condition 2 (light blue, orange lines), condition 3 (green line) and condition 4 (yellow line)***

Apparently for condition 2 the plastic bag did not increase the relative humidity but prevented the moisture control to increase the humidity and thus keeping the berries dryer then 90% RH. This is not a sensor error since both sensors installed measured the same condition. The relative humidity inside the plastic bag was not measured otherwise.
For condition 4 the sensor measured a humidity of almost 105% RH, physical this is not possible since the maximum RH is 100%. Unfortunately, this measurement was not doubled.
For condition 3 the peaks represent the defrost cycle of the cooling system.

The gas concentration for conditions 5 and 6 are given in Figure 8.

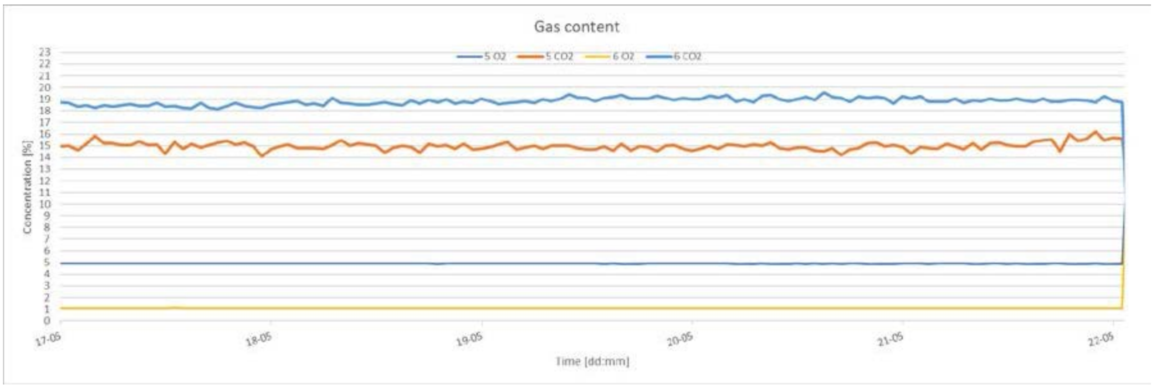

Figure 8 ***Oxygen and carbon dioxide during the storage period for condition 5 (dark blue, orange lines), condition 6 (light blue, yellow lines)***

The carbon dioxide for condition 6 is 2% lower than the set condition of 20%. The Smart-r-tag is measuring the oxygen concentrations according the expected accuracy. The offset for oxygen and carbon dioxide in both storage conditions are given in Figure 9.

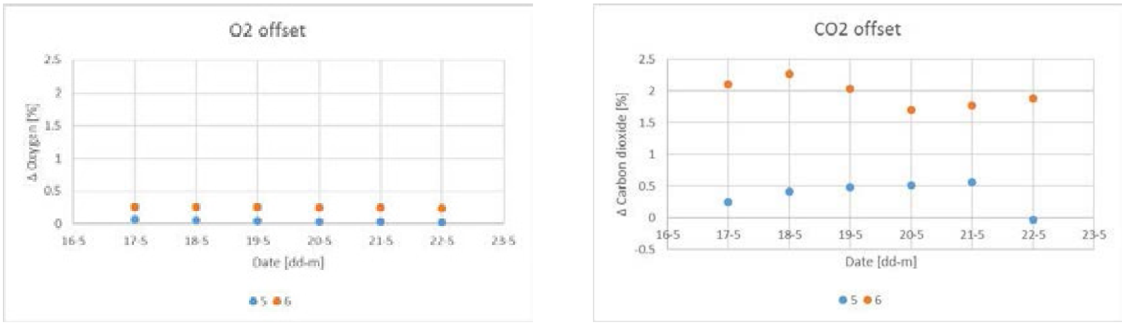

Figure 9 ***Oxygen and carbon dioxide difference with measured setpoint of storage conditions for condition 5 (blue) and condition 6 (orange)***

3.2 Avocado

3.2.1 Quality

During the supply chain simulation depending on the batch, the avocados softened over time (Figure 10).

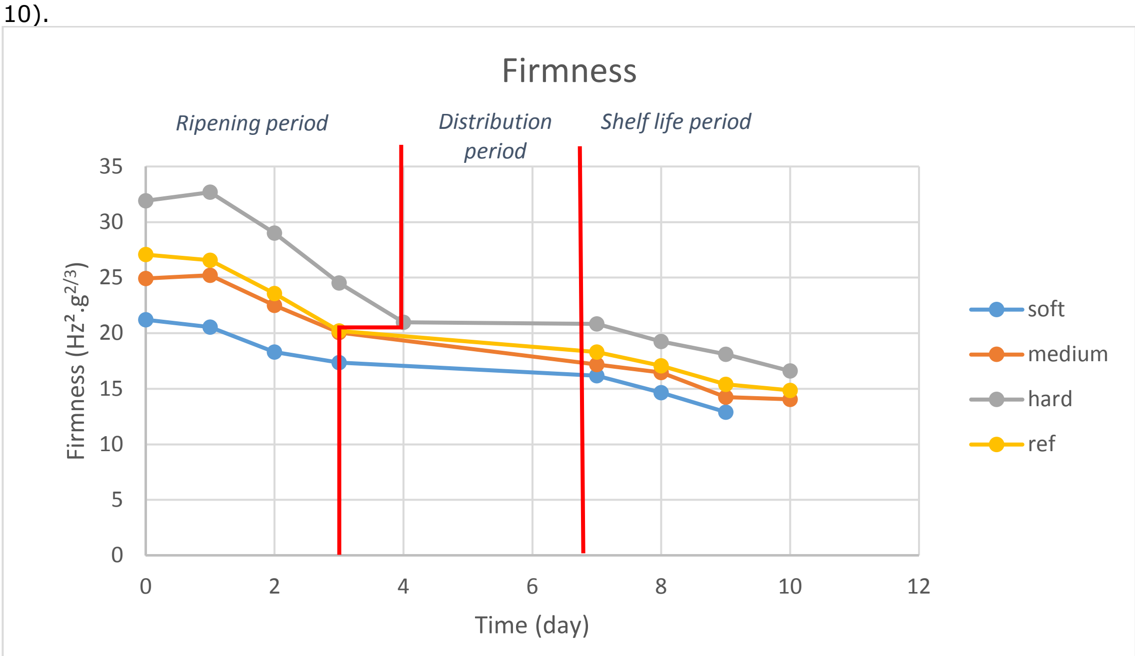

Figure 10 ***Firmness decrease of avocados over time for soft batch (blue line), medium (orange line), hard (grey line) and unsorted references (yellow line). Red vertical lines schematize the beginning and end of the ripening, distribution and shelf life periods.***

Depending on the initial firmness they softened on average from 27 to 15 $Hz^2 \cdot g^{2/3}$ over a period of 10 days. The initial soft avocados reached a ready-to-eat stage at day 8, the medium avocados on day 9, the unsorted (ref) on day 10 and the firm batch did not reach that stage before the experiment was stopped.

3.2.2 Sensor output

4 Smart-r-tags were installed to monitor the abiotic conditions. All 4 were able to measure the set conditions (Figure 11). The peaks during storage represent the measurement moments for firmness and door openings.

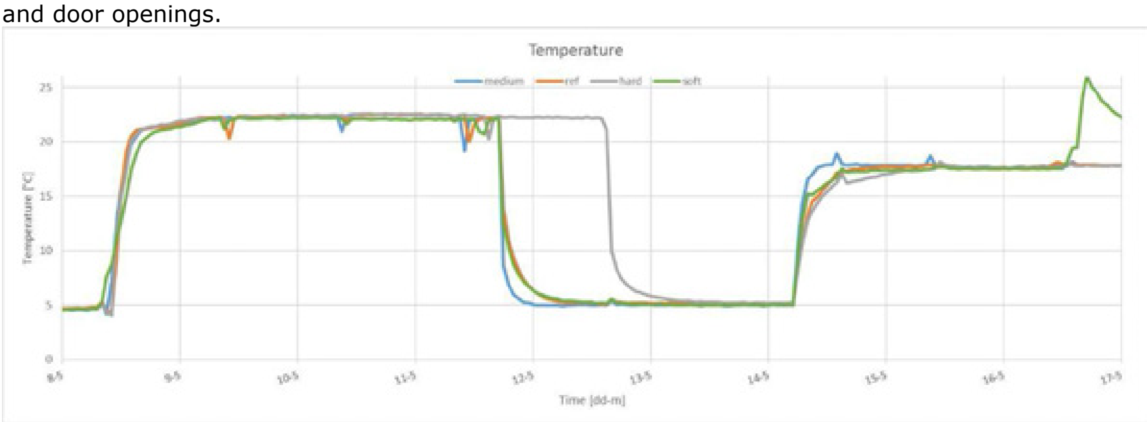

Figure 11 Temperature during the storage period for medium (blue line), ref (orange line), hard (grey line) and soft (green line)

Relative humidity is given in Figure 12.

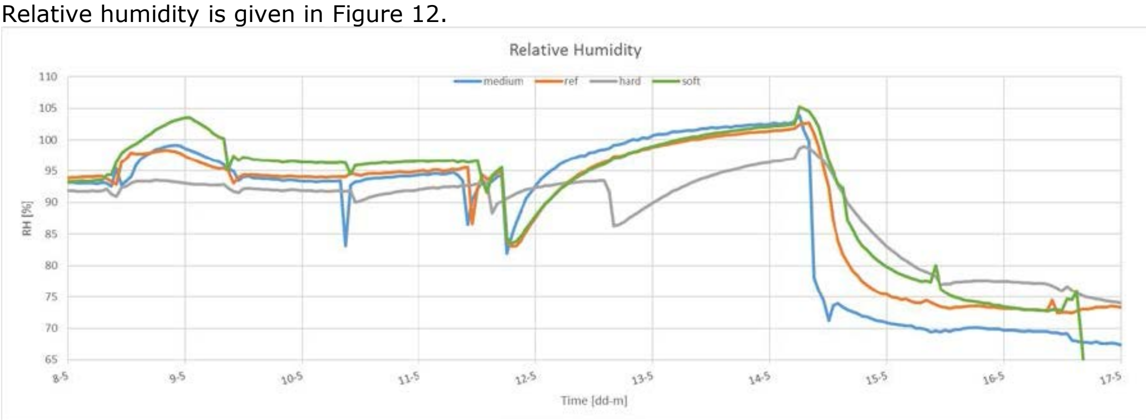

Figure 12 Relative humidity during the storage period for medium (blue line), ref (orange line), hard (grey line) and soft (green line)

For the medium, reference and soft batches the sensors measured a humidity of almost 105% RH, physically this is not possible since the maximum RH is 100%. This has probably to do with the difficulty of the sensor to measure RH above 95% and the accuracy of the sensor in this range. These three batches were stored in the same room which implies that similar relative humidity results are expected. It seems that the relative humidity sensors were not well calibrated or differ quiet a lot from each other. According to SensaData experts (short communication on 06-09-2018), this overestimation of the relative humidity may be explained by the accuracy specifications of the smart-tags sensor. The relative humidity sensor has an accuracy of ± 5%.

Similar inconsistencies in the relative humidity results were observed with the Smart-r-tags ver2 introduced inside the avocado packaging (Figure 13). Although the inaccuracy in the first two days could be explained by the ± 5% accuracy given by the sensor supplier, it seems that other mechanisms occurred later during the shelf life period that increased the inaccuracy of the relative humidity sensor.

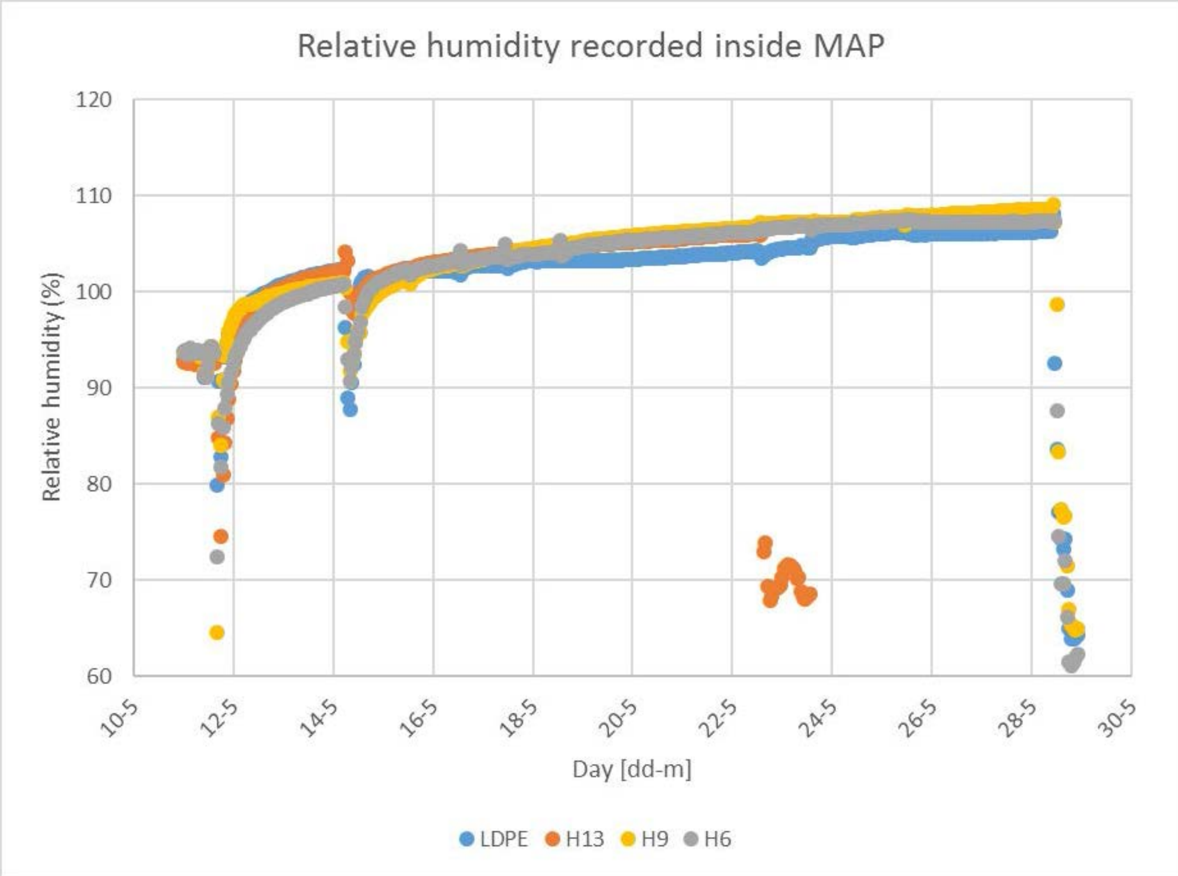

Figure 13 Relative humidity recorded by the Smart-r-Tags during the shelf life period of the packed avocados (shelf life storage conditions: 18 °C and 60% relative humidity). Smart-r-Tags sensors were packed inside the packaging together with two ripe avocados.

The gas content inside the packaging headspace was recorded every hour by the Smart-r-tag sensors. The daily average oxygen and carbon dioxide contents was then calculated (on basis of the Smart-r-tags ver2. outputs) and compared with the gas content measurement made with the Checkmate 2 gas analyser (one measurement point per evaluation day). Figure 14 shows a good correlation between the oxygen concentration measured with the Checkmate 2 (x-axis) and the average oxygen content recorded by the Smart-r-tag (y-axis). It seems that correlation between the two sensors outputs is better for oxygen content above 10%. When oxygen content is lower than 10% (packaging H9), the Smart-r-tags ver2. oxygen sensor is not able to differentiate the oxygen contents.

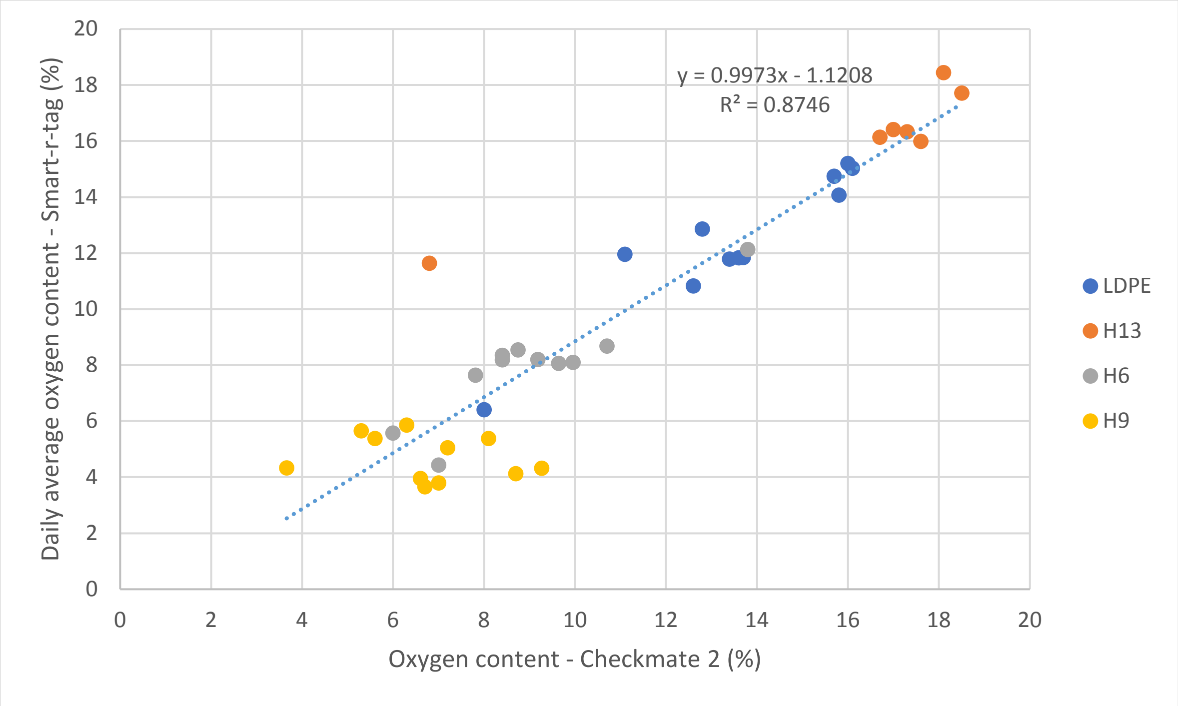

Figure 14 Oxygen content measured at 11 evaluation moments during the storage period of the 4 MAP samples. Oxygen content was measured with Checkmate 2 (x-axis) and plotted against daily average oxygen content recorded with the Smart-r-Tag sensors (y-axis).

Concerning the correlation between the carbon dioxide content measured with the Checkmate 2 and the carbon dioxide content recorded with the Smart-r-tag ver2., it seems that the Smart-r-tags are not able to measure CO_2 values correctly when they exceed 10 % (Figure 15). Figure 16 shows the specific accuracy of the results recorded below 10 %. According to the sensor specification, the range of the carbon dioxide sensor is between 0 and 25%. These specifications were verified and supported by the results obtained in the strawberry experiment (Figure 8). The inaccurate results of carbon dioxide content when this one was higher than 10% may be attributed to a side effect of high relative humidity condition on the sensor accuracy. The inconsistency in the CO_2 results were indeed observed in the similar recording period with a RH range over 100 %(Figure 13 and Figure 15). Additional tests under high and low relative humidity conditions are advised in order to verify this theory.

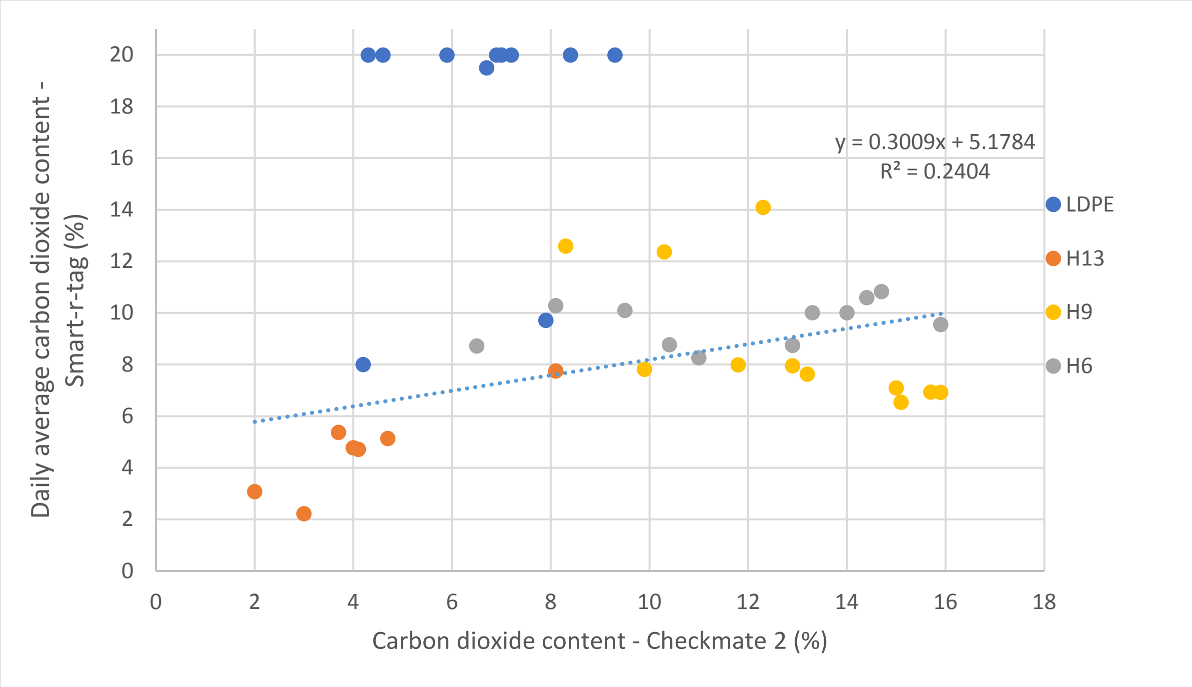

Figure 15 ***Carbon dioxide content measured at 11 evaluation moments during the storage period of the 4 MAP samples. Carbon dioxide content was measured with Checkmate 2 (x-axis) and plotted against daily average carbon dioxide content recorded with the Smart-r-tag sensors (y-axis)***

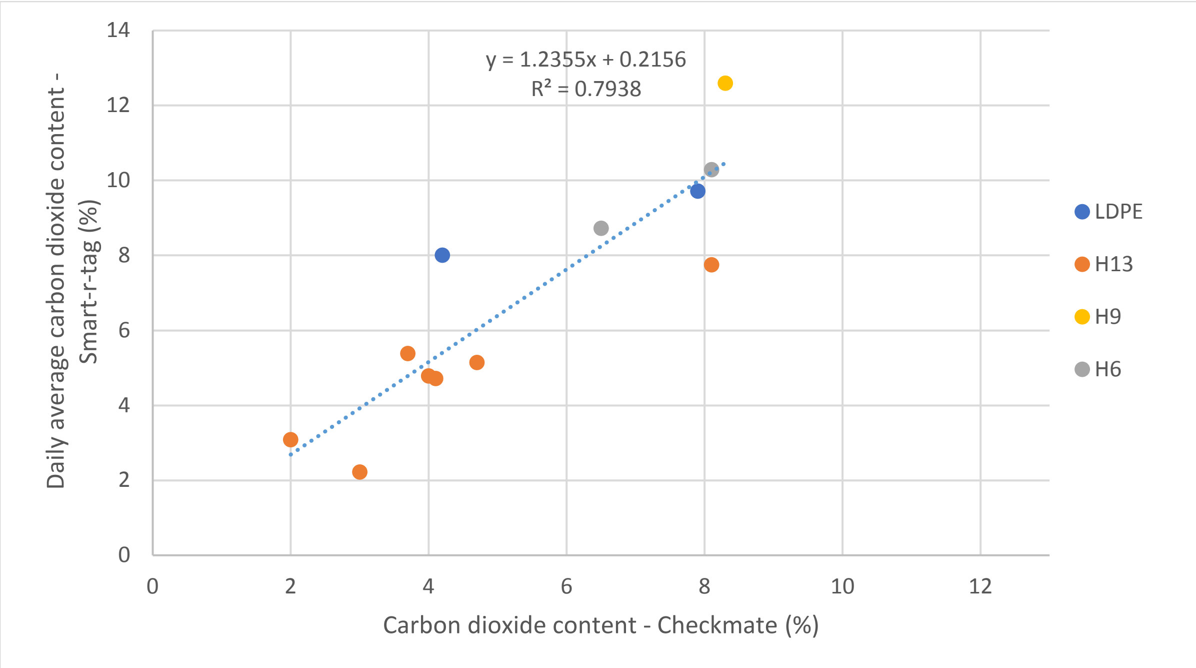

Figure 16 ***Correlation between carbon dioxide content measured with Checkmate 2 (x-axis) and recorded with the Smart-r-tag sensors (y-axis) when restricting the CO_2 range below 9%.***

4 Quality prediction

4.1 Strawberry

Using the data of the Smart-r-tags used in the experiment of the first 6 days as input into equation 1 and 2 gives the following quality prediction in terms of decay development over time (Figure 17). The development of decay after day six is an extrapolation of the setpoint temperature as storage temperature for the following days.

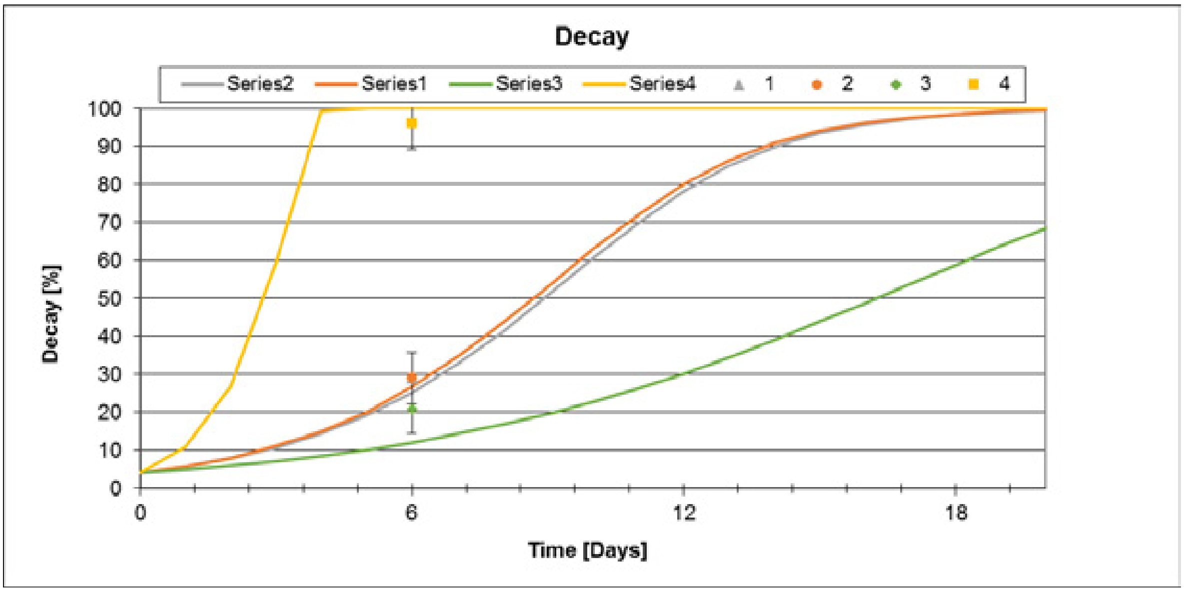

Figure 17 Decay development over time for storage condition 1 (grey line), condition 2 (orange line), condition 3 (green line) and condition 4 (yellow line). Together with realised decay on day 6 for condition 1 (grey triangle), condition 2 (orange circle), condition 3 (green diamond) and condition 4 (yellow square)

The storage condition 1, 2 and 4 are correctly predicted. For condition 3 there is an under prediction of the quality. This can be adapted by changing the E_a an $k_{s,ref}$ values in the used model. The current data is not sufficient to make those adaptions.

The remaining shelf life depends on the set criteria. For example, one can set the end-of-shelf-life on a decay percentage of 30%. The model predicts (also based on actual temperature data) that the shelf life for condition 4 would be ended on day 2, for condition 1 and 2 the shelf life ends on day 7 and condition 3 the shelf life ends on day 18.

4.2 Avocado

Using the data of the Smart-r-tags used in the experiment of the complete supply chain simulation as input into equation 2 and 7 for gives the following quality prediction in terms of quality loss over time (Figure 18). This translates in a keeping quality[2] when limit is set at a quality limit[3] of 92 %.

[2] Remaining quality assuming keeping temperature remains the same as last measured temperature
[3] Arbitrary

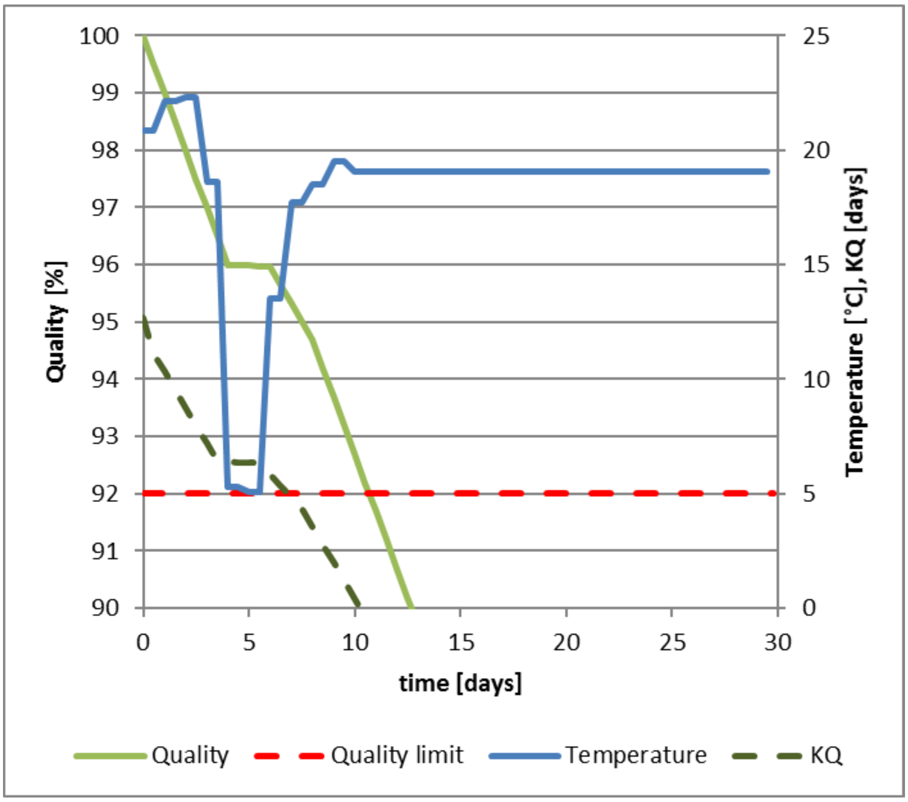

Figure 18 Generic avocado quality (light green solid line), temperature (blue solid line), keeping quality (green dashed line) over time for measured supply chain temperatures with quality limit (red dashed line) set at 92 %.

This model shows that after 11 days, quality scores below the acceptance limit (red line) when stored at 19 °C. The remaining quality (also called keeping quality) is then equal to 0. Depending on the consumer expectation, the acceptance limit can be adjusted on the quality axis. In the case of the avocado dataset and for European consumer, the minimal firmness for ready-to-eat avocado is fixed to $9Hz^2.g^{2/3}$. Per extrapolation on the Figure 10, avocado of batches medium and reference are reaching this minimum firmness after 11 days of storage. The data from the experiments shows in paragraph 3.2.1 that most fruit (except the hard batch) is almost ready-to-eat stage or already over (soft batch) another 4 days of shelf life is very feasible.
The present model can be applied for green and triggered avocado (consumer accepts in this case unripe avocado as still good avocado as he/she expects to consume the fruit once it reaches the perfect ripening stadia. In case of a model that predicts the quality of ready to eat avocado, the present model is then not correct as it is not possible to distinguish unripe avocado (too hard) from the ready to eat avocado.

5 Conclusion and recommendations

5.1 Conclusion

The research question to be answered is:
Do SensaDatas sensor tags capture abiotic conditions as input for good quality prediction for strawberry and avocado?

The used tags are able to measure and log the abiotic conditions (temperature, oxygen and carbon dioxide) in which the produce was stored. However, for relative humidity there are strange measurement above 100% RH. Furthermore when measuring the oxygen and carbon dioxide content inside modified atmosphere packaging, the carbon dioxide measurement were inaccurate when values were above 10% and when relative humidity in the packaging headspace was saturated.

This data (temperature) is as input useful for quality prediction. The quality prediction does not exactly match the observed quality; however this has more to do with the used model then with the acquired abiotic conditions. The models can be adapted or other models could be used to fit the data better.

5.2 Recommendations

The following recommendations can be given based on the work that was performed:

1. Validate relative humidity sensors when measuring at high humidity. In supply chains with perishable product like fruit and vegetables humidity is commonly above 90% RH and often higher than 95 % RH. It is important that the sensors operate well in this RH range for them to be useful in practice. Certainly a humidity cannot be higher than 100% RH.
2. Validate if the carbon dioxide sensor is measuring the correct concentration when measuring under high humidity. We found a discrepancy between our reference and the output of the Smart-r-tag ver2 sensor.
3. Select and use a quality prediction model that fits the need and support the decision making of the intended customer for the tags. There are many models described in literature, but they serve a certain purpose. Generic models are relatively easy to use, but might be too general for the case on hand. This has to be evaluated in a follow-up project, with practical pilots.

Literature

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