Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

I. Gerbert\textsuperscript{1}, M. Linke\textsuperscript{1}, W.B. Herppich\textsuperscript{1}, P. Kläring\textsuperscript{2}, M. Geyer\textsuperscript{1}

\textsuperscript{1}Leibniz-Institut für Agrartechnik Potsdam-Bornim e.V.
\textsuperscript{2}Leibniz-Institut für Gemüse und Zierpflanzenbau Großbeeren
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction
Thresholds
Modelling the Stiffness
+ Thermal Impact
+ Water Effect
+ Preharvest Influence
Modelling the Shelflife
Application
Summary

Fruit and vegetable supply chain

Big demand of all players in the fruit and vegetables supply chain to get online information on every step in the chain:

**Producer:** produce, pre harvest parameters (i.e. plant protection), produce quality, time, temperature at and after harvest ...

**Transport:** Time, temperature, rh ..

**Farm coop.:** + storage conditions, packaging, time, temperature, rel. humidity ...

**Transport:**

**Wholesale:** + time, temperature, rel. humidity ...

**Transport:**

**Retail:** + time, temperature, rel. humidity ...

**Transport:**

**Consumer:** ??

ColdChain 2008, Bonn
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction

Thresholds
Modelling the Stiffness
+ Thermal Impact
+ Water Effect
+ Preharvest Influence
Modelling the Shelflife
Application
Summary

Quality management

Producer
Farm cooperative
Wholesale
Retail
Consumer

Transport

Traceability

Wireless datalogger fitted with shelf life prediction model

- line-of-sight is not required
- rapid and simultaneous reading of tags resp. logger
- larger data storage capacity
- real-time information updates along the supply chain
- integration of sensors
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction
Monitoring the Environmental Conditions during Transport and Distribution and Predicting the Shelf Life

Input:
- produce
- producer
- time
- preharvest conditions
- quality relevant parameters
- ...

Output:
- producer
- transportation conditions
- quality
- shelf life
- ...

Webserver/Database
Control
Prediction Model
Procedere 1
Procedere 1
= expected shelf life

ColdChain 2008, Bonn
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Predicting the Shelf Life based on Thresholds of Marketability

**Consumer Preferences:**
- visual: [color, brightness, intactness, shape,...]
- olfactory: [smell,....]
- tactile: [consistency, elasticity, stiffness,...]
- gustatory: [taste, (texture),....]

(EU Norms)

**Properties and Processes:**
- compounds: [pigments, volatile components, acid, SSC, lipids,....]
- metabolism: [transpiration, respiration, degradation, transformation,...]

Threshold of marketability for tomato: stiffness
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions.

Predicting the Shelf Life based on Thresholds of Marketability

- **loss of water**
- **temperature = constant**
- **limit value 1**
- **limit value 2**
- **loss of compounds**
- **increasing boundary layer resistance**
- Microbiological degradation
- time after harvest >>>>>>>

**Introduction**

**Thresholds**

**Modelling the Stiffness**
+ Thermal Impact
+ Water Effect
+ Preharvest Influence

**Modelling the Shelflife Application**

**Summary**
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

**Modelling the Stiffness of Tomato**
Thermal impact [C. VAN DIJK (2006)]

Effect of storage time and temperature on the firmness of tomatoes at 3°C; 12°C; 20°C and 25°C
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Modelling the Stiffness of Tomato
Thermal impact [C. VAN DIJK (2006)]
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

### Modelling the Stiffness of Tomato

<table>
<thead>
<tr>
<th>cultivar 'Counter'</th>
</tr>
</thead>
<tbody>
<tr>
<td>n= 432</td>
</tr>
</tbody>
</table>

**preharvest conditions**

<table>
<thead>
<tr>
<th>packaging</th>
<th>closed package (cp)</th>
<th>open package (op)</th>
</tr>
</thead>
</table>

**storage temperature [°C]**

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>10</th>
<th>15</th>
<th>20</th>
</tr>
</thead>
</table>

**storage humidity [%]**

<table>
<thead>
<tr>
<th></th>
<th>98</th>
<th>98</th>
<th>98</th>
<th>78</th>
<th>45</th>
<th>43</th>
</tr>
</thead>
</table>

**water vapour partial pressure difference [hPa]**

<table>
<thead>
<tr>
<th></th>
<th>0.25</th>
<th>0.34</th>
<th>0.47</th>
<th>2.7</th>
<th>9.01</th>
<th>13.3</th>
</tr>
</thead>
</table>

**expert panel**

<table>
<thead>
<tr>
<th>n&lt;sub&gt;tomato&lt;/sub&gt;</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>N&lt;sub&gt;panelist&lt;/sub&gt;</td>
<td>30</td>
</tr>
</tbody>
</table>

**threshold of marketability (Young’s Modulus [Nmm⁻¹])**

| 1 (sphere 7mm, N<sub>max</sub> 3N) |
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Modelling the Stiffness of Tomato
Thermal impact

preharvest condition 2/400
initial stiffness ~ 2.5Nmm⁻¹
YM = f(t) Adj R²~0.95

△ 10°C_cp
△ 10°C_op
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction

Thresholds

Modelling the Stiffness

+ Thermal Impact

+ Water Effect

+ Preharvest Influence

Modelling the Shelflife

Application

Summary

Modelling the Stiffness of Tomato

Thermal Impact

![Graph showing Young's Modulus vs. time after harvest]

- Preharvest condition 2/400
- Initial stiffness ~ 2.5 N/mm
- YM = f(t) Adj R² ~ 0.95

- 10°C_cp
- 10°C_op
- 15°C_cp
- 15°C_op
- 20°C_cp
- 20°C_op

ColdChain 2008, Bonn
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

**Introduction**

Thresholds

**Modelling the Stiffness**

- Thermal Impact
- Water Effect
- Preharvest Influence

**Modelling the Shelflife**

**Application**

**Summary**

---

**Modelling the Stiffness of Tomato**

**Thermal Impact**

Initial stiffness $\sim 2.5 \text{Nmm}^{-1}$

$YM = f(t; T)$

Preharvest condition $2/400$

Adj $R^2 = 0.99$

(8d to 19 d)
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Modelling the Stiffness of Tomato
Thermal Impact + Effect of Water Regime

preharvest condition 2/400
initial stiffness ~ 2.5 Nmm⁻¹
YM = f(t; T)

**op** Adj R²=0.99
(8d to 19 d)

**cp** Adj R²=0.96
(13 d to 27 d)
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction
Thresholds
Modelling the Stiffness
+ Thermal Impact
+ Water Effect
+ Preharvest Influence
Modelling the Shelflife
Application
Summary

Modelling the Stiffness of Tomato
Thermal Impact + Effect of Water Regime

preharvest condition 2/400
initial stiffness ~ 2.5Nmm\(^{-1}\)
YM = f(t;T)

\[ \text{Youngs Modulus [Nmm}^{-1}\]\n
\[ \text{time after harvest [d]} \]
\[ \text{temperature [°C]} \]

\[ \text{Adj R}^2=0.99 \]
\[ \text{Adj R}^2=0.96 \]

ColdChain 2008, Bonn
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

**Modelling the Stiffness of Tomato**

Thermal Impact + Effect of Water Regime

<table>
<thead>
<tr>
<th>packaging</th>
<th>closed package (cp)</th>
<th>open package (op)</th>
</tr>
</thead>
<tbody>
<tr>
<td>storage temperature [°C]</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>thermal impact [°C*h] condition 2/400</td>
<td>6480</td>
<td>6480</td>
</tr>
</tbody>
</table>

YM = f(t; T)

---

Thermal impact [°C*h] condition

Preharvest condition 2/400

Initial stiffness ~ 2.5Nmm⁻¹

YM = f(t; T)
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Modelling the Stiffness of Tomato
Thermal Impact + Effect of Water Regime [VPD=f(t;rH)]

<table>
<thead>
<tr>
<th>packaging</th>
<th>closed package (cp)</th>
<th>open package (op)</th>
</tr>
</thead>
<tbody>
<tr>
<td>storage temperature [°C]</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>VPD [hPa]</td>
<td>0.25</td>
<td>0.34</td>
</tr>
<tr>
<td>thermal impact [°C*h] condition 2/400</td>
<td>6480</td>
<td>6480</td>
</tr>
</tbody>
</table>

preharvest condition 2/400
YM = f(t;T;VPD)
Adj R² = 0.96
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction

Modelling the Stiffness of Tomato
Thermal Impact + Effect of Water Regime [VPD=f(t;rH)] + Preharvest Influence

<table>
<thead>
<tr>
<th>Packaging</th>
<th>Closed Package (cp)</th>
<th>Open Package (op)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Temperature [°C]</td>
<td>10 15 20</td>
<td>10 15 20</td>
</tr>
<tr>
<td>VPD [hPa]</td>
<td>0.25 0.34 0.47</td>
<td>2.7 9.01 13.3</td>
</tr>
<tr>
<td>Thermal Impact [°C*h] Condition 2/400</td>
<td>6480 6480 6240</td>
<td>4560 3960 3840</td>
</tr>
<tr>
<td>Thermal Impact [°C*h] Condition 2/1000</td>
<td>9600 9360 9600</td>
<td>6960 5040 4320</td>
</tr>
</tbody>
</table>

YM = f(t;T;VPD)
Adj R² = 0.92

YM = f(t;T;VPD)
Adj R² = 0.96
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Thermal Impact + Effect of Water Regime [VPD=f(t;rH)] + Preharvest Influence

Modelling the Shelf Life of tomato

Accuracy ± 0-3 days

preharvest condition 2/400
preharvest condition 2/1000

ColdChain 2008, Bonn
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Thermal Impact + Effect of Water Regime [VPD=f(t;rH)] + preharvest Influence

Accuracy ± 0-3 days

Preharvest condition 2/400
Preharvest condition 2/1000
Preharvest condition 9/400
Preharvest condition 9/1000
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Input:
- produce
- producer
- time
- preharvest conditions
- quality relevant parameters
- ...

Output:
- producer
- transportation conditions
- quality
- shelf life
- ...

Application

Webserver/Database

Input: Control

Output: Prediction Model

Procedure 1

Procedure 1

= expected shelf life
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction

Thresholds

Modelling the Stiffness
+ Thermal Impact
+ Water Effect
+ Preharvest Influence

Modelling the Shelflife

Application

Summary

Application

Webserver / Database

<table>
<thead>
<tr>
<th>Produce</th>
<th>Tomato</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar</td>
<td>Counter</td>
</tr>
<tr>
<td>Cargo [Info]</td>
<td>Info</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>t_{transport} [d]</td>
<td>10</td>
</tr>
<tr>
<td>T_{mean} [°C]</td>
<td>14.6</td>
</tr>
<tr>
<td>\Phi*T_{max24} [K]</td>
<td>2</td>
</tr>
<tr>
<td>rH_{mean} [%]</td>
<td>98</td>
</tr>
<tr>
<td>VPD [hPa]:</td>
<td>0.32</td>
</tr>
<tr>
<td>Therm.Imp. [°C*h]</td>
<td>3500</td>
</tr>
<tr>
<td>Shelflife_{max} [°C*h]</td>
<td>9000</td>
</tr>
<tr>
<td>Shelflife_{max} [d]</td>
<td>25</td>
</tr>
<tr>
<td>Remaining Shelf Life [d]</td>
<td>15</td>
</tr>
<tr>
<td>T_{alternativ} [°C]</td>
<td>11</td>
</tr>
<tr>
<td>Alternative shelf life [d]</td>
<td>?</td>
</tr>
</tbody>
</table>

Protocoll

96 %
15.9 °C

Prediction Model

ColdChain 2008, Bonn
Introduction

Thresholds

Modelling the Stiffness + Thermal Impact

+ Water Effect + Preharvest Influence

Modelling the Shelflife

Application

Summary

Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Webserver / Database

<table>
<thead>
<tr>
<th>Produce</th>
<th>Tomato</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivar</td>
<td>Counter</td>
</tr>
<tr>
<td>Cargo [Info]</td>
<td>Info</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>t\text{Transport} [d]</td>
<td>3</td>
</tr>
<tr>
<td>T\text{mean} [°C]</td>
<td>11.5</td>
</tr>
<tr>
<td>°T\text{max24} [K]</td>
<td>1</td>
</tr>
<tr>
<td>rH\text{mean} [%]</td>
<td>45</td>
</tr>
<tr>
<td>VPD [hPa]:</td>
<td>7.1</td>
</tr>
<tr>
<td>Therm.Imp. [°C*h]</td>
<td>864</td>
</tr>
<tr>
<td>Shelflife\text{max} [°C*h]</td>
<td>5000</td>
</tr>
<tr>
<td>Shelflife\text{max} [d]</td>
<td>17</td>
</tr>
<tr>
<td>Remaining Shelf Life [d]</td>
<td>14</td>
</tr>
<tr>
<td>T\text{alternativ} [°C]</td>
<td>?</td>
</tr>
<tr>
<td>Alternative Shelf Life [d]</td>
<td>7</td>
</tr>
</tbody>
</table>

Protocoll

| 49 % | 12.8 °C |

Prediction Model

ColdChain 2008, Bonn
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Introduction

Thresholds

Modelling the Stiffness

+ Thermal Impact

+ Water Effect

+ Preharvest Influence

Modelling the Shelflife

Application

Summary

- Wireless datalogger as well as active RFID tags can support quality management and traceability in fresh produce supply chains
- Knowledge about produce shelf life and quality are important and needed
- Presentation of a data based system:
  - Decrease of stiffness as a function of easily measurable terms of time, temperature and water effects (VPD)
    \[ \text{Stiffness} = f(\text{thermal Impact}(t,T), \text{VPD}(T, RH)) \]
  - Shelf Life as a function of thermal impact and water effects
    \[ \text{Shelf Life} = f(\text{thermal Impact}(t,T), \text{VPD}(T, RH)) \]
  - Development of an applicable system for monitoring the needed parameters in praxis and a practicable user interface
Future Prospects

- Further Parameters to take into account:
  - fluctuation of temperature
  - fluctuation of air humidity
  - preharvest conditions and cultivar
  - PAR in preharvest
  - ....

- Thresholds for other varieties and produces
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Thank you for your attention
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

![Graph showing the relationship between total CO₂ release and thermal impact under different storage temperatures.](Image)

- **x-axis**: Thermal impact [°C*h]
- **y-axis**: Total CO₂ release [mg/cm²]
- **Legend**:
  - Blue line: 10°C
  - Red line: 20°C
  - Green line: 10°C to 20°C

**Storage Temperature**

- 10°C
- 20°C
- 10°C to 20°C
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

Temperature characteristic and expected Shelf Life of broccoli in terms of percentage as a function of thermal impact during the postharvest period

- Harvest 100%
- ex yard 72.7%
- Picking 71.8%
- Arrival Wholesale 72.2%
- ArrivaRetail 69.6%
- Shelf stocking 62.9%
- Arrival Retail 69.6%
- End-customer sale 39.6%
Modelling the Stiffness of Tomato

<table>
<thead>
<tr>
<th>packaging</th>
<th>closed package (cp)</th>
<th>open package (op)</th>
</tr>
</thead>
<tbody>
<tr>
<td>storage temperature [°C]</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Storage Humidity [%]</td>
<td>98</td>
<td>98</td>
</tr>
<tr>
<td>Watervapourpartial-pressedifference [hPa]</td>
<td>0.25</td>
<td>0.34</td>
</tr>
<tr>
<td>Threshold of Marketability (Young’s Modulus [Nmm⁻¹])</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>preharvest condition</th>
<th>condition 2/400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time [d]</td>
<td>27</td>
</tr>
<tr>
<td>thermal impact [°C*h]</td>
<td>6480</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>preharvest condition</th>
<th>condition 2/1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time [d]</td>
<td>40</td>
</tr>
<tr>
<td>thermal impact [°C*h]</td>
<td>9600</td>
</tr>
</tbody>
</table>
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

\[ \text{Shelflife} = f(\text{thermal Impact}(t, T), \text{VPD}(T, RH)) \]

\[ \rightarrow \text{Shelflife} = f(\text{thermal Impact}(t, T), \text{VPD}(T, RH), ^\bullet T, ^\bullet RH) \]

\[ \rightarrow \text{Shelflife} = f(\text{thermal Impact}(t, T), \text{VPD}(T, RH), ^\bullet T, ^\bullet RH, \text{Param}(\text{Produce})) \]
Modelling the shelf life of fruit depending on pre-harvest and post-harvest conditions

**Introduction**

Thresholds

**Modelling the Stiffness**

+ Thermal Impact

+ Water Effect

+ Preharvest Influence

Modelling the Shelflife

Application

Summary

---

**Modelling the Stiffness of Tomato**

Thermal Impact

Preharvest condition 2/400

Initial stiffness ~ 2.5 Nmm⁻¹

\[ YM = f(t) \text{ Adj } R^2 \approx 0.95 \]

- 10°C_cp
- 10°C_op
- 15°C_cp
- 15°C_op

---

**ColdChain 2008, Bonn**