EFFECT OF STORAGE CLIMATE ON GREEN-LIFE DURATION OF BANANAS

Ulrike Praeger[1], Manfred Linke[1], Reiner Jedermann[2], Axel Moehrke[3], Martin Geyer[1]

[1] Leibniz-Institut für Agrartechnik, Potsdam Bornim (ATB), Max-Eyth-Allee 100, 14469 Potsdam, Germany, upraeger@atb-potsdam.de
[2] Institute for Microsensors, -actors and –systems (IMSAS), University of Bremen, FB1, Otto-Hahn-Allee, Build. NW 1, D-28359 Bremen, Germany
[3] Dole Europe Import BVBA, Antwerpen, Belgium

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Abstract

The presented studies are part of the research project „The intelligent container: Linked intelligent objects in logistics“ with the task to optimize climate control in transport containers for perishable foods. During shipment of tropical bananas product loss occurs due to undesirable accelerated fruit ripening and decay which cannot be detected until the ware is discharged. A green-life prediction model for bananas was developed in order to describe the storability of fruits during the transport as a function of temperature, humidity and CA-conditions. As main parameter to determine the green-life duration NDVI was measured by a spectrometer. The green-life period decreases exponentially with increasing temperature above 13°C. Below 13°C the storability of green-ripe fruits decreases fast due to chilling injury symptoms. In a range of 15°C up to 18°C increased CO_2-concentration up to 5 % causes an average extension of green-life of 7 days compared to storage in normal air and high humidity. Additional decreased O_2-concentration to 2 % additionally prolonged green-life at storage temperature of 13°C or 15°C. Low relative humidity of 50-60 % accelerates yellowing of the fruits compared to storage in 98 % humidity. A high variation of fruit storability was observed for different fruit shipments during the year.

Introduction

Tropical bananas for the European market are harvested green-ripe and wrapped in plastic film and paperboard boxes for the transport in containers by ship during two weeks. Transport temperature inside the container is regulated by a cooling unit. Optimal storage temperature of green ripe banana is 13-14°C (Kader 2012, Kerbel 2004). Deviation of the optimal temperature causes chilling injury (< 13°), or accelerated ripening (> 13°C). The optimal relative humidity for storage of green bananas is 90-95 % (Kerbel 2004). Lower relative humidity reduces green life period (Broughton und Wu (1979). During container transport of bananas the atmosphere is influenced using closed MA-packages (banavac) where exact CO_2- and O_2-concentrations are unknown or containers with equipment for CA-conditions. In CA-containers fruits are wrapped in perforated plastic film. In order to reduce respiration and ethylene production of the fruits atmosphere of 2-5 % O_2 and 2-5 % CO_2 is recommended (Bishop 1990 in Kerbel 2004, Kader 2012, Yahia und Singh 2009). The main effects of decreased O_2-concentration and increased CO_2-concentration are delayed ripening, suppression of diseases, e.g. crown rot, and maintaining fruit freshness (latex flow). Quality loss occurs during banana transport due to accelerated and sporadic ripening (yellowing) or decay due to pathogens which should be avoided and cannot be detected until the ware is discharged.

The aim of our study was to determine the effect of deviation from optimal climate conditions on green-life duration of bananas. Therefore the influence of temperature, humidity and atmosphere on the green-life period of stored banana fruits was determined and the time which is needed to induce chilling injury by temperatures below the optimum. A green-life model was developed for 1) prediction of the remaining storage life before the beginning of the climacteric ripening phase and 2) adapting the climatic conditions during shipment in an 'intelligent transport container' in order to avoid undesirable early ripening. Based on green-life prediction data also a rescheduling of logistical processes following the banana transport may be realized.

Material and Methods

Storage experiments were performed with ‘Cavendish’-bananas harvested in Costa Rica from several shipments in the years 2011 and 2012. The harvest time of the fruits was chosen according to the common criteria for commercialisation. The bunch age was uniform for each transport but varied between 12 and 15 weeks for different cultivation periods during the year. The transport by shipment and truck took about two weeks. After arrival in Potsdam (Germany) the green-ripe fruits were separated from the hands and wrapped at the stem end in stretchable plastic film in order to avoid water loss at the tissue rupture. The physiological older fruits from the top of the bunch (hand 1 and 2) and the younger fruits from the bottom (hand 6 and 7) were examined separately.

For investigating the effect of temperature, humidity and CO_2-concentration bananas were stored in glass vessels (3 per vessel) with cover plates with different opening areas in temperature conditioned rooms. The adjustment of humidity and atmosphere with different opening areas of the cover plates (Fig. 1) was carried out in preliminary experiments and controlled regularly during the tests. The additional effect of low O_2-level in the atmosphere was examined using a CA-container test facility.

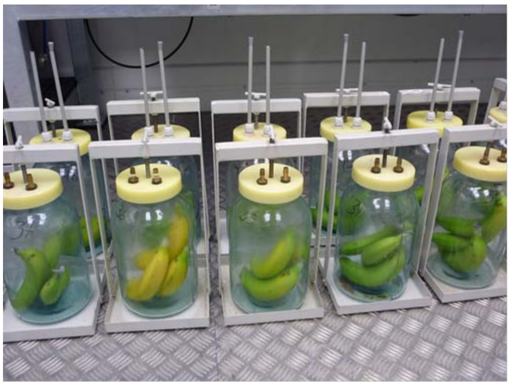

Fig. 1: Banana fruits in storage vessels

The following climate conditions were chosen in different experiments:

- temperature: 12°C / 15°C / 18°C / 25°C / 30°C in high humidity (98%) and normal air
- humidity: low (50-60 %) / middle (80 %) / high (98 %) at storage temperatures of 15°C and 18°C
- O_2/CO_2-concentration: 21/0,03 %; 19/2 %; 16/5 % at temperatures of 15°C and 18°C,

  2/5 %; 5/5 % at temperatures of 13°C, 15°C and 18°C

Fruits were stored until the changeover to the climacteric phase. In case of mold incidence before yellowing fruits were removed from the storage vessels respective CA-containers.

As criteria for determining the end of green-life the parameter NDVI (normalized difference vegetation index) was measured with a hand-held spectrometer (Pigment Analyser, CP Falkensee, Germany). The NDVI indicates chlorophyll content in plant material and is calculated from the reflected light intensity I in the following manner: NDVI= (I_{780} nm – I_{660} nm) / (I_{780} nm + I_{660} nm). Additionally CO_2-production of the fruits was measured in a closed system fitted with infrared sensors (FYA600, Ahlborn, Germany) as well as elasticity with a Texture Analyser (TA.XT.plus, Stable Microsystems, UK) and mass loss. Measurements for testing the effect of humidity and elevated CO_2-concentration in the glass vessels were carried out twice a week with twelve fruits as replicates for each storage condition. In order to evaluate the fruit storability in the CA-containers, measurements were done twice or once in two weeks.

Results and discussion

Determination of green-life period

The NDVI values of green bananas at ripening stage 2 were between 0,2 and 0,6 and decreased up to -0,9 when the skin color turned yellow. A NDVI value < 0 was defined as end of green-life according to results from comparative measurements of respiration (Fig. 2), color and visual observation of ripening stages (data not shown). When the NDVI decreases below the value 0 the CO_2-production of the fruits rises indicating the beginning of the climacteric stage.

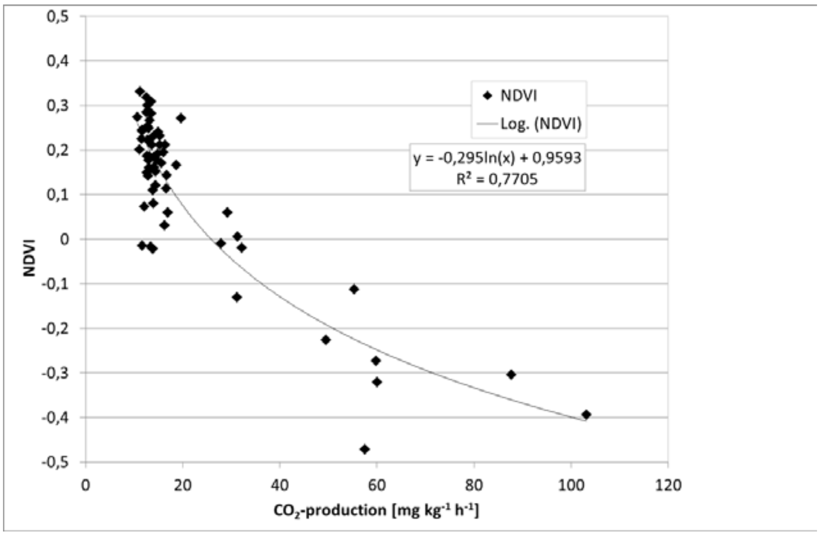

Fig. 2: Relation between CO_2-production and NDVI of banana fruits ripening without ethylene treatment at 18°C

Effect of storage climate on the green-life period

The green-life period of banana fruits varied clearly in between the samples (n=12) regarding all storage experiments. Fig. 3 shows exemplary the increase of percentage of fruit with finished green-life which have been stored at 18°C in different humidities. It took up to two weeks from the ripening start of the first fruit until the ripening start of the last fruit in one storage condition.

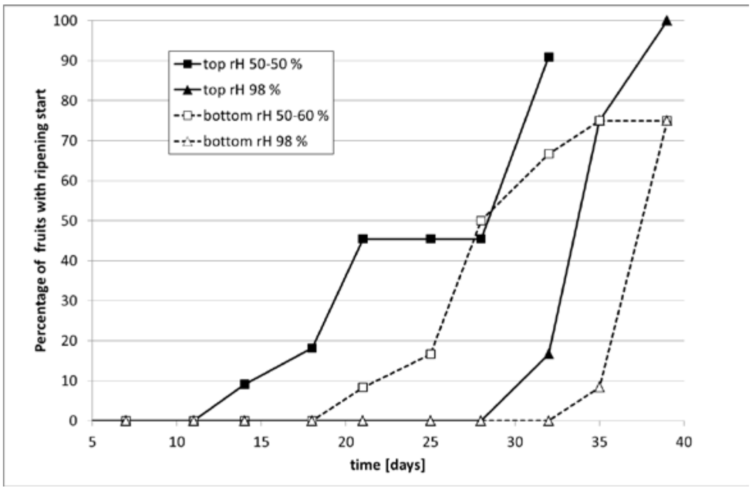

Fig. 3: Percentage of fruits from upper and lower bunch position (n=12) with beginning ripening (yellowing) after storage at 18°C in different humidities

For storage in normal air at high humidity (98 %) exponential functions were found for the relationship between temperature (T, °C) and the average green-life period (GP, days) for a temperature range between 12°C and 30°C (y_{GP} =159,86 $e^{-0,124\ T}$) and for the relationship between lower storage temperature (5°C up to 11°C) and the time period needed until chilling injury symptoms are induced at the peel surface. (CP, days) ($y_{CP} = 0{,}0481\ e^{0{,}1969\ T}$) (Fig. 4).

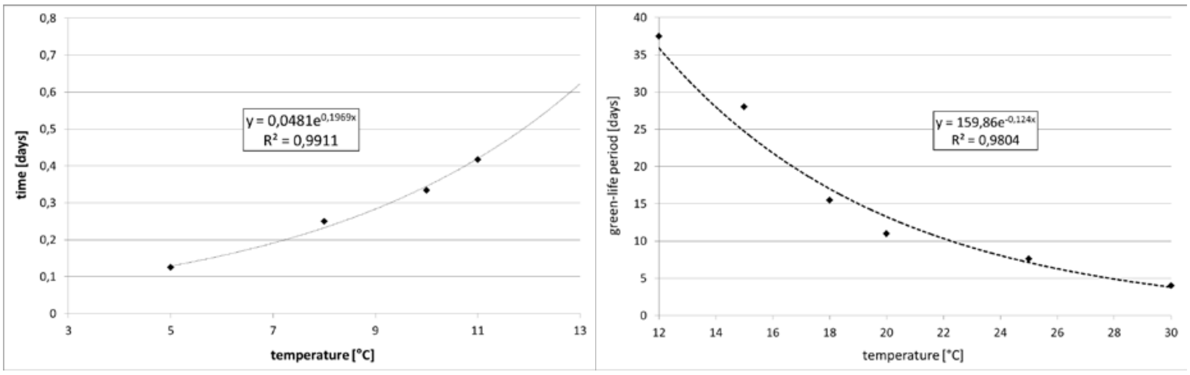

Fig. 4: Storability of green-ripe banana fruits (left: average storage time until chilling injury occurs (5°C up to 11°C), right: average green-life duration for a temperature range from 12°C up to 30°C)

For 'Cavendish' bananas green-life period of similar dimension (20 days at 20°C and 8 days at 30°C) has been found by Scott and Gandanegara (1974) in Turner (1997) when we take into consideration that our tests started 2 weeks after harvest. Marriott et al. (1979) used firmness to determine the duration of the green-life period and found for different clones grown in Jamaica at storage temperature of 13,5°C differing periods for the preclimacteric phase between 17 and 38 days.

In 2012 the fruits from the tests for the effect of humidity and elevated CO_2-concentration showed overall much higher green-life period than the fruits of the temperature experiment in 2011 (Fig. 5 and table 2). Therefore we calculated the mean change of green-life period compared to the data from the temperature tests in order to estimate the effect of humidity and elevated CO_2-concentration. Some tests showed prolonged green-life for fruits from lower banana bunch positions compared to the fruits at the top of bunches because of retarded ripening (Fig. 3) but this effect of bunch position was not consistent and neglected for model calculations.

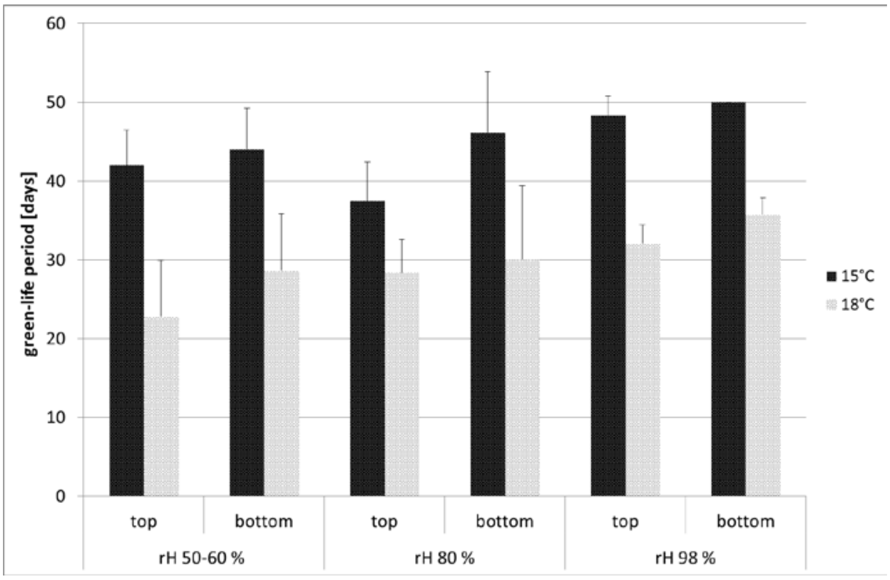

Fig. 5: Average green-life period of fruits from different bunch positions stored in different humidities and temperatures (experiment start 2/2012)

At temperatures of 15°C and 18°C on average low humidity of 50-60 % reduced the green-life period for 7 days and middle humidity (80 %) for 4 days compared to high relative humidity of 98 %. Reduced green-life period of stored bananas due to low relative humidity has been described by other authors. George et al. (1982) supposed that water stress induces ethylene production which causes earlier climacteric respiration rise.

Increased CO_2-concentration prolonged the green-life at 15°C and 18°C on average for 7 days. The initial exponential function for the temperature effect was adapted in the following manner:

Normal air / 50-60 % rH: $y_{GP} = 390{,}07\ e^{-0{,}205\ T}$

Normal air / 80 % rH: $y_{GP} = 229{,}51\ e^{-0{,}159\ T}$

5 % CO_2 / 98 % rH: $y_{GP} = 122{,}14\ e^{-0{,}09\ T}$

Scott und Gandanegara (1974) in Turner (1997) observed that the green-life period of 'Cavendish' bananas in MA-package is increased up to 10 days for a temperature range between 15°C and 30°C with a slightly higher effect in low temperature compared to the control in normal air. The modified atmosphere inside the packages caused improved storability in a similar dimension as the elevated CO_2-concentration of 5 % in our experiment.

Storage in CA-conditions increased storability of bananas compared to storage in normal air. The fruits which have been stored in atmosphere with 5 % CO_2 / 5 % O_2 or 5 % CO_2 / 2 % O_2 at temperatures of 13°C and 15°C showed reduced respiration (Fig. 6) after storage, higher firmness, lower weight loss and delayed yellowing compared to fruits after storage in normal air.

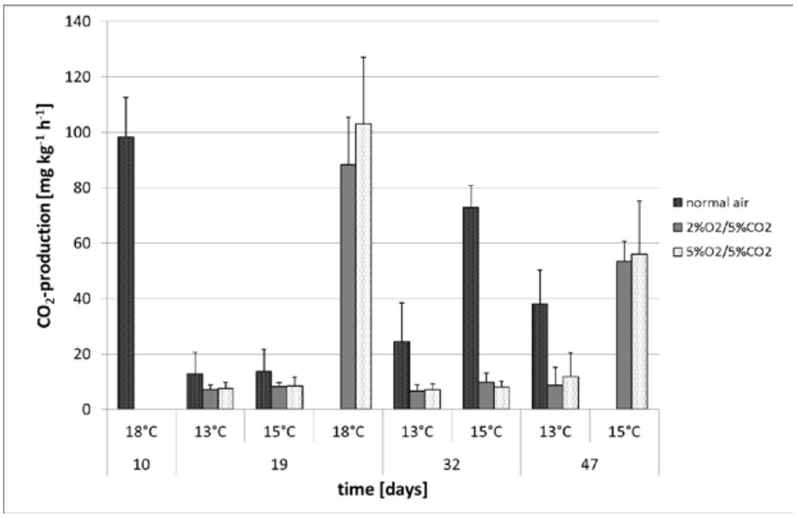

Fig. 6: Respiration of banana fruits at their storage temperature after storage in different atmosphere

The longest green-life of fruits stored in 13°C or 15°C was determined for the atmosphere with 5 % CO_2 and 2 % O_2 (table. 1)

Table 1: Average green-life of banana fruits stored in controlled atmosphere

Green-life period [days]	normal air	5 % CO_2 / 5 % O_2	5 % CO_2 / 2 % O_2
13°C	16	27	40
15°C	18	20	26
18°C	4	5	5

The totally short green-life and the small effect of CA-conditions at 18°C is most likely due to the fact that at the beginning of this experiment the visual ripening stage of the fruits was just turning from 2 to 3 (defined end of green-life).

Influence of banana shipment

We observed high variations of storability between fruits from different shipments during the years 2011 and 2012. Table 1 shows average green-life period from fruits stored at 18°C in normal atmosphere in high humidity with high variation between 4 days (October 2012) and 44 days (April 2012). These differences are partially reflected by ripening parameters as elasticity and NDVI. As an example already at the start of the experiment in October 2012 the fruit turned to the visual ripening stage 3 and showed a low NDVI (0,13) and a low modulus of elasticity (2,9 MPA) compared to the fruits transported in march and April 2012 with high NDVI and high firmness. Fruits with short green-life lost their mass remarkable faster than fruits with long green-life. This means the green-life prediction functions should be adapted according to the maturity of the fruits at the beginning of the transport.

Table 1: Comparison of banana fruits from different shipments at the beginning of the experiments

Start of experiment	6 / 2011	8 / 2011	1 / 2012	2 / 2012	3 / 2012	4 / 2012	10 / 2012
average green-life [days] Storage at 98% rH	20 ± 2 18°C	11 ± 8 18°C	28 ± 3 18°C 27 ± 2 15°C	34 ± 3 18°C 49 ± 2 15°C	39 ± 14 18°C 57 ± 4 15°C	44 ± 9 18°C 60 ± 6 15°C	4 18°C 17 15°C
mass loss / day [%] during 14 days storage at 98% rH	-	-	0,13 18°C 0,07 15°C	0,09 18°C 0,07 15°C	0,05 18°C 0,03 15°C	0,03 18°C 0,02 15°C	0,21 18°C 0,12 15°C
NDVI	0,45 ± 0,11	0,30 ± 0,13	0,21 ± 0,05	0,18 ± 0,17	0,5 ± 0,09	0,31 ± 0,08	0,13 ± 0,18
modulus of elasticity [MPA]	-	-	3,7 ± 0,4	4,3 ± 0,3	4,4 ± 0,4	5,7 ± 0,6	2,9 ± 0,4

Conclusions

At optimal storage temperature of 13-15°C and high humidity green-life of ‘Cavendish’ bananas may take several weeks before yellowing. Storage in low relative humidity shortens green-life obviously. Elevated CO_2-concentration and low O_2-concentration extends green-life period compared to normal air storage. High variation of the green-life period was observed for the fruits of one shipment as well as between fruits of different shipments during the year. One reason might be differences in transport temperature before the start of the experiments. For example the tests beginning March and April 2012 with extremely long fruit green-life in the transport boxes the transport temperatures were low (13-14°C) compared to previous transport temperature (14°C-15°C).

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