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FACULTY OF ENGINEERING

DEPARTMENT OF TECHNOLOGICAL EQUIPMENT OF BUILDINGS

DIPLOMA THESIS

TECHNIQUES AND TECHNOLOGICAL ASPECTS OF TRANSPORT AND STORAGE OF FRUIT IN CONTROLLED ATMOSPHERE CONDITIONS

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DECLARATION

I hereby declare that I have worked on this Diploma Thesis called "Techniques and technological aspects of transport and storage of fruit in controlled atmosphere conditions" on my own, and all used sources are in the references list.

In Prague, April 10, 2012,

Alexey Dobrynin

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ABSTRACT

Banana belongs to the list of top-20 commodities produced in the world, and is 10th commodity imported into the European Union. International dessert banana trade relays on long-distance transportation, mostly transoceanic. Maintaining the consistent high quality of the product requires special techniques applied to the marketing chain: from the field to the customer. This Diploma Thesis focuses on the post-harvest technology of dessert bananas with accent on the transportation and the ripening process, both in controlled atmosphere. Ripening technology was studied, and measurements of temperature, ethylene concentration and relative humidity were conducted. Evaluation of dessert bananas quality was done according to peel color and aromatic composition changes.

Key words: banana, post-harvest, ripening, ethylene, controlled atmosphere, respiration

ABSTRAKT

Banány patří mezi 20 nejvýznamnějších komodit na světě a jejich importovaný objem do EU je řadí na 10 místo. Mezinárodní obchod banány závisí na možnostech dopravy, převážně však na transoceánské. Udržení konzistentní vysoké kvality tohoto produktu vyžaduje speciální techniky aplikované ve všech procesech, od sklizně k dodávce konečnému zákazníkovi. Tato diplomová práce se zabývá posklizňovými technologiemi s důrazem na dopravu a dozrávání, obojí v kontrolované atmosféře. Byly prostudovány dozrávací technologie a provedena měření teploty, koncentrace ethylenu a relativní vlhkosti. Hodnocení kvality sladkých banánů bylo provedeno na základě změn barvy slupky a aromatických látek.

Klíčová slova: banány, posklizňové úpravy, dozrávání, ethylen, kontrolovaná atmosféra, respirace

CONTENT

I. INTRODUCTION

It is obvious that we live in the era of globalization. Nowadays we cannot imagine our life without automobile, mobile phone or the Internet. Even fresh strawberries in winter are usual in northern countries. Most of consumers of these goods and services never ask themselves a question: ‘How do I get this juicy watermelon on my table in Murmansk with -30°C outdoors?’ or ‘How is it possible that I can hold a videoconference with my friends from the USA, Russia and New Zealand?’ So common it became.

In the past, for instance, back in the beginning of the XX century, nobody could even imagine all these inventions and conveniences, which we use every day. Let us compare food store a century ago and a supermarket today. I believe in old-times food store there were mostly locally produced products and a little of exported ones. Among those exported we could find coffee, tea, tobacco, spices, etc. Generally, these goods were ones with very long shelf-life. It was possible to transport them for months via sea without any special conditions. Today’s supermarket is full of both local and imported goods.

II. BACKGROUND

2.1 Overview

What is a banana?

Nowadays banana is a usual fruit in European countries. Everyone knows that a banana is a 15 cm long yellow fruit covered by inedible peel with tasty flesh inside. Usually fruits are attached to each other and form so called hands, consisting of 3 to 10 single bananas. But this yellow banana we all eat almost every day is only one out of dozens different species and cultivars. According to Paull *et al* (2011), in the genus *Musa*, to which banana belongs, there are more than 50 species and subspecies. Some of them are edible, some are used for cooking, and other wild ones have large seeds (Setijati 1980). The difference between these species is due to genetic composition. Bananas cultivated in industrial scales are hybrids originated from two wild diploid ($2n$ = 22): *Musa acuminata* Colla (genomic composition AA) and *Musa balbisiana* Colla (genomic composition BB) (Setijati, 1980; Kang *et al*, 2006; Kole, 2007; Mohan Jain 2009; Robinson *et al*, 2010; Paull *et al*, 2011).

Banana is considered to be one of the most common fruit in tropics and one of the oldest known by humans (Berger, 2007). Banana has a key role in culture and economics of many states. It is one of the most important crops grown in more than 120 tropical and subtropical countries in the world (Kang *et al*, 2006). Banana fruits, as was mentioned before, can be eaten either fresh as a dessert or cooked as a side dish. Also dried bananas and banana chips are very common. Other parts of banana plant can be used as animal fodder, for fiber extraction or brewing. Sometimes bananas are grown as a shade crop for coffee and cocoa plants (Winch, 2006).

Most of cultivars presented in table 1 are suitable only for local markets due to relatively small production rate and very short shelf-life. But such banana cultivars, as ‘Grande Naine’, ‘Poyo’ and ‘Williams’, which belong to Cavendish subgroup (triploid AAA), are the main export varieties (Mohan Jain 2009). The share of Cavendish bananas in overall world banana production was 47% in 1998-2000 (Arias et al). So in this work I restricted myself within studying of Cavendish bananas exported to the European Union.

Table 1

Fruit characteristics of some major cultivars within groups and subgroups (Paul et al, 2011)

Group	Subgroup	Characteristics
AA	Sucrier	Small fruit (8-12 cm long), thin golden skin, light orange firm flesh, very sweet, 5-9 hands per bunch, 12-18 fingers per hand.
	Lakatan	Medium to large straight fruit (12-18 cm), golden yellow, flesh light orange, firm, dry, sweet and aromatic, 6-12 hands per bunch, 12-20 fingers per hand.
AAA	Gros Michel	Medium to large fruit, thick skin, creamy white flesh, fine-textured, sweet and aromatic, 8-12 hands per bunch.
	Cavendish	Medium to large fruit, yellow skin, white to creamy flesh, melting, sweet, aromatic, 14-20 hands per bunch, 16-20 fingers per hand.
AAB	Silk	Small to medium yellow fruit (10-15 cm), thin yellow-orange skinm white flesh, soft, slightly subacid, 5-9 hands per bunch, 12-16 fingers per hand. Skin frequently has blemishes.
	Pisang Raja	Large fruit (14-20 cm)m thick skin, cooking banana, creamy orange flesh, coarse texture, 6-9 hands per bunch, 14-18 fingers per hand.
	Plantain	Yellow skin, creamy orange firm flesh, few hands per bunch.
ABB	Bluggoe	Medium to large cooking banana, thick coarse skin turns brownish-red when ripe, creamy orange flesh, starchy, 7-10 hands per bunch.
BBB	Saba	Stout, angular, medium to large cooking banana (10-15 cm), thick yellow skin, creamy white flesh, fine textured, 8-16 hands per bunch, 12-20 fingers per hand.

Production

World banana production in 2009 was more or less 102 mln metric tons, what makes it the top 15^{th} commodity produced and top 18^{th} commodity by value with equivalent of 28 bln US dollars (FAOSTATS, 2012). The importance of banana for human diet all over the world cannot be overestimated.

Table 2

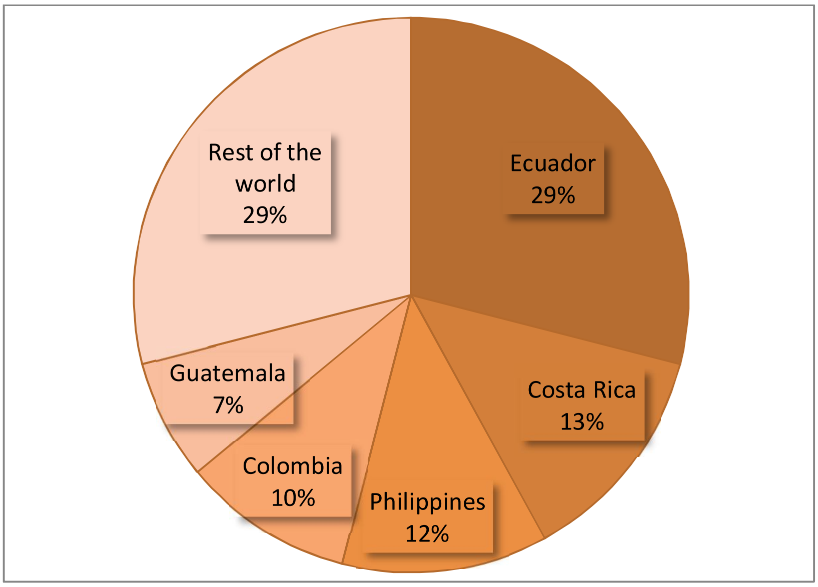
World Production of Bananas, 2010 (data from FAO UN, 2012)

Rank	Country	Production, thousands MT	Percentage to total world production, %
1	India	31,898	31.2
2	China	9,849	9.6
3	Philippines	9,101	8.9
4	Ecuador	7,931	7.8
5	Brazil	6,978	6.8
6	Indonesia	5,815	5.7
7	Republic of Tanzania	2,925	2.9
8	Guatemala	2,622	2.6
9	Mexico	2,103	2.1
10	Colombia	2,034	2.0
11	Costa Rica	1,804	1.8
12	Thailand	1,585	1.6
13	Viet Nam	1,481	1.5
14	Papua New Guinea	1,326	1.3
15	Egypt	1,039	1.0
16	Cameroon	950	0.9
17	Bangladesh	818	0.8
18	Kenya	792	0.8
19	Dominican Republic	735	0.7
20	Uganda	600	0.6
	Other countries	9,739	9.5
	Total	102,115	100.0

But not all countries do export bananas. For example, in India almost all produced bananas stay for local consumption. The most important exporters of bananas on the scale of the whole world are countries in the Central American region: Ecuador, Costa Rica, Colombia and others. Banana import in the European Union, according to (2012), was 6.713 mln tons (ranks as the 10th top commodity imported, by quantity), or to 6.015 bln in the US dollars equivalent (ranks as the 16th top commodity imported, by value), both in 2009 (data from FAOSTATS, 2012).

Figure 1

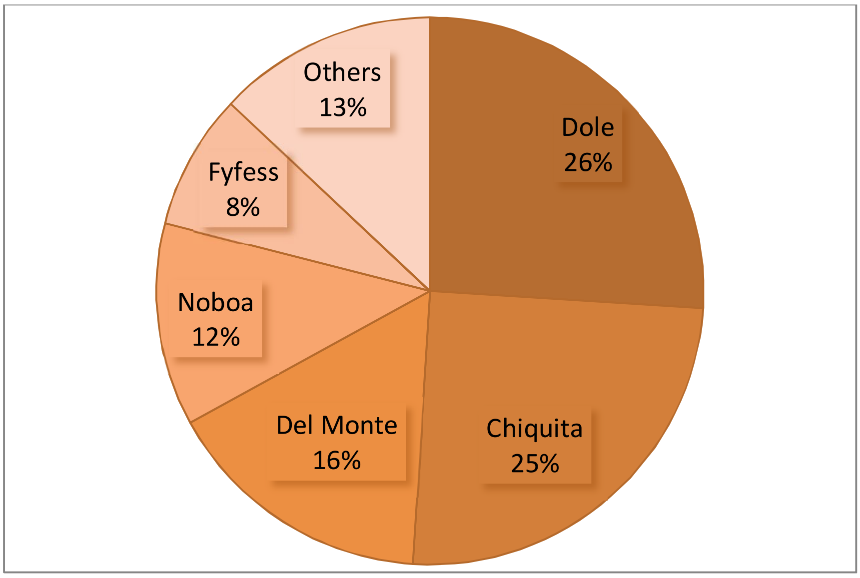
Contributions of countries to world trade of bananas, 2007 (data from FAO UN, 2012)



According to United Nations Conference on Trade and Development from 2009, the 60% of international market of bananas was controlled by three companies: Chiquita, Dole and Del Monte.

Figure 2

Contribution of companies to world trade of bananas, 2007 (data from FAO UN, 2012)

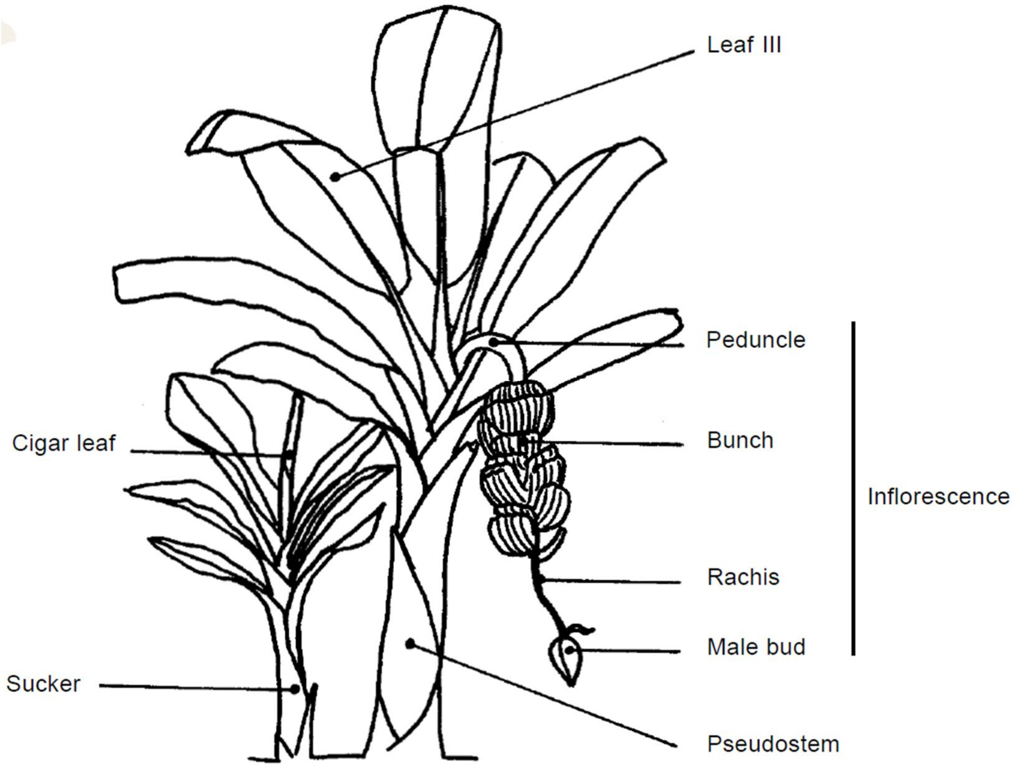


Botany

Banana plants are known to be robust perennial monocotyledonous herbs cultivated in tropical and subtropical regions (Kole, 2007). It means that there is no wood in banana stems, and, botanically, banana plant is just a grass. The plant grows relatively fast: up to height of 4 meters in a year after starting the vegetation. The so called stem – actually, it is a pseudostem – consists of fleshy upright leaves growing very close to each other have origin in underground corm. The real stem begins in corm as well, and during vegetation period it grows through pseudostem and forms peduncle with flowers – the inflorescence bunch – usually after 1 year after planting. The inflorescence consists of both female and male flowers, and on some species hermaphrodite or neutral flowers can be found. On the end (top) of the peduncle there is a male bud, and going down the peduncle, after rachis – empty space on peduncle – female flowers are found. They form hands, and hands are situated in spiral rows (Morton 1987; *IPGRI* 1996; Thompson 2003; Robinson 2010; Vezina 2012).

Figure 3

Pseudostem and sucker. Morphology (from IPGRI, 1996)



Cavendish cultivar usually has up to 15-18 rows of female flowers. After pollination the peduncle moves down under the weight of fruits (Morton 1987; IPGRI 1996; Thompson 2003; Robinson 2010; Vezina 2012).

Root system of banana plant consists of primary and adventitious systems. They originate from corm, as well as lateral shoots (Vezina 2012). There are essential characteristics of banana roots, which must be considered in cultivation.

- High water-loss potential due to high area of leaves;
- Shallow root system (90% of roots are concentrated in top 30 cm of soil);
- Absorbing water from drying soil is very low;
- Water deficit has very fast physiological response (Paull, 2011).

Lateral shoots, so called ‘suckers’ are young plants connected with mother plant. As it was mentioned before, suckers grow from mother’s corm, so they are genetically identical and can be used for reproduction. Young leaves, still rolled as a cylinder, often are called ‘cigar leaves’ (Morton 1987; Vezina 2012).

Cultivation

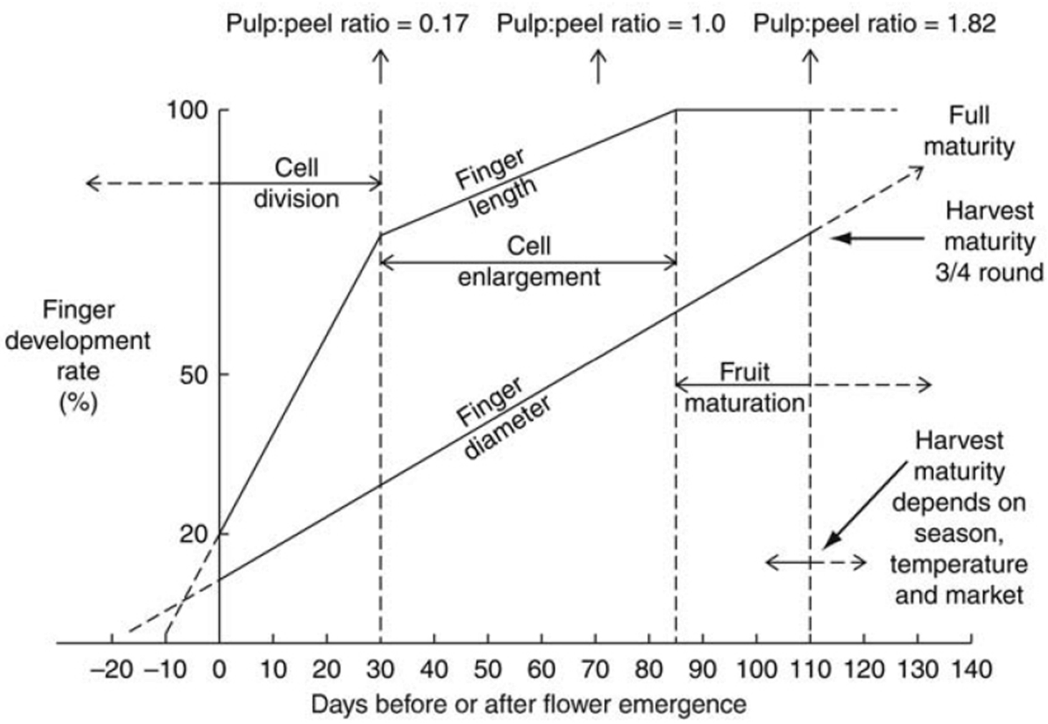
Banana cultivation always fulfills two following requirements. The first one is the extensive drainage: banana plantation is full of trenches carrying water from nearby rivers or other water supplies. The second requirement is passages between rows for tractors or mules and workers for easier access to plants during vegetation (Somogyi 1996). Typical planting patterns for Cavendish banana are listed below (after Paull 2011).

- Equilateral triangle with sides 2.5 – 2.7 m. Density – 1800-2000 plants/ha.
- Double row: 2.25 m between plants in a row and 3.75 m between rows. Density – 1840 plants/ha.
- Square with dimensions 2.4 x 2.4 m.

Following these patterns allows using of machinery for both cultivation and harvesting. And also it provides best possible conditions for each plant. According to Paull (2011), cableways are used more and more often to reduce labor and increase automation in banana plantations in such operations, as transportation of fertilizers to plants and taking fruits to packing houses. The temperature limits for banana plant lay in a range of 15-38°C with optimum at 27°C. Sprinklers are often used for irrigation (Paull 2011).

Figure 4

Diagrammatic representation of banana fruit development (pre-flowering to harvesting) under tropical conditions (from Robinson et al, 2010)



Polyethylene foils 30-40 μm thick are used for improving yield and quality of fruit. They create special microclimate around growing bunches and help to protect fruits against insects and some diseases. Moreover, export bananas producers use plastic pads, placing them between developing hands. It reduces bruising and chafing. Other technique is cutting of the distal hand (or hands) in a bunch to avoid competition in it and achieve bigger and uniform fruits (Morton 1987; Paull 2011).

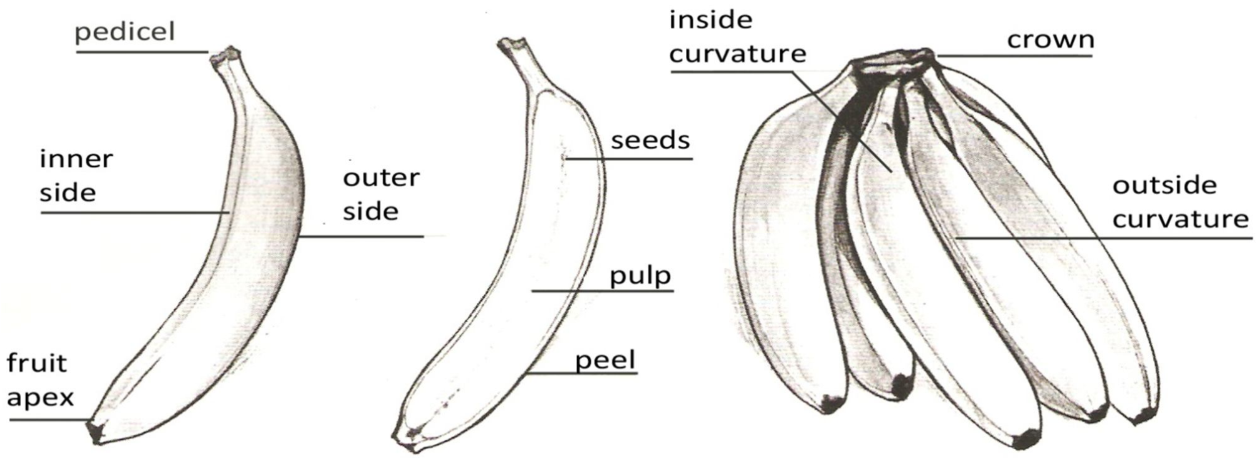
Banana Fruit

From botanical point of view, fruit of banana is a berry with leathery peels. Cavendish cultivar is characterized by a slightly curved fruit 15-25 cm long, with green to yellow peel color, white to creamy or ivory flesh color and definitely without any seeds. The flavor of flesh can be sweet or a little bit sour (depends a lot on sugar content), the texture of flesh depends on cellulose and starch content and can vary from firm and gummy to soft, melting in the mouth (Morton 1987, Mohan Jain 2009). After pollination process banana fruit develops for 85-100 days in good conditions and up to 210 days in unfavorable (e.g. lower temperatures, less sunny days) (Paull 2011). Average yields are 1000-1200 bunches/ha or 16000-27600 hg/ha (Winch 2006).

"*Dessert bananas have become very popular in modern westernized diets. They are popular for their flavour, texture and convenience value, being easy to peel and eat. Bananas make a useful contribution to the vitamin A, C and B6 content of the diet, and are an important and immediate source of energy. They are also cholesterol-free and high in fiber*" (Robinson et al 2010).

Figure 5

A banana finger (left), a longitudinal cut of banana finger (middle) and a hand of bananas (right) (from Unknown, 2001)



One banana (130 g) contains approximately 400 kJ of energy and approximately 450 mg of potassium, which is 15% of adult's daily demand (Paull, 2011).

Table 3

Summary of nutritional constituents, mineral composition and vitamin contents of mature banana fruit pulp (modified from Robinson 2010)

Nutritional constituents, % of pulp fresh mass	
Water	75.7
Carbohydrate	22.2
Protein	1.1
Fat	0.2
Ash	0.8
Mineral composition, mg/100 g pulp fresh mass	
P	27
K	460
Ca	7
Mg	36
S	34
Vitamin content, mg/100 g pulp fresh mass	
A	Medium
Thiamine (B1)	0.04
Riboflavin (B2)	0.07
Pantothenic acid (B5)	0.26
Pyridoxine (B6)	0.51
Ascorbic acid (C)	10

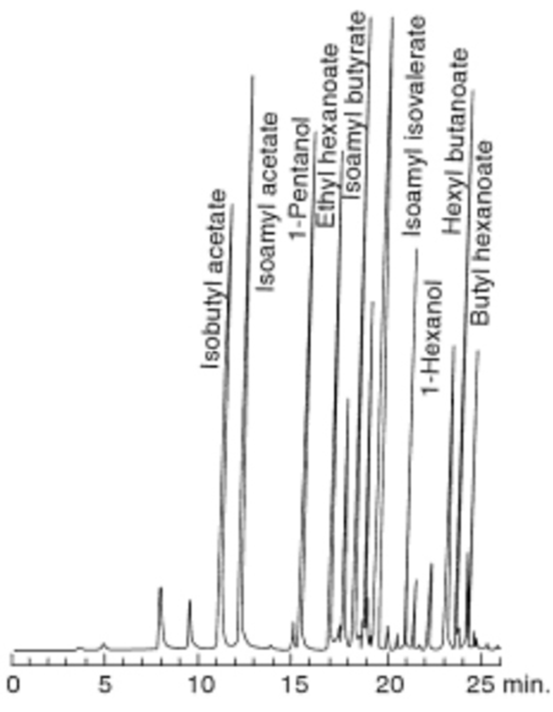
Pulp of ripen banana contains maltic, citric and oxalic acids, which are responsible for low pH level of fruit: pH 4.0 (Robinson 2010). Major pigments of Cavendish banana peel are chlorophyll (green color) and carotenoids (from yellow to orange, red colors) and (Robinson et al 2010; Paull 2011). Also, ripen banana pulp contains 1% of fiber, which makes it a desired meal for better digestion (Chiquita, 2012).

Aromatic composition

The flavor of banana pulp is very specific and cannot be mixed up with other flavors. A number of researches were conducted to specify aromatic composition of a ripe banana pulp, and Berger (2007) summed it up.

- Esters: isopentyl acetate, isobutyl acetate
- Alcohols: 3-methyl-1-butanol, 2-pentanol, 2-methyl-1-propanol, hexanol, linalool.
- Acetates: isoamyl acetate, butyl butanoate, acetal, hexanal, ethyl butanoate
- 2-pentanone
- Phenols: elemicine'

Figure 6
Gas chromatographic patterns of the SPME extract of banana (extraction 60°C, 30 min) (from Hui, 2010)



Isopentyl acetate has the character flavor of a banana (Taylor et al, 2010), is a constituent of banana oil (McMurry 2007), is essential in banana flavor (Hui 2010) and is common ester in banana pulp (Taylor et al, 1996).

Standards

According to Unknown author (1989), international standards for bananas do not exist at all. But there are local standards for bananas, which are hold in exact countries or regions. The European Union operates with Commission Regulation (EC) No 2257/94 of 16 September 1994 by European Commission, which specifies minimum standards for banana fruits. Some points of this of this Regulation, relevant to this Diploma Thesis work, are quoted below.

1. *"Quality*
    a. *Minimum requirements in all classes are that, subject to special provisions and tolerances for each class, the bananas must be:*

- *green and unripened, intact, firm and sound;*
- *clean and practically free from visible foreign matter, and from pest or disease damages;*
- *pedicel intact, without bending, fungal damage or desiccation, and pistils removed;*
- *free from malformation or abnormal curvature of fingers; and*
- *practically free from bruises and damages due to low temperatures, and*
- *also free of any foreign smell and/or taste, and from abnormal external moisture.*

There are also minimum requirements for hands and clusters.

  b. *Classification – Bananas are classified into three classes: (i) Extra; (ii) Class 1; and (iii) Class 2. These differ in tolerance levels for defects, both in number and in size. Under no circumstances may defects affect the flesh of the fruit.*

<…>

4. *Presentation*
    a. *Uniformity – Contents of each package must be uniform and consist exclusively of bananas of the same origin, variety and/or commercial type, and quality. The visible part of the contents must be representative of the entire package.*

b. *Packaging – Bananas must be packed so as to protect the produce properly. Materials used inside the package must be new, clean and must not cause any external or internal deterioration of the produce. Use of materials such as wrapping papers or adhesive labels bearing commercial markings is allowed provided the printing and labeling is done with non-toxic ink or glue. Packages must be free from any foreign matter.*
c. *Presentation – Bananas must be presented in hands or clusters (parts of a hand) of at least four fingers. Some tolerances regarding number of fingers per cluster are allowed. In the producing regions, bananas may be marketed by whole bunch.*

5. *MARKING*

Each package must bear the following particulars in writing, all on the same side, legibly and indelibly marked, and visible from the outside:

a. *Identification*
b. *Nature of produce – The word 'Bananas' where the contents are not visible from the outside, plus name of the variety or commercial type.*
c. *Origin of the product – Country of origin and, in the case of EU produce: production area and (optionally) national, regional or local name.*
d. *Commercial specifications – Class, net weight and size expressed as minimum length and, optionally, as maximum length.*
e. *Official control mark (optional)*" (Commission Regulation (EC) No 2257/94)

2.2 Postharvest handling

Marketing Chain

The way of a product from the place of origin to consumer is often called the marketing chain (Kader, 2002). The production chain of banana is presented in the figure 8.

Harvesting

Bananas for export are harvested 10-14 weeks after emergence, when they are still green – at 75% maturity. The exact time of harvesting is determined by measuring the caliper of middle finger – it should be in range 31-41 mm. Color of peel is measured as well, using colored ribbons: each color grade on it refers to exact week of growing (Paull 2011). According to Robinson (2010), three factors are considered when harvesting time is determined:

- Phenology (emergence to harvesting time, E-H value);
- Colored ribbons;
- Caliper measurement.

Thompson (2003) refers to special calipers, either plastic of metal, with two sides: smaller one – 31 mm, bigger one – 41 mm. Using this kind of equipment increases productivity of labor.

Commercial dessert bananas harvesting pattern is more or less the same all over the world (Robinson 2010). A carrier approaches the best position for catching the bunch, a cutter cuts the bunch from the pseudostem. Meanwhile the covering plastic bag is removed. The bunch is put on cut banana leaves for 10 minutes to drain and then transported to packshed via cableway or truck. Any contacts of bunch with other ones or with soil must be avoided to eliminate infestation risk and bruising. Both overheating and direct sunlight exposure are unaccepted (Thompson 2003; Robinson 2010; Paull 2011).

Postharvest Treatment

In packinghouse freshly harvested bunches are cut into separate hands. As bigger as possible part of crown should stay on the hand to eliminate risk of fingers detachment (Thompson 2003). Either curved or straight knifes, or chisels are used for this operation. Immediately after disintegration, hands should be placed in a water tank for at least 20 minutes. As long as the water can contain fungi spores, fungicides are used widely as additive (e.g. chlorine at 100 mg/l or alum at 10 g/l). Robinson (2010) reports usage of dishwashing detergents in some farms. This bathing procedure serves for cleaning (from dirt and fungal spores) and delatexing – coagulation and extraction of latex from the crown residues (Kader 2002, Thompson 2003; Robinson 2010; Paull 2011). If latex remains of a banana, it causes staining and decreases market value of the fruit (Thompson, 2003). According to Kader (2002), the tank actually is a pool with fresh water and banana hands on the inlet, and washed bananas floating down with wastewater towards the outlet. On the outlet side of the pool workers provide following operations:

- take the hands out of the water;
- clean fingertips from floral residues (if they are still present);
- cut large hands into smaller ones to meet consumers' expectations;
- sort out undesired, damaged, deformed and blemishing fingers (Kader 2002; Thompson 2003; Robinson 2010; Paull 2011).

Selected clean bananas are treated with fungicide solution via sprayers or emerging into buckets or other tanks containing the fungicide. Spraying on conveyer lines is more desirable because of moderate solution consumption and continuous work of operators. Labeling fingers with stickers is done on the conveyer line, too, and hands are sent to packing area (Robinson 2010). Fungicide treatment can be enhanced with adding ethylene inhibitor, such as 1-Methylcyclopropene (1-MCP) or gibberellins, to delay banana ripening (Hui 2006).

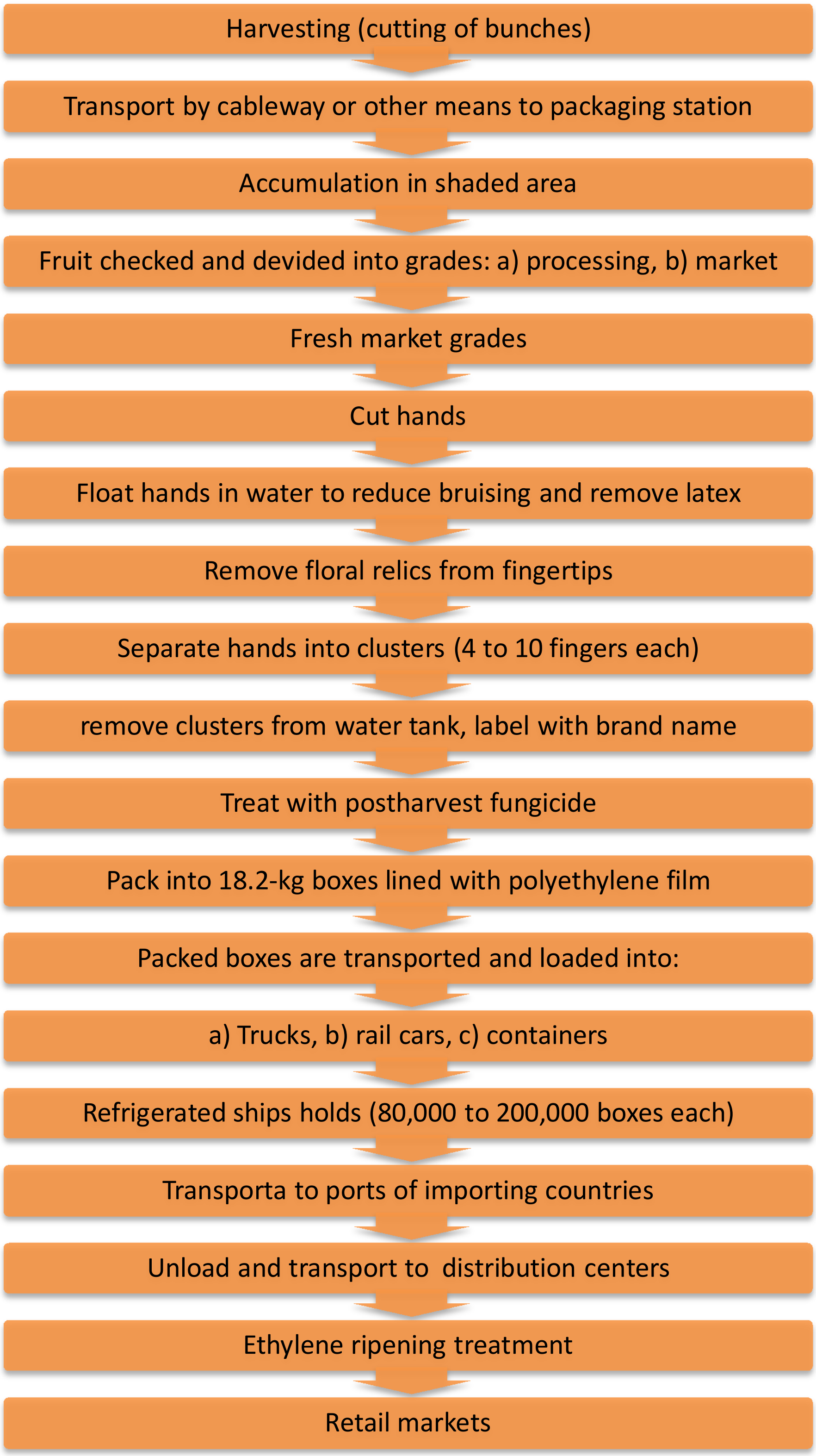
Figure 7

Carton of green dessert bananas

(author Alex Dobrynin, 2011)

Figure 8

Postharvest handling of bananas (from Kader, 2002)



Packing

Hands of banana cultivar ‘Cavendish’ are relatively easy-to-pack into carton boxes. Usual mass of one box is 18.1 kg (Kader 2002; Paull 2011). Each box should be entirely covered with double layer of polyethylene film (0.03 mm thick) from the inside. Hands are put crown downward, 5 layer, and each of them should be separated with plastic foil (Thompson 2003). Polyethylene film is used for reducing mass losses due to increased transpiration rate and to protect fruits from chafing damage. Enough space between hands is required to ensure even ventilation inside the box, which provides desired temperature and relative humidity and gas composition around each finger (Robinson 2010). Vacuum packing with sealing of polyethylene films sometimes is used. In this case bananas are treated with 1-methylcyclopropene (1-MCP) and immediately sealed or sealed together with potassium permanganate packs. Both compounds eliminate ethylene effect on banana ripening for up to 18 days (Thompson 2003).

After packing carton boxes usually are palletizes and then cooled down to 13°C and are ready to be sent to further points. Dessert bananas exporting is done mostly by shipping (Paull 2011).

2.3 Preservation of the food

History

The problem of saving food always was the second biggest issue, after getting the food itself; and not only for humans, but even for animals. It is well known, that some animals try to deposit feed, when it is abundant, in natural hiding places. For instance, forest birds save insects and seed in holes inside trees or under its' roots. Squirrels save nuts and mushrooms, beavers save green twigs. The list can be easily extended. Prehistoric people used fire and cooling to preserve meat of mammoth after successful hunting. In the beginning of civilization, salt and honey were found to preserve some foods. Taking it into account, we can assume that saving food is more or less an instinct, which helps animals and humans to survive bad times and win the battle for the life in the theatre of natural selection.

Nowadays a plenty methods of preserving the food are known and used every day. Thousands years ago people used primitive methods of preserving: heating, salting, candying, drying, freezing, fermenting and others. They used all those methods without any scientific knowledge, relying on practical experience only. Louis Pasteur in the 19^{th} century was the first who explained sterilization procedure – heat treatment – from the point of view of the science. WJ Scott in the middle of the 20^{th} century was the first who saw relation between water activity levels a_w and fungi growth (Scott, 1953). It helped to explain mechanisms of action of sugar, salt, freezing, drying and other methods of food preserving scientifically.

But food preserving via food processing cannot provide us with fresh fruits and vegetables. Fresh horticultural products are richer in nutrients (vitamins, enzymes, etc.), compare to processed ones, and have absolutely different organoleptic properties: taste, flavor, texture, appearance. For consumers, definitely, the most important factor to choose fresh product versus processed one, is the complex of organoleptic properties (Mudambi 2006).

Controlled atmosphere technology is the best solution for preserving fresh horticultural products. It is based on changing the composition of air around products: elevation of carbon dioxide or declining of oxygen. The science of controlled atmosphere was known in the 19^{th} century, however, wide commercial use began in the 2^{nd} half of the 20^{th} century. But even ancient Egyptians stored fruits in sealed limestone caves. In Oriental cultures fruits were taken to temples as a sacrifice, and smoked with incense, resulting in faster ripening. Fruits were found in some ancient crypts with mummies, and it is believed, that fruits consumed oxygen and thus preserved the mummy from decaying (Thompson, 2010). Nowadays controlled atmosphere techniques are used not only for horticultural products, but for dairy and meat products, cereals, snacks and so on.

2.3.1 Post-harvest physiology

Importance

'Growth, maturation and senescence are the three important phases through which fruits and vegetables pass, with the first two terms often referred to as 'fruit development'. Ripening … is considered the beginning of senescence, a term defined as the period when anabolic processes give way to catabolic processes leading to aging and final death of the tissue' (quoted from Robertson, 2006). Supplying horticultural products in any place any in any season requires either transportation (e.g. mangoes from India to Japan) or long-term storing (e.g. local apples in Denmark until next harvest) of the fresh product (Man 2000). Fruits and vegetables are perishable by nature. It is caused by internal, almost irreversible changes in the product: chemical, physical, microbiological (Man 2000; Kader 2002). These changes can be delayed to a certain point by adjusting the following environmental conditions to the optimal for a given commodity: temperature, relative humidity, atmosphere composition, light intensity or other factors, highly specific for given crops (Charalambous 1993; Thompson 2003).

Respiration

Since fresh fruits and vegetables are living organisms, they 'breathe'. The process of respiration gives energy to living cells, which allows them to stay alive and grow. Respiration involves enzymatic oxidation of sugars, starch and organic acids resulting in energy and carbon dioxide, water and heat as by-products:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{usable energy (32 kJ)} + \text{heat (48 kJ)}$$

(Robertson 2006; Paull 2011).

During postharvest life it can result in weight losses of the product, rated typically about 3-5%. The rate of respiration can be considered as an index of storage life of horticultural products: the higher the rate, the shorter is the postharvest life, and vise-versa (Robinson 2006).

Table 4

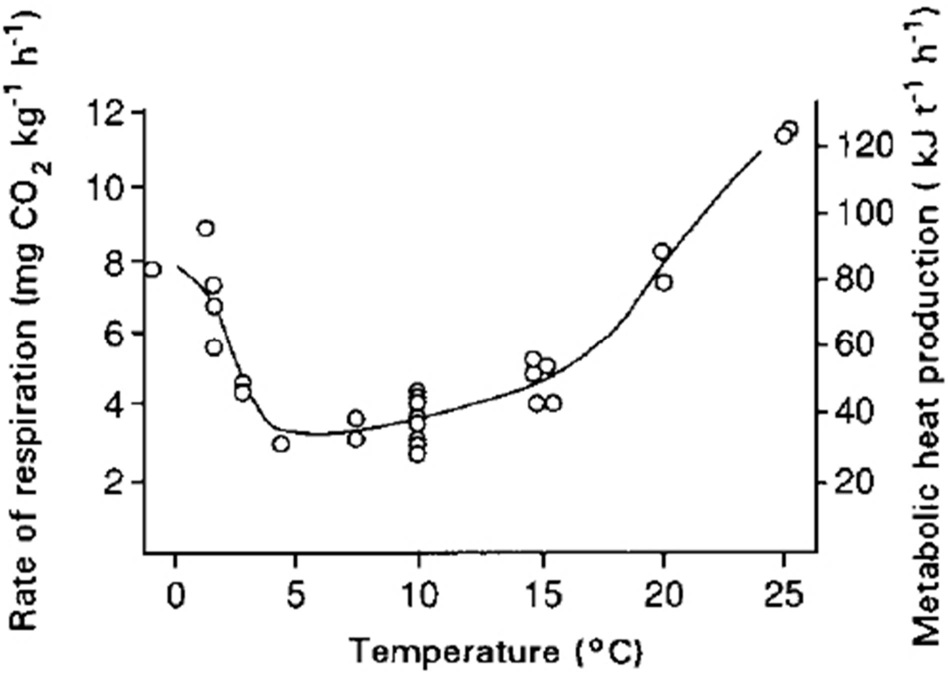
Respiration and ethylene production rate of selected commodities at 20°C (compilation from Robinson 2006; Paull 2011)

	Respiration		Ethylene	
Class	Range, mg/kg/k	Commodity	Range, µl/kg/h	Commodity
Very low	<35	Pineapple, carambola, onions, cabbage, tomatoes, carrots, leeks,	0.01-0.1	Cherries, citrus, grapes, pomegranates, strawberries
Low	35-70	Eggplant, lettuce, radishes, banana (green), papaya, litchi	0.1-1.0	Blueberries, kiwifruit, pineapples, raspberries, carambola
Moderate	70-150	Mango, guava, beans, spinach, Brussel sprouts	1.0-10.0	Banana, guava, mango, litchi, durian, figs, tomatoes
High	150-300	Avocado, banana (ripe), broccoli, peas, sweet corn	10-100	Avocado, apples, apricots, plums, peaches, pears, nectarines
Very high	>300	Soursop	>100	Cherimoya, passion fruit, sapote, soursop

Respiration rate per unit weight has the highest value at immature stage, and goes down as fruit is ripening and aging (Wills 2007). From technical point of view, respiration rate is essential value due to it determines heat load of cooling system in storing facility. For longer storing, respiration rate should be decreased, and cooling down the product is the only way. But tropical fruits require special care, because low temperature, even above freezing point, can lead to chilling injuries, which significantly decrease quality of the stored commodity (Paull 2011). On the other side, excessively high temperatures cause higher respiration and transpiration rates, which lead to faster death of tissues. Almost all horticultural commodities (except cabbage and some apple cultivars) suffer freezing injuries at temperatures below 0°C (Will 2007). Temperature ranges during storing optimal for selected commodities are presented in the table 7.

Figure 9

Respiration rated of potato tubers at different temperatures (from Thompson, 2003)

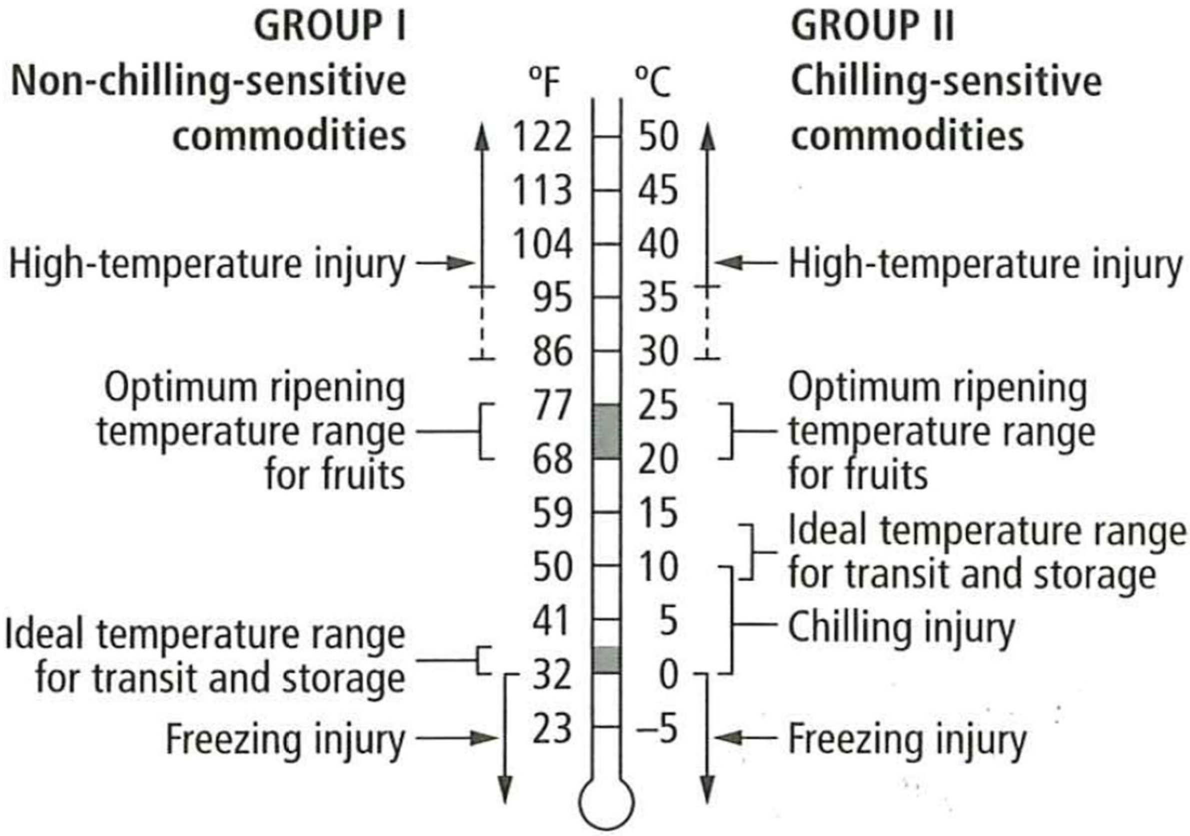


Transpiration

Another source of water losses is transpiration from fruit and vegetable. Transpiration can lead to weight losses of the stored product. Commodities can withstand losses up to certain points, for example, 7% (cauliflower, carrot), or 6% (apple, strawberry), or 4% (lettuce, broccoli), and higher losses result in organism collapse. Transpiration rate depends on the relative humidity of air and its temperature. Thus, controlling of these environmental parameters allows transpiration losses reduction (Unknown, 1989).

Figure 10

Effects of elevated and reduced temperatures on commodity groups (from Kader, 2002)

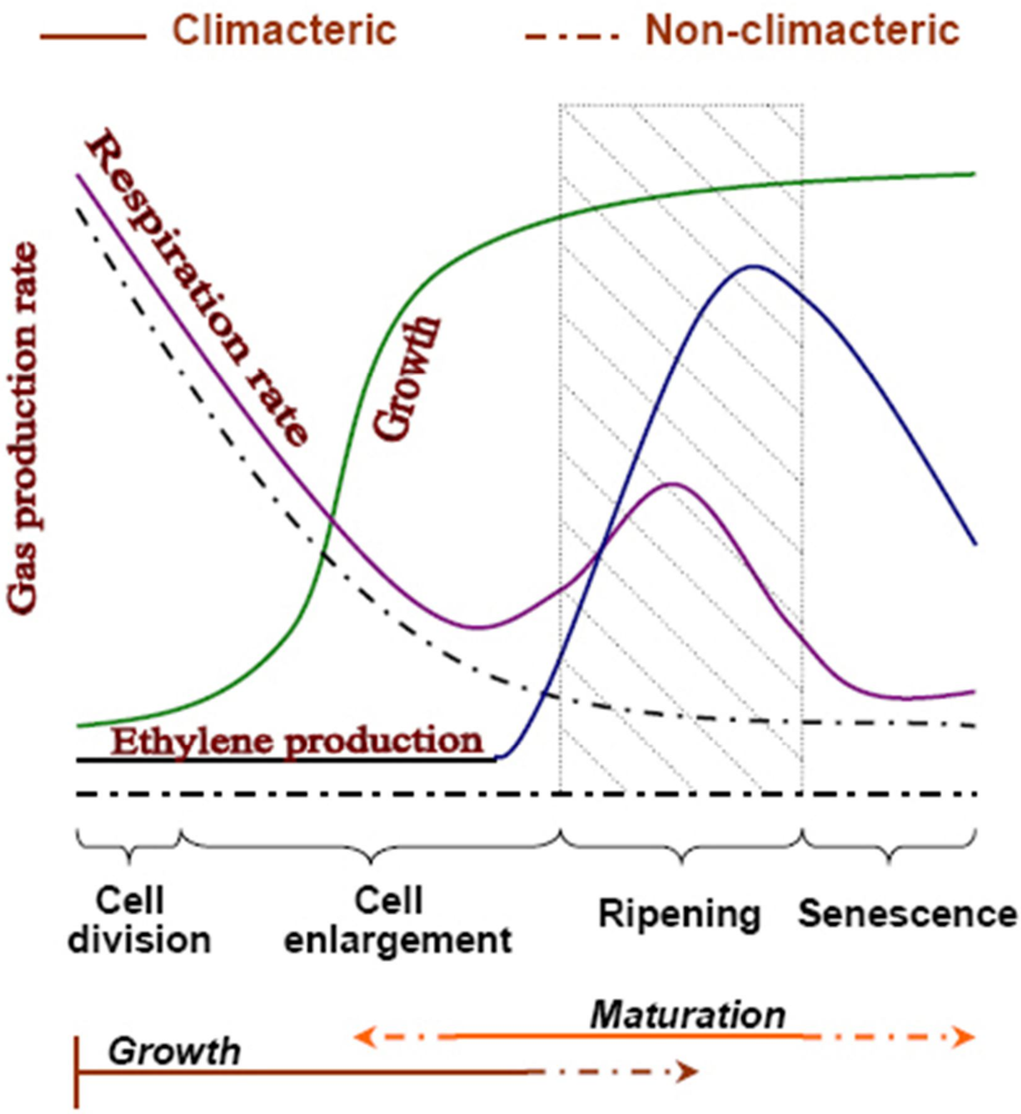


Climacteric and Non-climacteric species

All fruits and vegetables can be divided into two groups: climacteric and non-climacteric. This kind of division is based on the respiratory pattern during postharvest period (Paull 2011). Climacteric fruits and vegetables are characterized by significant increase of respiration rate, caused by elevation of internal ethylene production. After the climacteric rise, both processes go down. Ethylene is required for co-ordination and completion of ripening process. Non-climacteric fruits and vegetables are those, which respiration rates are more or less constant or gradually decline during ripening. Their internal ethylene production is very low, and ethylene itself affects respiration only, but not ripening (Robinson, 2006; Reeds, 2012).

Figure 11

Growth and respiration in climacteric and non-climacteric species (from Kader, 2002)



From producers' point of view, climacteric fruit can be picked mature, but unripe, and fully ripe during storing. On the other hand, non-climacteric fruit cannot fully ripe after harvesting; therefore it must be picked when mature and ripe (Reeds, 2012). For example, banana or papaya can be harvested when green and mature and ripe in storage, but orange or pineapple should be harvested already ripe and ready to eat (Paull, 2011). Some of climacteric and non-climacteric fruits and vegetables are presented in the table 5.

Table 5

Selected climacteric and non-climacteric species (compilation from Kader, 2002; Rees, 2012)

Climacteric species	Non-climacteric species
Apple	Blackberry
Apricot	Cherry
Avocado	Cucumber
Banana	Eggplant
Cherimoya	Grape
Kiwifruit	Grapefruit
Mango	Lemon
Nectarine	Loquat
Papaya	Lychee
Passion fruit	Mandarin
Peach	Muskmelon
Pear	Orange
Pepper (chilli)	Pepper (bell)
Persimmon	Pineapple
Plum	Pomegranate
Quince	Pricky pear
Sapodilla	Rambutan
Sapote	Strawberry
Tomato	Watermelon

Ethylene

Ethylene (C2H4) is colorless, hydrocarbon gas with a faint, sweetish odor that is easily detected in parts per million. Boiling point at 760 mm Hg is -103.7°C, and freezing point is -169.2°C. Flammable limits in air are: lower – 3.1% by volume; upper – 32% by volume (Kader 2002). Ethylene is a natural plant hormone, affecting ripening initiation. It is physiologically active in trace amounts (<0.1 ppm). The most important effect of ethylene on plants is increasing the respiration rate and activating and hastening ripening processes as well as senescence and death. For horticultural producers and transporters ethylene presence in storing facilities means loss of the product quality and even loss of the product itself. Climacteric fruits and vegetables are much more susceptible to ethylene, thus special care should be taken during postharvest handling (Robinson, 2006).

Table 6

Effects of ethylene (from Wills et al, 2007)

Commodity group	Effects of ethylene
Cucumbers	Turn yellow and become soft
Unripe fruits	Accelerates ripening
Flowers	Wit and/or drop off
Leafy vegetables	Turn yellow, russet spotting on leaves and abscission of leaves

On the other hand, ethylene is commercially used for controlled ripening of fruits, mostly of dessert bananas. The effect of ethylene of plant tissues depends on not only internal factors, but on external ones as well. Such factors, as temperature, exposure time and ethylene concentration can affect both (a) effect of ethylene on fruit (vegetable) itself and (b) effect of ethylene production by the plant itself (Wills, 2007). The rate of ethylene production by plants is shown in table 4.

Oxygen and carbon dioxide

The lower oxygen concentration or higher carbon dioxide concentration in the atmosphere, do reduce the respiration rate of horticultural products. Obviously, changing of the atmosphere composition is a tool for prolonging storing period. Concentrations of oxygen lower than 10% significantly reduce respiration rate of tissues, but those lower than 1-3% (for most commodities) activate glycolysis (anaerobic catabolism). It results in formation of acetaldehyde and ethanol, which are toxic for plant cells. Elevated concentrations of carbon dioxide tend to inhibit ethylene susceptibility and delay ripening. Excessive carbon dioxide concentrations, above20%, activate undesirable glycolysis, too (Robertson, 2006). Concluding these two facts, optimal concentration of both oxygen and carbon dioxide should be used to obtain best result during storing.

2.3.2 Controlled and Modified Atmospheres

Controlled atmosphere (CA) and modified atmosphere (MA) are terms for storing technique based on changing the air composition around a product in a storage room, transport container or consumer package. The levels of oxygen, carbon dioxide, nitrogen, and ethylene are manipulated to be different than in atmospheric air. The term 'controlled atmosphere' is used for techniques with higher precision of monitoring and controlling of the gaseous composition, compare to 'modified atmosphere', technique of changes the initial gaseous composition and no further control (for example, sealed package with potato chips) (Charalambous, 1993). In horticulture the controlled atmosphere method is used to reduce the metabolic rate via reducing respiration and ethylene production. Storing in controlled atmosphere includes following aspects:

- Gaseous composition control;
- Temperature control;
- Relative humidity control (Thompson, 2010).

Values of CO_2, O_2 concentrations, relative humidity and temperature ranges, optimal for selected commodities, are presented in table 7. They all were defined owing to practical experiences in industry and laboratory experiments.

Temperature control

The most convenient and accurate, as well as effective, method of cooling the storage is refrigerating an insulated camera. Any basic refrigerator consists of an evaporator, a compressor, a condenser and an expansion valve. The evaporator is a pipe, placed inside the storing room. Refrigerant liquid flows inside the system. High pressure of the liquid is made by the compressor, and in the evaporator's pipes the pressure goes down, causing evaporation. Evaporation requires energy, and the energy supply for it is heat in the storing room, which mean lowering the temperature. Refrigerant at atmospheric pressure goes to compressor, closing the cycle. Fans are installed in the storing room for even distribution of the cooled air (Thompson, 2003; Thompson, 2010).Cooling system work in limits: maximum and minimum allowed temperatures. Temperature sensors read the temperature and send the values to relay. As long as the temperature rises up to

Table 7

Summary of recommended CA or MA conditions furing transport and/or storage of selected fruits (compilated from Charalambous, 1993; Kader 2002, Rees 2010)

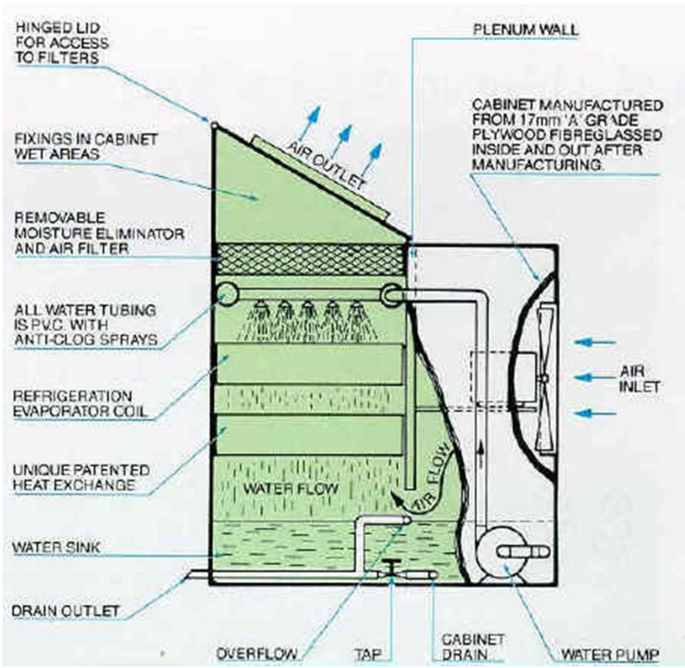
Commodity	Temperature range, °C	RH, %	CA		Commercial use
			O_2, %	CO_2, %	
Apple	0-5	85-95	1-2	0-3	About 60% of production is stored in CA
Apricot	0-5	85-95	2-3	2-3	
Avocado	5-13	85-90	2-5	3-10	Used during marine transport
Banana	12-16	90-95	2-5	2-5	Used during marine transport
Cherry	0-5	80-90	3-10	10-15	Used within pallet covers or marine transport
Durian	12-20	85-90	3-5	5-15	
Fig	0-5	85-91	5-10	15-20	Limited use during transport
Grape	0-5	85-92	2-5	1-3	Incompatible with SO2
Grapefruit	10-15	85-90	3-10	5-10	
Kiwifruit	0-5	85-95	1-2	3-5	Expanding use during transport and storage
Lemon	10-15	85-90	5-10	0-10	
Lime	10-15	85-90	5-10	0-10	
Lychee	5-12	90-95	3-5	3-5	
Mango	10-15	85-90	3-7	5-8	Used during marine transport
Nectarine	0-5	80-90	1-2	3-5	Limited use during marine transport
Nuts	0-10	15-50	0-1	0-100	Delay rancidity and control insects
Olive	5-10	95	2-3	0-1	Limited use to extend processing season
Orange	5-10	85-90	5-10	0-5	
Papaya	10-15	85-95	2-5	5-8	
Peach	0-5	80-90	1-2	3-5	Extension canning season; marine transport
Pear	0-5	80-90	2-4	0-3	About 25% of production is stored in CA
Pineapple	8-13	90-95	2-5	5-10	Used to reduce endogenous brown spot
Plum	0-5	80-90	1-2	0-5	Used for long-term storage
Pomegranate	5-10	85-90	3-5	5-10	
Rambutan	8-15	90-95	3-5	7-12	
Strawberry	0-5	85-90	5-10	15-20	Used within pallet covers during transport

the upper limit, relay automatically turns on the refrigerator. As soon as the temperature falls down to the lower limit, relay turns the refrigerating off. The heating equipment works according to the same relay principle (personal communication with Vesely, 2012). The product load must be adequate to the refrigerator's power. Chilling demand, start temperature, mass of the product, packaging and stacking pattern should be taken into account (Unknown 1989).

Humidity control

Due to temperature differences in the evaporator and the air in the room, water vapor condenses on the evaporator's pipe. This is the main reason of water losses from the air. Thus, a range of humidifying devices can be used to maintain relative humidity at the desired level: vaporizers, sprayers, spinning disk humidifiers, etc. (Thompson 2003).

Figure 12
Scheme of air humidifier (from Wills, 2003)

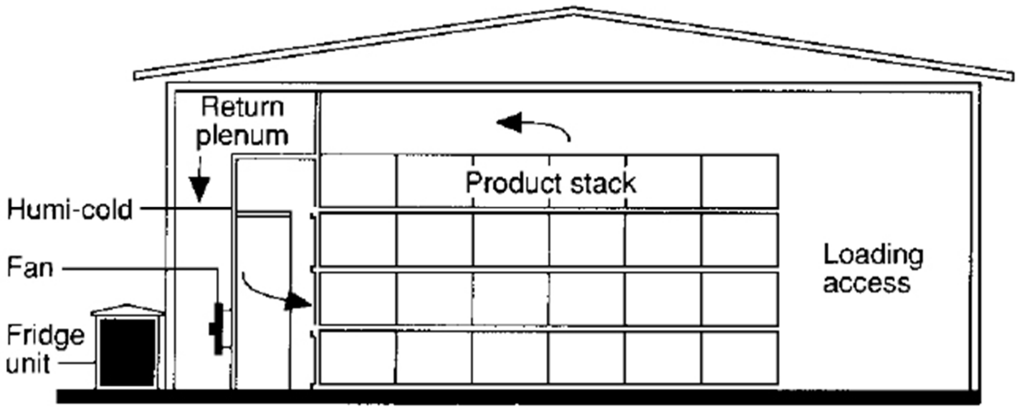


Air ventilation

All controlled atmosphere rooms require active ventilation. The ventilation provides proper air mixing and uniform distribution of gases and heat (cold) medium. Also, fresh air ventilation decreases carbon dioxide concentration and introduces oxygen. The average requirement of ventilation for horticultural crops is 1-2 m^3 per ton/hour. Maximal air requirement should be 600-700 m^3 per kW of cooling effect (Unknown, 1989; Thompson 2003).

Figure 13

A forced-air high-humidity cooler using the letterbox ventilation system (from Thompson, 2003)



Gas composition control

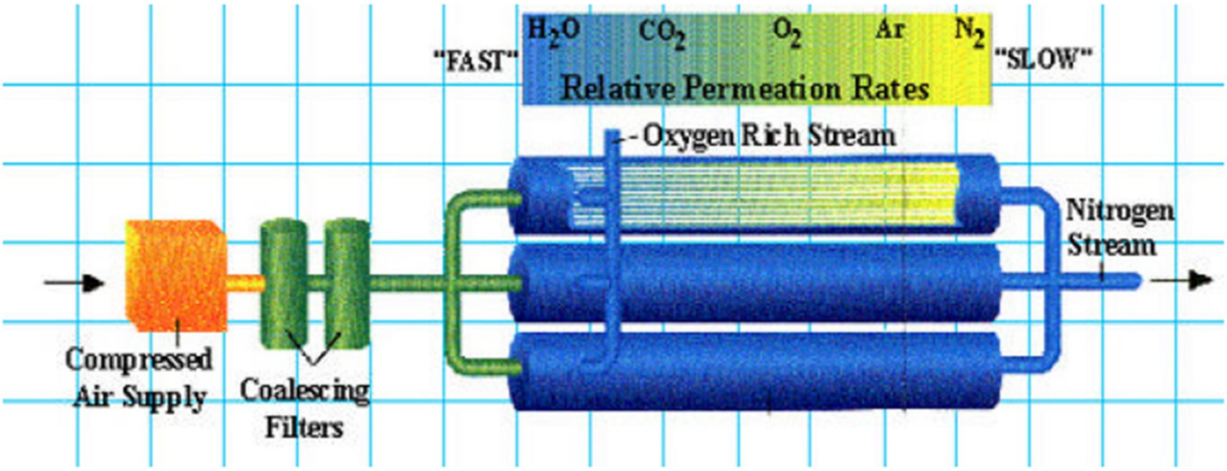
Gas analyzers are placed inside the camera and constantly read the air. Most common is installing analyzers for (1) oxygen, (2) carbon dioxide, (3) ethylene. Proper calibration must be performed according to the suggested CA composition. The data from gas analyzers are sent to the central controller, which operates with all equipment. Usually, controllers have such functions:

- control output for store ventilation when oxygen is low;
- control output for nitrogen purge when oxygen or carbon dioxide is high;
- control output for scrubbers when carbon dioxide is high;
- control output for adding CO2 when carbon dioxide is low;
- adding ethylene can be either manual or automatic.

High-pressure cylinders with carbon dioxide or oxygen are relatively expensive for commercial use, so scrubbers are used instead. Scrubbers are devices cleaning the air from gases. A scrubber consists of a filter chamber, a low-pressure ventilation, an air-transport system, a control unit and a buffer system. The device monitors the gas concentration in the air and filters the gas when necessary. The mostly common are scrubbers fixing carbon dioxide from the air. The operating part of the filter is absorbent material –activated charcoal (or $Ca(OH)_2$, NaOH, zeolites, etc.) which fixes the CO_2. When needed, the gas can be released in the atmosphere (Thompson, 2003).

Figure 14

Nitrogen separation from compressed air supply (after Thompson, 2003)



Properties of the camera

The camera supposed to be used for CA and storing, must meet a number of requirements. First of all, the camera must airtight and it must be equipped with an airtight door. Obviously, it is required to keep the inside atmosphere separately from the air outside. Constructing an airtight unit is relatively expensive, so more economically effective could be 'almost airtight' camera. A compromise between degree of airtightness and expenses on additional losses (heated or cooled air, gases, and vapor) should be found in each particular case. Adequate insulation is a must.

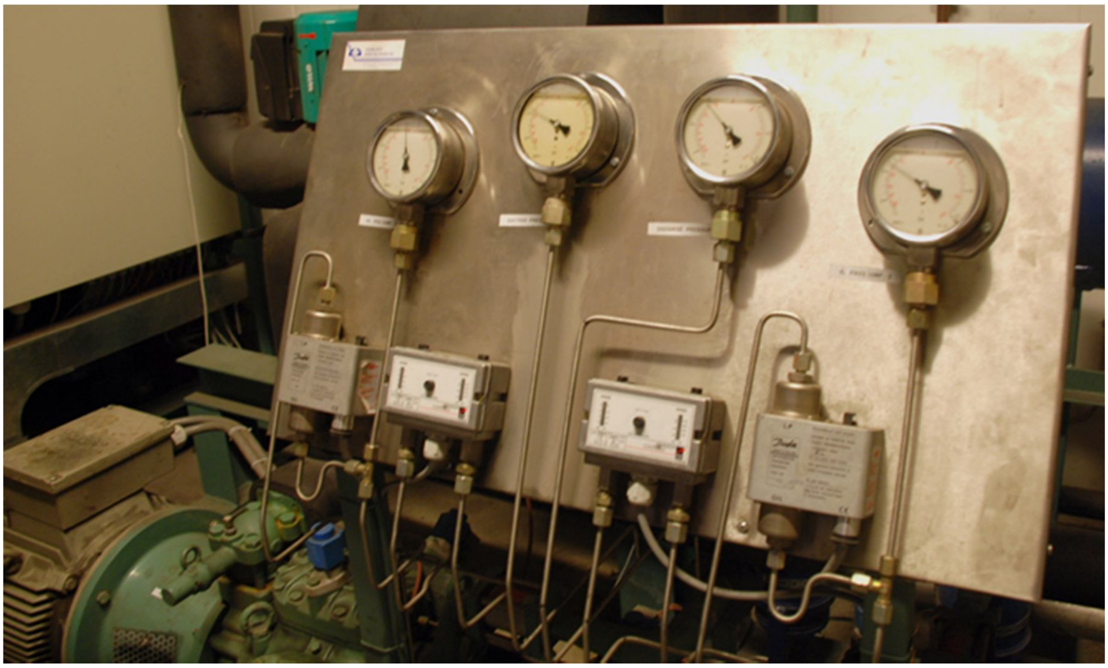
The changes of pressure inside the camera can cause damages to the walls and the door. To reduce the impact, expansion bags are installed. The bags are airtight, partially filled with gas and are placed outside the cameras. If the store air volume increases then this will automatically further inflate the bag and when the pressure in the store is reduced then air will flow from the bag to the store. The inlet of the expansion bag must be before the cooling system inlet, to cool down the air from the bag before injecting to the camera (Thompson, 2003).

Figure 15

Expansion bags author (Alex Dobrynin, 2009)

Figure 16

Gas composition control for controlled atmosphere storage (author Alex Dobrynin, 2009)



2.3.3 Changes in a banana fruit during ripening

Ripening is a process, which contains a number of independent biochemical reactions. During ripening process complex compounds break down to simple compounds. The most important changes regarding ripening bananas are peel color changes and starch-sugar conversion. Peel color determined with a human eye is a property, widely used to determine the stage of ripening of a banana fruit. A table consisting of 8 different grades for Cavendish bananas was developed and approved by banana producers. So, grade 1 refers to a harvested banana, grade 4 – to a banana after commercial ripening, number 7 – a fully ripe banana (Unknown, 2001; Robinson, 2010).

Table 8

Color stages of the ripening Cavendish banana (compilation from Wills et al, 2007; Somogyi et al, 1996 and Hui et al, 2010)

Stage	Peel color	Comment
1	Green	Hard, rigid; no ripening
1a	Sprung green	Bends slightly, ripening started
2	Green, trace of yellow	
3	More green than yellow	
4	More yellow than green	
5	Yellow, green tip	
6	Full yellow	Peels readily; firm ripe
7	Yellow, lightly flecked with brown dots	Fully ripe, aromatic
8	Yellow with increasing brown areas	Over-ripe; pulp spft and darkening, highly aromatic

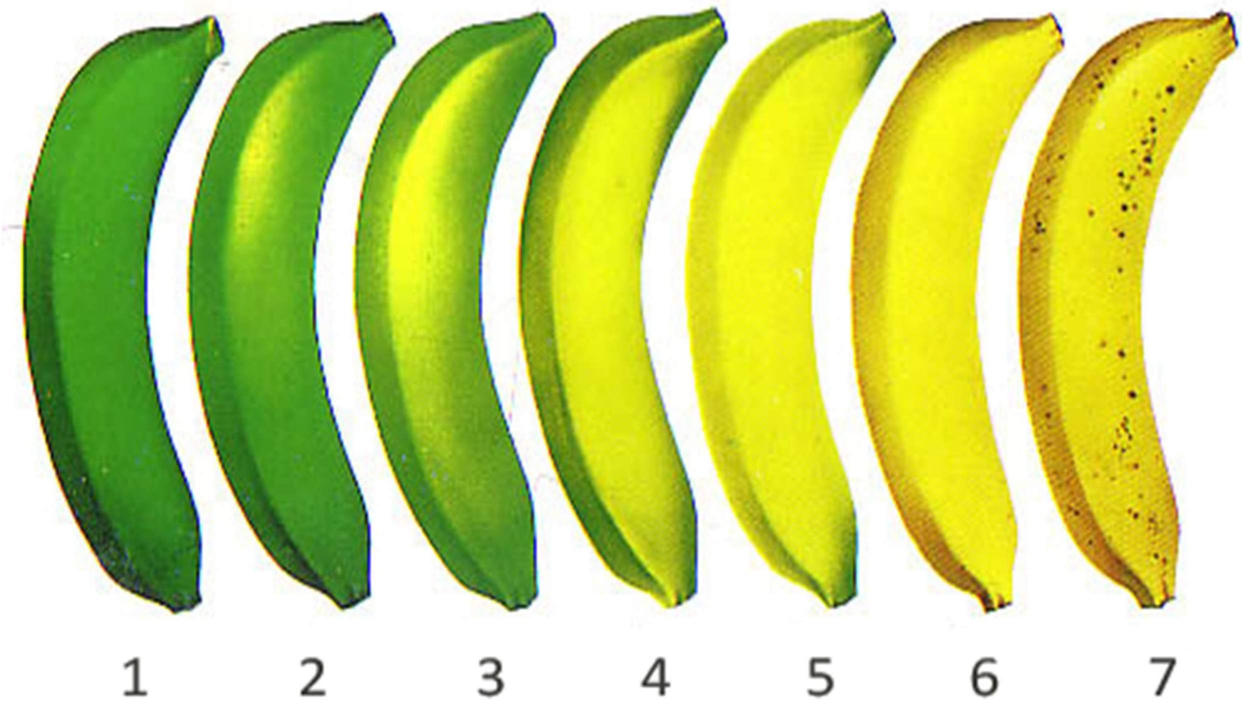
Changes of peel color are caused by chlorophyll degradation and carotene formation (Will, 2007).

Other property – sugar to starch ratio – is a very representative measurement. The starch breaks down into simple soluble sugars (fructose and glucose). If suppose, that at the stage 1 starch content takes 100% and soluble sugars – 0%, then at stage 7 and 8 starch will take 0%, but sugars – 100% (Wills, 2007). But checking the content of soluble sugars is commercially used only prior harvesting (with means of refractometer), because it requires sap from the fruit, and ripen banana does not have enough of free sap to conduct the measurement (Wills, 2007; Robinson, 2010).

The iodine test is also used to determine the best harvesting time. Starch and iodine form a complex compound with character dark blue color. A banana fruit is diametrically cut and iodine solution is introduced to the cross-section. The higher the content of starch, the higher is the blue color intensity. The result is compared to standard chart (Dadzie *et al*, 1997).

Figure 17

Color stages of the ripening Cavendish banana (Unknown, 2001)



The significant changes in banana during ripening were defined by Dadzie *et al*, 1997:

- Peel and pulp color changes.
- Conversion of starch into sugars.
- Changes in pulp to peel ratio.
- Changes in pulp firmness.
- Changes in total soluble solids content.
- Changes in pulp pH and total titratable acidity.

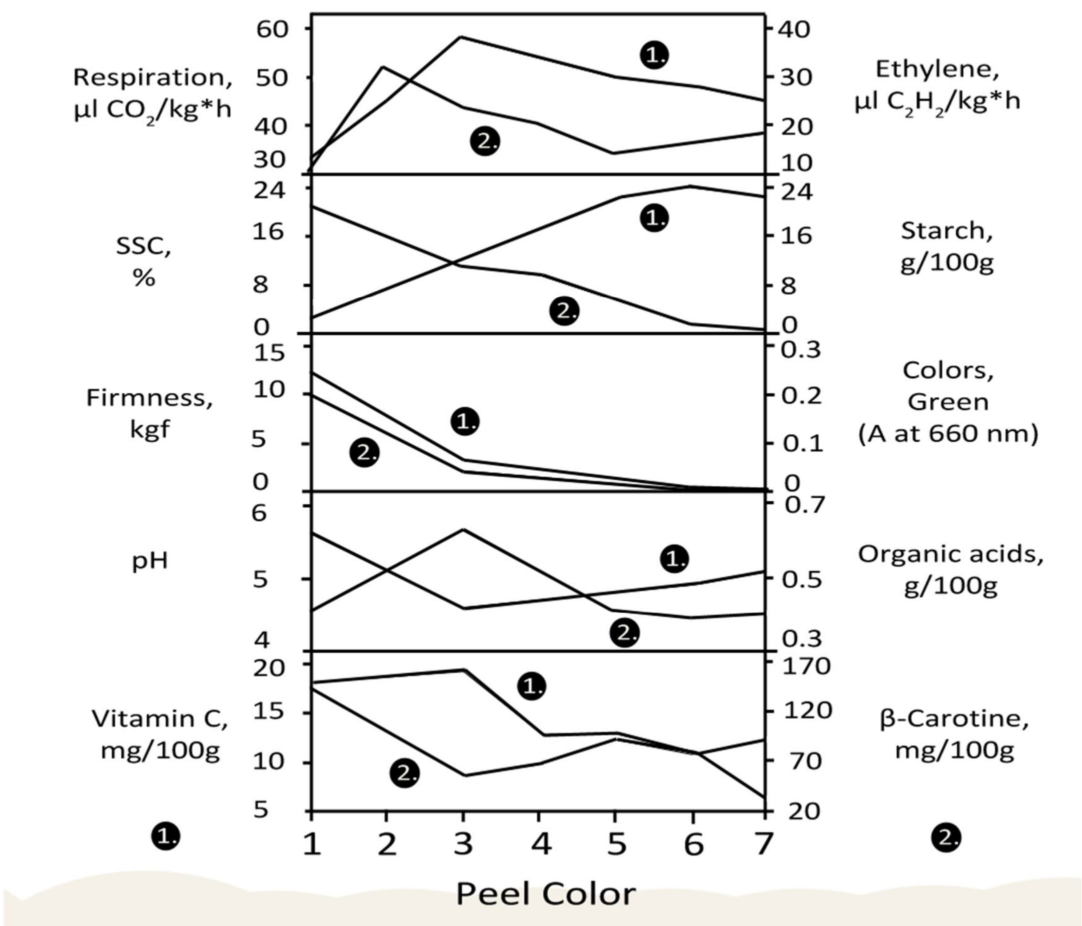
- Changes in peel and pulp moisture and dry matter content.
- Changes in respiration rate and ethylene production.

Most of these changes are not used commercially to determine the ripening stage. But they are widely used in banana processing industry (Dadzie *et al*, 1997).

Wills (2007) conducted an experiment with ripening bananas. He emulated ripening process of Cavendish bananas and studied the biochemical changes all along the process. His results are presented in the following figure.

Figure 18

Physiochemical changes that occur during ripening of the Cavendish banana. Peel color refers to: 1 – green, 6 – yellow (from Wills, 2007)



The characteristic aroma of a ripe Cavendish banana is caused by combination of volatile compounds (found around 300 ones). They form due to metabolic processes during ripening. The common groups are: esters, acetates, alcohols and carbonyls. The aroma emission increases with ripening, and a the last stage (brown peel) declines (Thompson 2010).

2.4 Transportation and ripening

Transportation

Export bananas after palletizing should be transported to ships into refrigerated holds – so called reefers. This operation is desired in maximum 24 hours after packaging. The temperature during transportation is in range of 13-14°C to prevent ripening and spoilage. Ventilation and refrigerating of the reefer should be started before loading. Maintaining the quality requires air renewal rate at 30 times per hour per container (Robinson 2010). Adequate ventilation is required to provide even distribution of cooling. Solid stacking of pallets is not allowed due to blocking ventilation holes in some cartons. Usually each pallet has free space around it, and space between pallets is ensured (Thompson, 2003). After shipping bananas are distributed to ripening rooms by trucks (trains).

For storing and transportation of green Cavendish bananas reduced temperatures are recommended. Reduced temperatures, on one hand, delay ripening of the fruit, and, on the other one, should be high enough to prevent chill injuries (Paull, 2011). Controlled atmosphere is often used as well. Conditions optimal for green Cavendish bananas storing and long-distance transportation, according to independent authors:

- 12-14°C, 90-95% RH, 2-3 weeks (Unknown, 1989);
- 12-16°C, 2-5% O_2, 2-5% CO_2 (Kader 2002);
- 13-14°C, 90-95%RH, 2-5% O_2, 2-5% CO_2 for 1-4 weeks (Thompson 2003);
- 12-14°C, 1-10% O_2, 5-10% CO_2 (Huy, 2010);
- 13-14°C (Robinson. 2010; Paull, 2011).

Other authors recommend conditions very similar to the listed ones. To sum up, temperature 13-14°C and RH 90-95% is a must; controlled atmosphere is common. Long-term storage of bananas in controlled atmosphere can last up to 3 months (Kader 2002). But instead of controlled atmosphere, anti-ethylene treatment can be used. Exposing green bananas to 1-methylcyclopropen (1-MCP) at 0.01-1.0 ppm for 24 hours delays ripening and suppresses respiration. Instead of exposure, sealing bananas in polyethylene bags (0.03 mm thick film) containing 1-MCP has the same effect. Both treatments can prolong shelf-life up to 58 days (Thompson, 2003).

Shipping bananas from Central America to Europe takes up to 3 weeks (Kader, 2002).

Ripening

As long as bananas are transported to ripening facility, they should be immediately loaded into a ripening camera. If happens, that there is no vacant ripening camera, bananas should be kept in a refrigerator at the same temperature, as it was during transportation, until ripening room vacates.

Initiation of banana ripening is achieved at ethylene concentration in the range 1-10 ppm at 14-19°C with 24 hours exposure (Thompson, 2003).

Commercial ripening of Cavendish bananas runs in closed chambers. Air temperature, relative humidity, CO_2 and ethylene concentrations are monitored and modified to get the optimal values. The ripening process contains of three stages:

1. Temperature increase (up to 18°C);
2. Ethylene injection (1000 ppm for 12-24 hours);
3. Ventilation during decreasing the temperature.

Relative humidity should be maintained at 90-95%. Carbon dioxide accumulation around fruits is not allowed (air ventilation solves this problem). Ripening process is finished when bananas are at grade 4 (see the figure above) (Thompson, 2003; Robinson, 2010; Paull, 2011). The temperature during all stages depends on the length of the process. After ripening, bananas are stored at 13-14°C and RH 95% (Robinson 2010).

Figure 19

Optimal temperature pattern for Cavendish banana ripening, according to Thompson, 2003

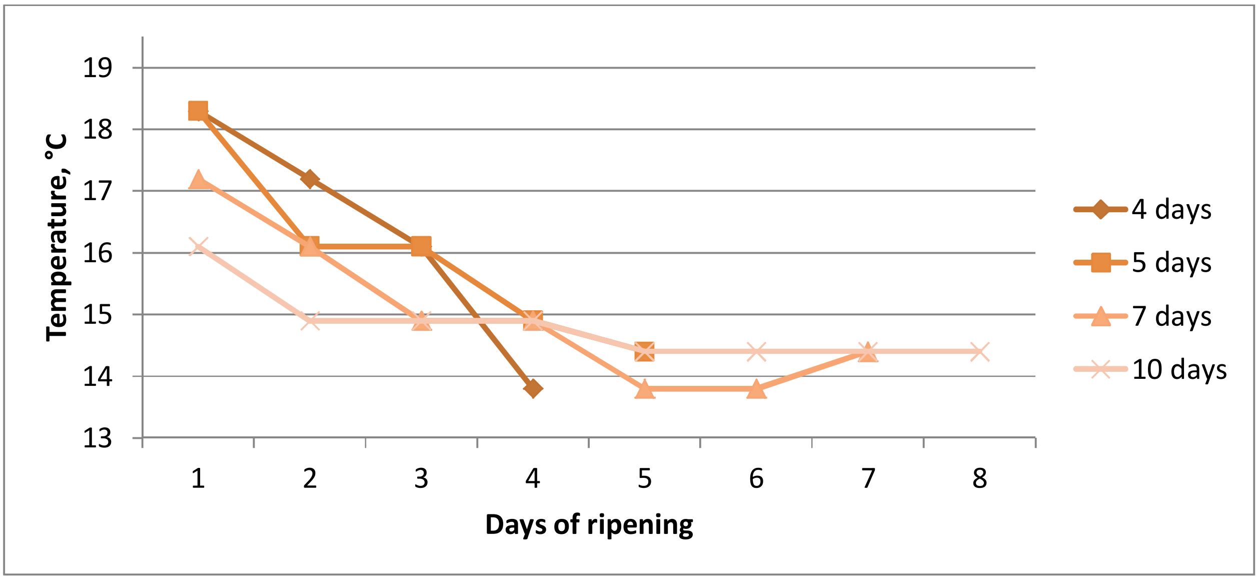


Figure 20

Optimal temperature pattern for Cavendish banana ripening, according to Robinson, 2010

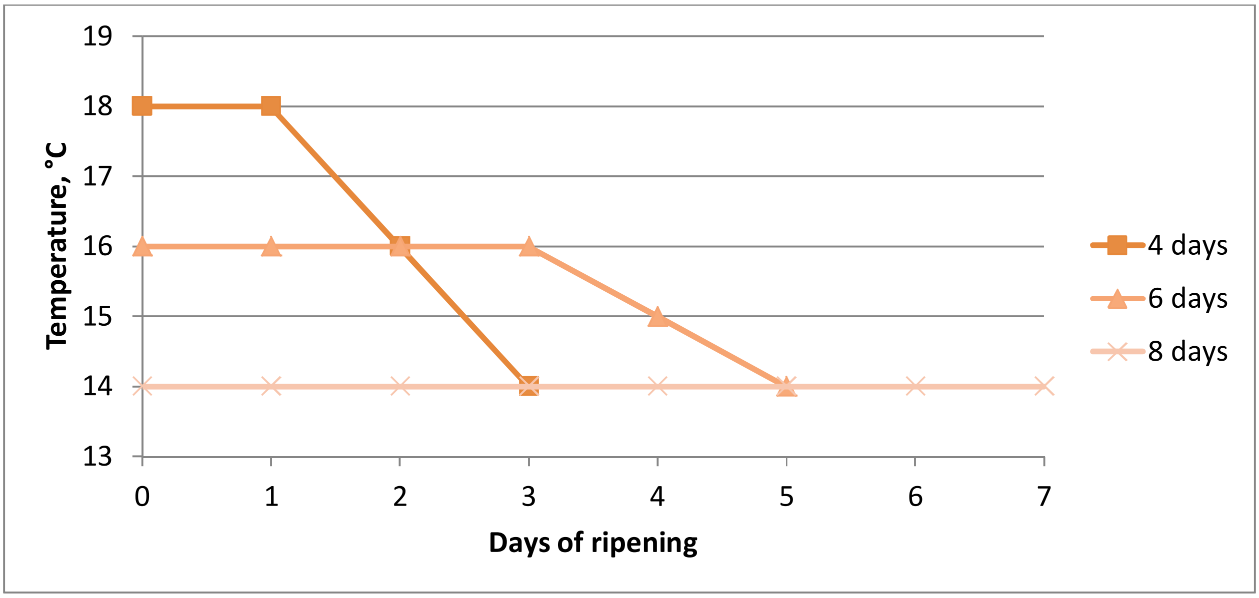
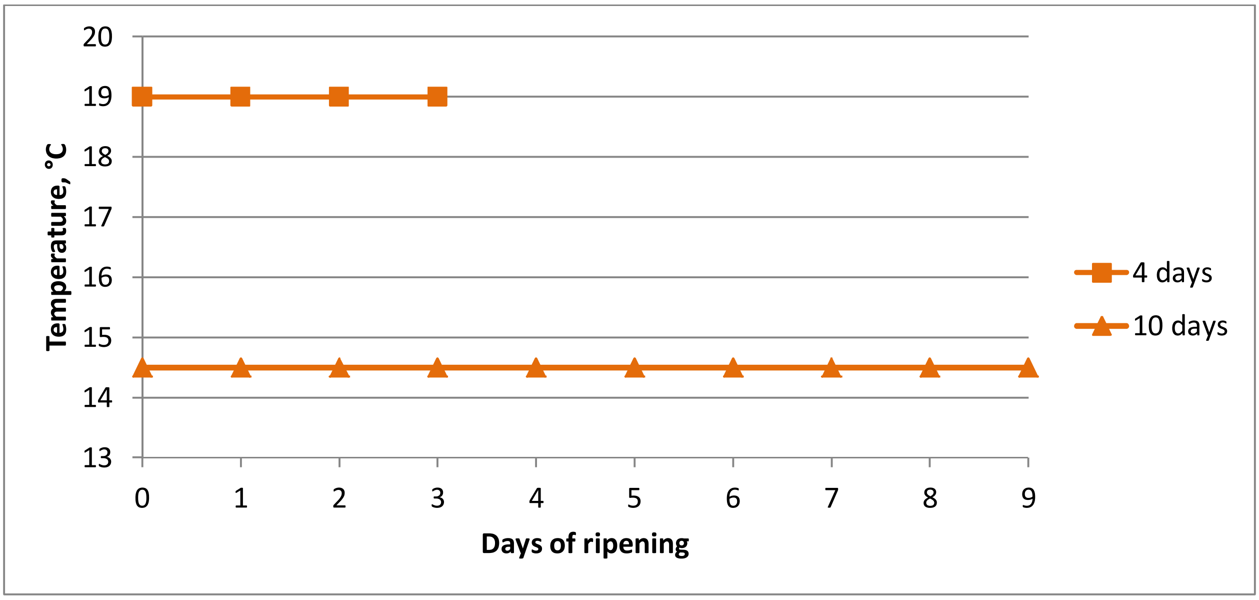


Figure 21

Optimal temperature pattern for Cavendish banana ripening, according to Paull, 2011



Although temperature patterns are different, all 3 authors recommend RH 90-95% and ethylene treatment at 1000 ppm for the 1st 24h of the ripening process.

Possible problems

Increased temperature (>25°C) at the beginning of ripening causes development of soft pulp while the peel remains green – so called ‘green ripe’. On the other hand, low temperature (<13°C) cause fruit discoloration and greyish-green color of peel (Thompson, 2010).

Low temperature and/or insufficient ethylene can cause uneven ripening (Thompson, 2010).

III. AIMS OF THE DIPLOMA THESIS

The aims of the Diploma Thesis are:

- Description of industrial methods of post-harvest operations in storage and transport of fruits;
- Description of the post-harvest handling technology of dessert bananas;
- Comparison of a real operational technology with the scientific researches results;
- Optimization of a real operational technology.

IV. MATERIALS AND METHODS

In terms of this Diploma Thesis a number of measurements were conducted. The whole ripening process of banana fruits was monitored. The changes of the ripening stages of fruits were controlled by measuring the changes of the peel color and the changes of aromatic composition of the pulp. Controlling of all parameters was performed once per every day during ripening cycle. Three full cycles were monitored.

4.1 Ripening process

Materials

The ripening process was studied at Chiquita LLVK limited liability company storage and ripening facilities (V Korytech 3136/73, 10000 Prague 10 – Strasnice, Czech Republic). Chiquita LLVK llc deals with ripening and storing of bananas and further wholesale trading with local distributors and retails. Measurements were registered with sensors and a control unit provided by Aseko limited liability company (Videnska 340, 25242 Vestec u Prahy, Czech Republic). Aseko llc is a manufacturer of gas analyzers and sensors and provides technical solutions for fruit ripening facilities, too.

The choice of Chiquita company for performing the experiments was made due to several factors:

- Chiquita is one of the biggest international companies dealing with bananas;
- Chiquita controls the whole process of producing the banana: from a seed (seedling) to a retail;
- Consistency of final Chiquita products is ensured by applying the same technology all over the world.

Aseko company was chosen due to its history on the market. Aseko deals with banana ripening technologies from the very beginning of introduction them to the Czech Republic (1990's).

Chiquita llc operates with 8 ripening cameras and cooled storage. Every ripening camera is controlled by central computer manufactured by Aseko. Cameras are thermo isolated and almost airtight when closed. Aseko provides their central operating computers with different programs of ripening. These programs differ in temperatures and time periods, according to the optimal condition for exact fruit species and cultivars.

Characteristics of the ripening camera:

• Dimensions (length, width, height)	3.6 x 3.0 x 15 m
• Capacity	24 pallets (48 boxes each), 20736 kg
• Door	airtight, rail-sliding
• Central operating computer	Aseko ASIN A.R.T.
• Cooling system	2 x 6 kVA
• Heating system	4 x 2.5 kVA
• Ventilation system	9 x 0.57 kVA, total 50,000 m^3/hour
• Ethylene source	2 x high-pressure cylinder, serving all cameras
• Ethylene supply	via plastic pipes
• Lighting	8 x 60 W
• Power supply	3 x 380 V, 50 Hz
• Maximum concurrent power	20kVA
• Energy consumption per 1 cycle (4 days)	750 – 800 kWh

Characteristics of the ethylene concentration transmitter Aseko GTC Et:

• Type of sensor	catalytic
• Measuring range	0 – 2000 ppm
• Test-retest reliability	5%
• Temperature operating range	-40 – +60°C

Figure 22

Scheme of ripening camera Aseko (from Simanek, 2012)

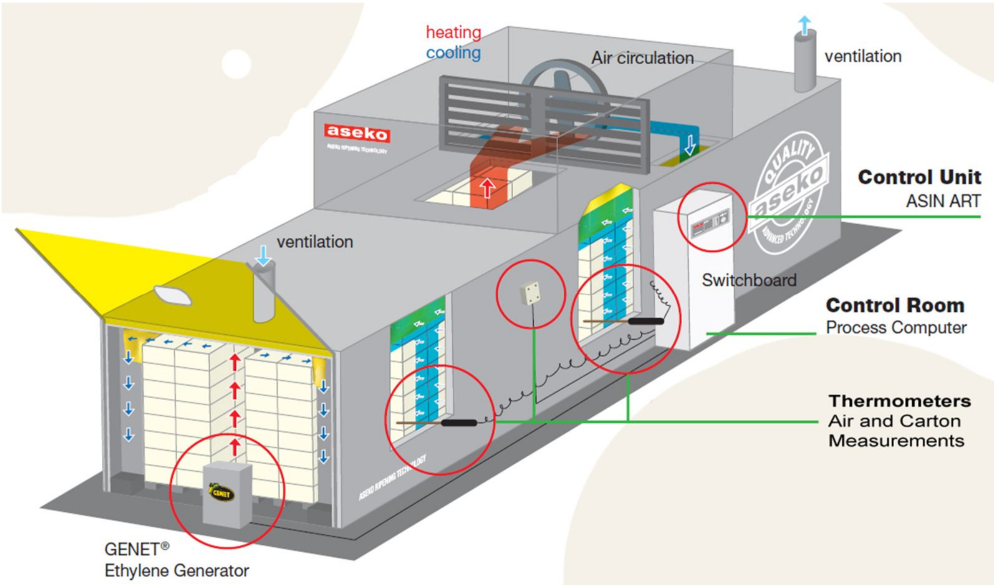


Figure23

Airtight door at the ripening camera by Aseko. Control unit is on the right side of the doors (author Alex Dobrynin, 2011)

Characteristics of relative humidity and temperature transmitter Aseko RHT:

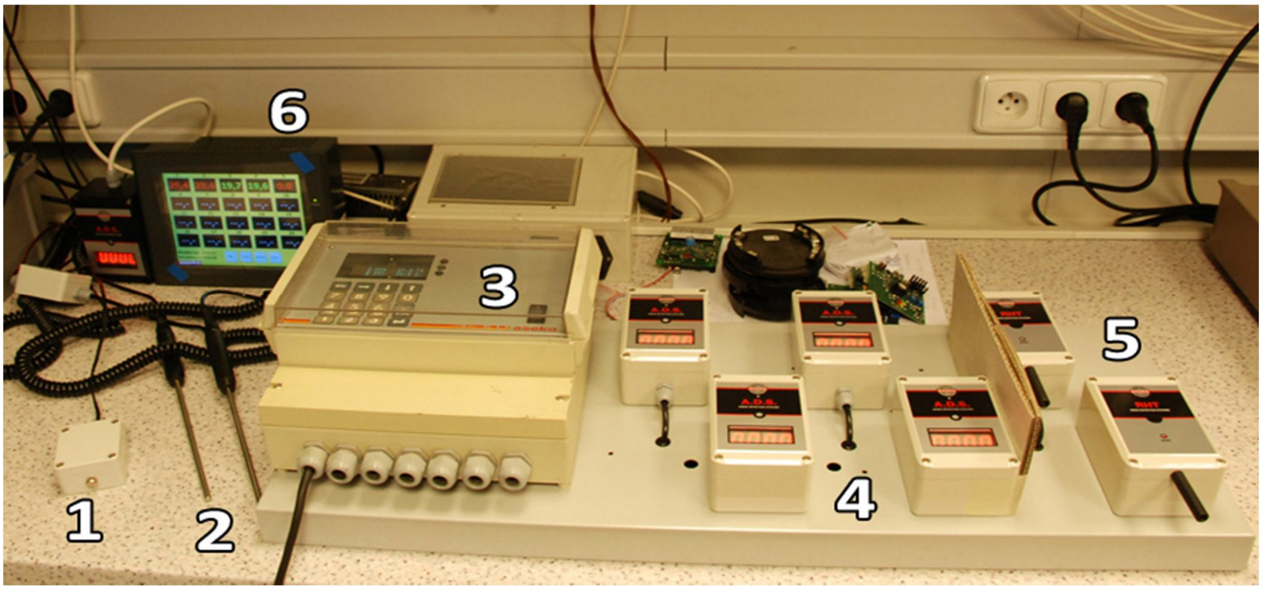
- Type of sensor (relative humidity) capacitive
- Type of sensor (temperature) band-gap
- Maximum relative humidity tolerance ± 3% RH
- Maximum temperature tolerance ± 0.4°C
- Relative humidity operating range 0 – 100% RH
- Temperature operating range -40 – +60°C

Logger Aseko ASIN DL8:

- Number of inputs and outputs 8 +8 pcs
- Memory capacity 4000 data sets

Figure 24

A system for monitoring conditions in the ripening room for bananas by Aseko: (1) air thermometer, (2) inside-carton thermometer, (3) logger, (4) ethylene concentration transmitter, (5) relative humidity transmitter, (6) central operating computer. All sensors are connected to the logger, and logger is connected with the computer (author Alex Dobrynin, 2012).



Mounting all the sensor in the ripening camera was done to provide real representative measurements. Temperature sensors were placed on a middle height in the middle of the central pathway and at a point close to the door. Ethylene sensors were placed close to the ceiling on a pallet, and on the floor, in the middle of the camera and in its corner. The same position was chosen for RH-meters. This layout was supposed to ensure representative evaluation. All sensors were connected to a logger with wires. Signals from each sensor were logged once per 5 minutes.

The technology of ripening was studied on the example of banana cultivar Cavendish. Fruits were exported from Ecuador via banana ships across the Atlantic Ocean to Hamburg, Germany; and from Hamburg via trucks to Prague, Czech Republic. Studied bananas were harvested, stored and transported according to the technology, described earlier in this Diploma Thesis.

Studied bananas:

- Variety: Cavendish banana
- Brand: Chiquita
- Class: A (Best premium quality)
- Maturity: 100%
- Packaging: palletized carton box, 18.14 kg per box

Figure 25

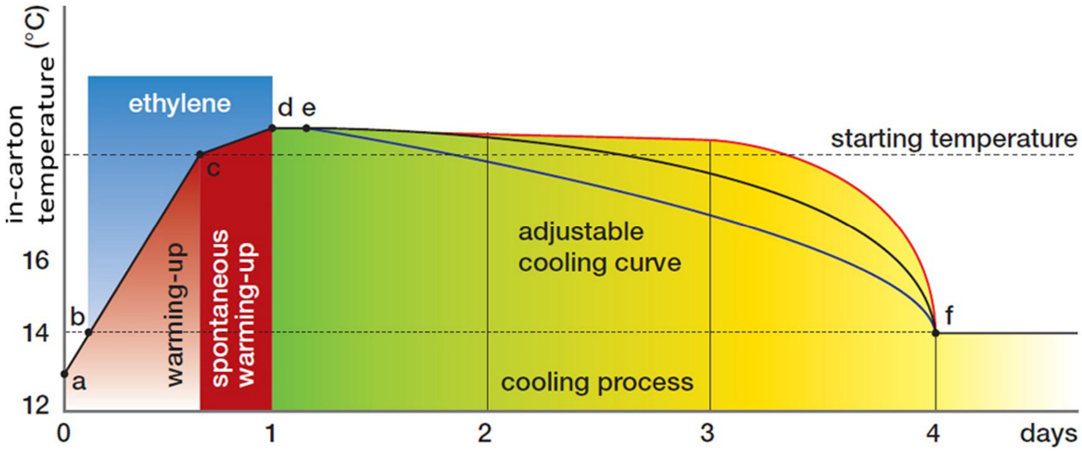
A studied banana fruit (author Alex Dobrynin, 2012)

Methods

Banana ripening process is standardized according to ISO 3959:1977. Chiquita ripening facility receives palletized cartons with bananas delivered by trucks, according to ISO 931:1980. Banana pallets are unloaded and polyethylene, covering the pallets from outside, is removed. Samples of bananas are inspected. If the quality is good, pallets with cartons are immediately transported inside the ripening camera with forklifts. One batch – means one fully loaded truck – is placed in one camera. No mixing is allowed. As soon as the entire batch is inside the camera, the airtight door is closed and the chosen program of ripening in the central operating computer is turned on. The operator sets up the desired color of bananas as the output, and the time period, in which the ripe bananas are needed. The central operating computer chooses the optimal temperature, relative humidity, ethylene concentration and exposure. Also, manual setting of these parameters along the cycle is possible. The program used for studied bananas is presented in the figure 26.

Figure 26

Scheme of the ripening process (Simanek, 2012)



During transportation by trucks, bananas are kept at 13°C. This temperature is starting one for the ripening process. The first step of the cycle is heating up to 18°C. As soon as the temperature of bananas rises up to 14°C – usually it takes couple of hours – ethylene is introduced. Exposure to the ethylene is supposed to be 24 hour. During this time, the camera must be airtight closed. Exposed to ethylene and elevated temperature, bananas start to produce heat by themselves. It causes spontaneous warming up: from pre-heated 18°C up to 19-20°C. In 24 hours after introduction of the ethylene, ventilation is turned on. The temperature gradually declines according to set-ups or corrections, and it should be at 14°C by the 4th day. This is the final temperature, which is kept until banana distribution.

Due to the experiment, after completing the ripening process, a part of banana batch was stored at normal conditions: room temperature (20°C, RH 65%) to study the further changes in the fruits. Such conditions are not suitable for proper industrial storing, but are usual for the final consumers.

In term of this Diploma work, 3 sequential measurements were conducted. Following values were monitored:

- Temperature of the air in the ripening camera (with 2 thermometers);
- Relative humidity of the air in the ripening camera (with 2 RH-meters);
- Ethylene concentration in the air in the ripening camera (4 gas analyzers).

Measuring devices were installed in different point of the camera to ensure representative measurements. The average value of all parameters was calculated for each of the measurements.

Figure 27

Ripening room loaded with a batch of bananas. (1) Palletized cartons with bananas as packed in Ecuador, (2) ventilation outlets, (3) lighting, (4) moisturizer author (Alex Dobrynin, 2012)

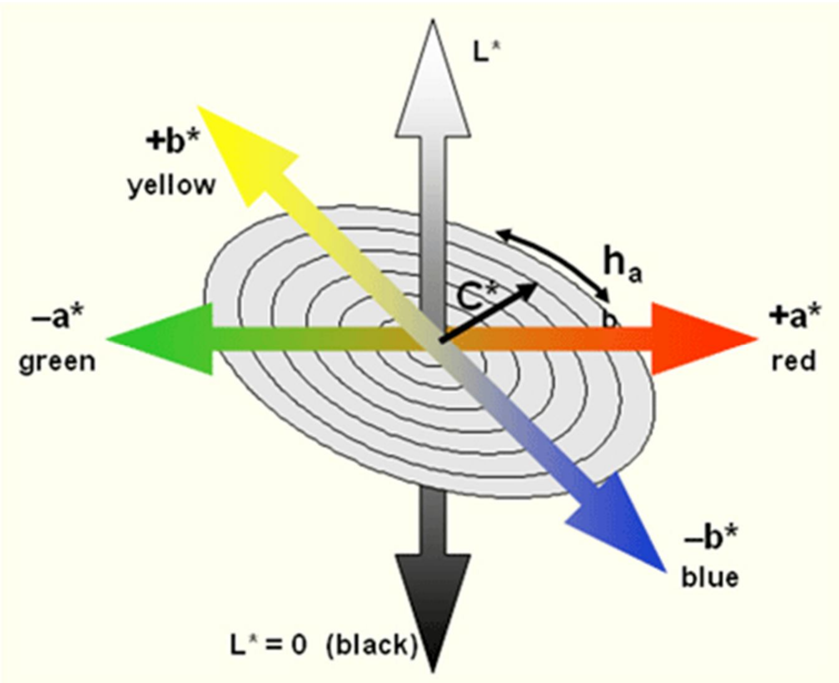
4.2 Color Measurement

The color of banana peel is known to be the most widely used parameter of fruit ripening. Measurements of the peel color were carried out in the Institute of Chemical Technology in Prague at Department of Chemistry and Food Analysis with supervision of MSc. Frantisek Pudil, Ph.D..

L*a*b color space was chosen because of its uniformity and highly precise determination of the color. The "L" coordinate is a measure of lightness (white – black and ranges from no reflection L=0 to perfect diffuse reflection L=100), the "a" scale ranges from negative values for green to positive values for red and the "b" scale ranges from negative values for blue to positive values for yellow.

Figure 28

*L*a*b color space, scheme. (Image from GlobalSpec Inc., 2012)*



Materials

Specimen:

Cavendish banana samples, taken according to ISO 874:1980. Samples were taken from ripening room every day, starting from day 0 (loading to the ripening room), at 9 A.M. and transported to the Institute of Chemical Technology in Prague in thermo-isolated boxes.

Equipment:

- Standard fiber optic spectrometer Avantes AvaSpec-2048
    - Optical bench: symmetrical Czerny-Turner, 75 mm focal length
    - Wavelength range: 200-1100 nm;
    - Resolution: 0.04 – 20 nm;
    - Detector: CCD linear array, 2048 pixels.

Software:

- AvaSoft version 7.4 (full);
- Data processor Microsoft® Office® 2010;
- Adobe® Photoshop® CS5.

Methods

Color measurement was done with a spectrometer with an 8 mm measuring head. Prior every session, spectrometer was calibrated, according to the manual. Measuring head was put on the peel surface; data from the supporting program was logged. For the experiment total 10 representative bananas were taken. Total 10 measurements for each banana were conducted: 5 on the inside curvature (so called 'face') and 5 on the lateral surfaces (so called 'sides'). Mean values were calculated for each parameter (L, a and b) for 'face' and 'side' separately, for samples taken every day during ripening.

4.3 Gas chromatography – mass spectrometry

For identifying the aromatic composition of studied banana fruit samples was used method of GC/MS – gas chromatography – mass spectrometry. Tests were carried out in the Institute of Chemical Technology in Prague at Department of Chemistry and Food Analysis with supervision of MSc. Frantisek Pudil, Ph.D..

Materials

Specimen:

Cavendish banana samples, taken according to ISO 874:1980. Samples were taken from ripening room every day, starting from day 0 (loading to the ripening room), at 9 A.M. and transported to the Institute of Chemical Technology in Prague in thermo-isolated boxes.

Equipment:

- Gas chromatograph Fisons Instruments GC-8000 series;
- Mass detector Fisons Instruments MD-800;
- Capillary column DB-5
  - Length 30 m;
  - Diameter 0.20 mm;
  - 5% phenyl polysiloxane phase.
- Solid phase microextractor: manual holder Supelco, SPME Fiber assembly. Layer of 65 µm carbowax™ (divinylbenzene) on fused silica base.

Software:

- GC/MS software MassLab version 1.4, Finnigan Software Inc;
- Library of chemical compounds and specters NIST (National Institute of Standards and Technology, the USA);
- Data processor Microsoft® Office® 2010.

Methods

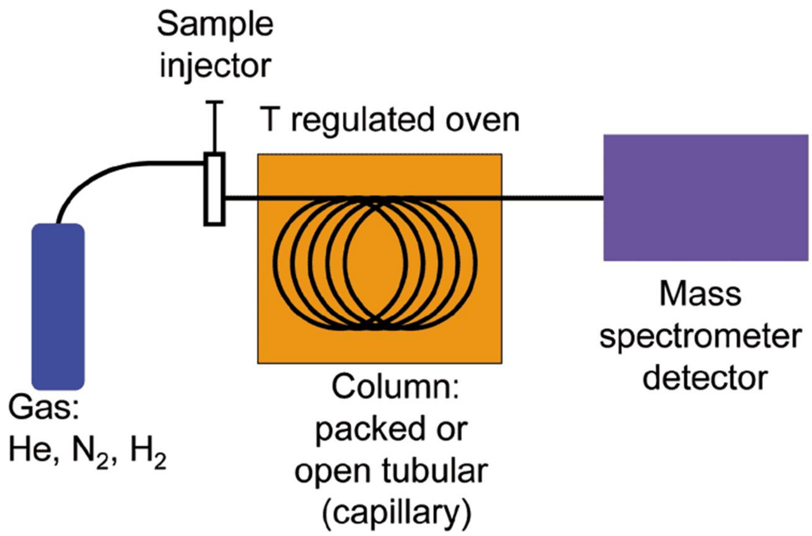
The procedure of GC/MS must be done according to the manual of the given equipment.

The algorithm used for GC/MS:

- Combined sample of banana pulp with mass of 100.0 g was prepared (ISO 874:1980). Each sample contains pulp of 5 randomly chosen bananas from different hands taken from the storage every day during ripening process. Banana fruit was opened and cut in small pieces with stainless steel knife, mixed and weighted and closed with aluminum foil.
- Glass flask was filled with banana pulp sample, installed on thermostat with fixed temperature of 60°C for 1 hour. Manual holder with absorbing fiber was inserted into the flask in the beginning of heating.
- After sample heating absorbing fiber was inserted into the sample injector of gas chromatograph.
- Settings of procedure:
    - Maximal temperature of the oven: 230°C;
        1. Beginning of cycle: isotherm 3 min, 50°C;
        2. Heating up: 5°C/min, up to maximal temperature (230°);
        3. Completion: isotherm 15 min, 230°C.
    - Temperature of the detector: 250°C;
    - Inert gas: helium, 0.5 ml/min injection;
    - Electron energy applied: 70 eV;
    - Mass spectrum range: 27 – 350 m/z.
- Due to elevating temperature and injection of inert gas, molecules absorbed from the given sample travel through the column with different speed. The lower the molecular weight of molecule is, the faster it passes through the column. The time a molecule requires to go through the column is called retention time.
- After ejecting out of the column the molecule enters the mass spectrometer and is ionized with energy of 70 eV. Due to ionization, studied molecules break down into less complex ones.
- Full Scan (FS) analysis was performed, which results in specters, corresponding to each 0.001 minute of the procedure.
- Graphs with retention time and corresponding specters were analyzed with MassLab program using NIST library. Identified compounds are presented below.

Figure 29

Gas chromatography mass spectrometry, schematic (picture by Murray, 2006)



V. RESULTS AND DISCUSSION

5.1 Ripening process

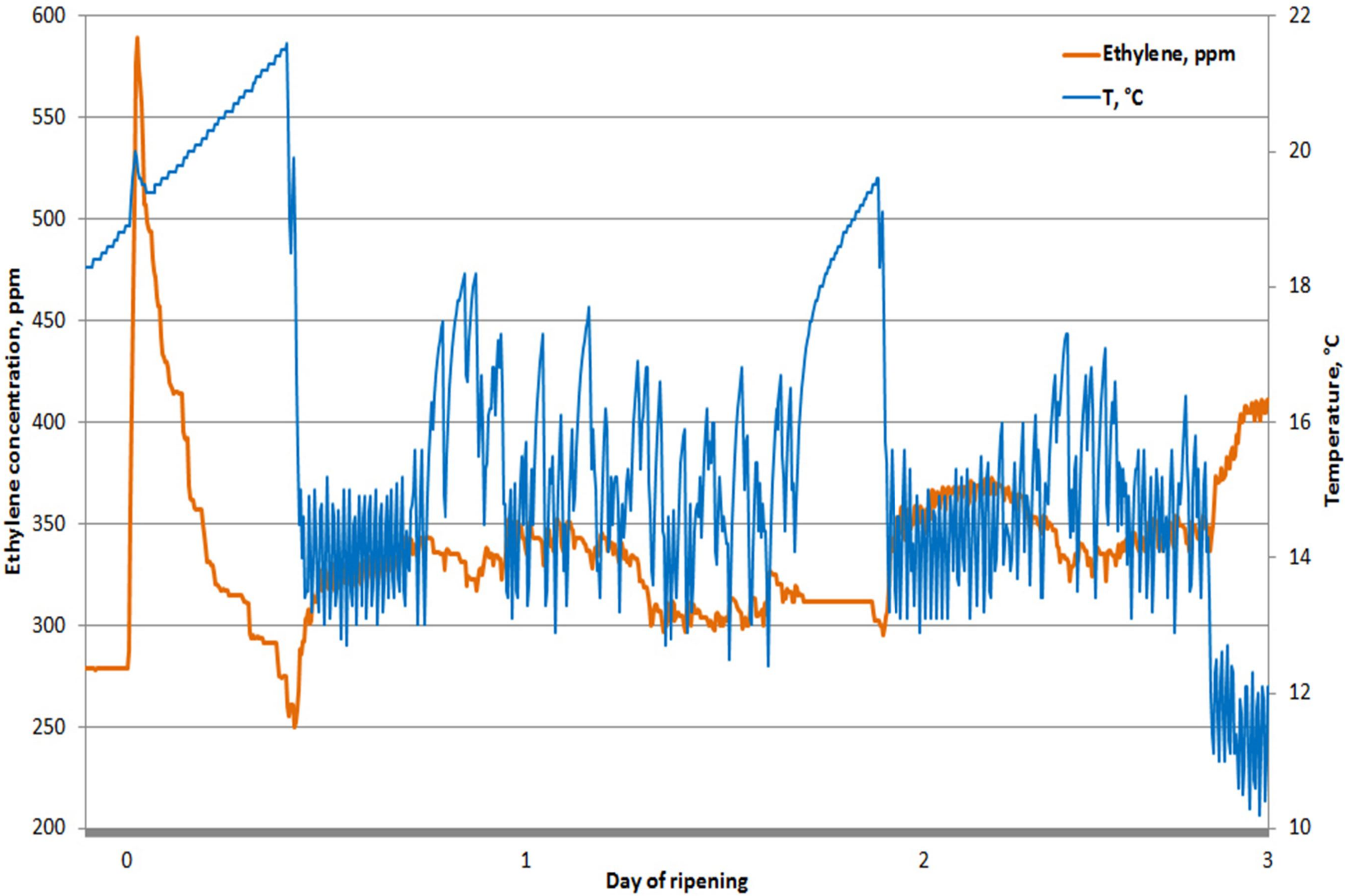
As long as banana is a biological material, every batch is more or less different from other ones (of course, in terms of one quality class and standards). Acquiring two absolutely identical bananas in impossible. Differences can be caused by a range of independent internal and external factors, such as weather during harvesting or region of origin. Technicians, working at banana ripening facilities, can distinguish any slight differences, according to one's personal experience, and correct the pre-set program of ripening. In other words, computer-aided ripening program is a template that meets the requirements of 'an idealized batch'. In routine industry every batch expects at least a minor modification of the program.

Table 9

Mean values of temperature, ethylene concentration and RH during ripening and further storing by days, with evaluated color grade

Day in the sequence, no.	Temperature, °C	Ethylene concentration, ppm	Relative humidity, %	Color grade
0	19-21	350-600	90-95	2
1	14-16	300-350	85-90	3
2	13-15	270-320	85-90	3
3	13-15	300-350	85-90	4
4	20	n/a	85-90	5
5	20	n/a	85-90	6
6	20	n/a	85-90	6
7	20	n/a	85-90	7

Figure 30
Ethylene concentration and temperature changs in the ripening room



5.2 Color measurement

The L value, representing luminosity, increases, which means a development of a lighter color. The a value (laying on the 'green to red' axis) gradually increases to 0 (R^2 = 0.9052), which means that green color rate decreases during ripening and the fully ripe banana has no green color in its specter. This change is caused by chlorophyll degradation, started during ripening process. The b value (laying on the 'blue to yellow' axis) has almost no change compare the beginning of the process with its end. This could mean that color changes in the peel are caused mostly by the chlorophyll degradation, but not formation of new pigments. The stage of dessert banana ripeness can be evaluated by measuring the intensity of green color in the peel spectra.

Figure 31

Visible interpretation of measured L, a, b values (Alex Dobrynin)

There are no significant differences in color changing rates between the inside curvature and the lateral sides of a dessert banana fruit. The rate of chlorophyll degradation is slightly higher on the lateral sides of a fruit.

Figure 32

Results of color measurements of banana peel. Mean values for spots on the inside curvatures and on the lateral sides of banana fruits

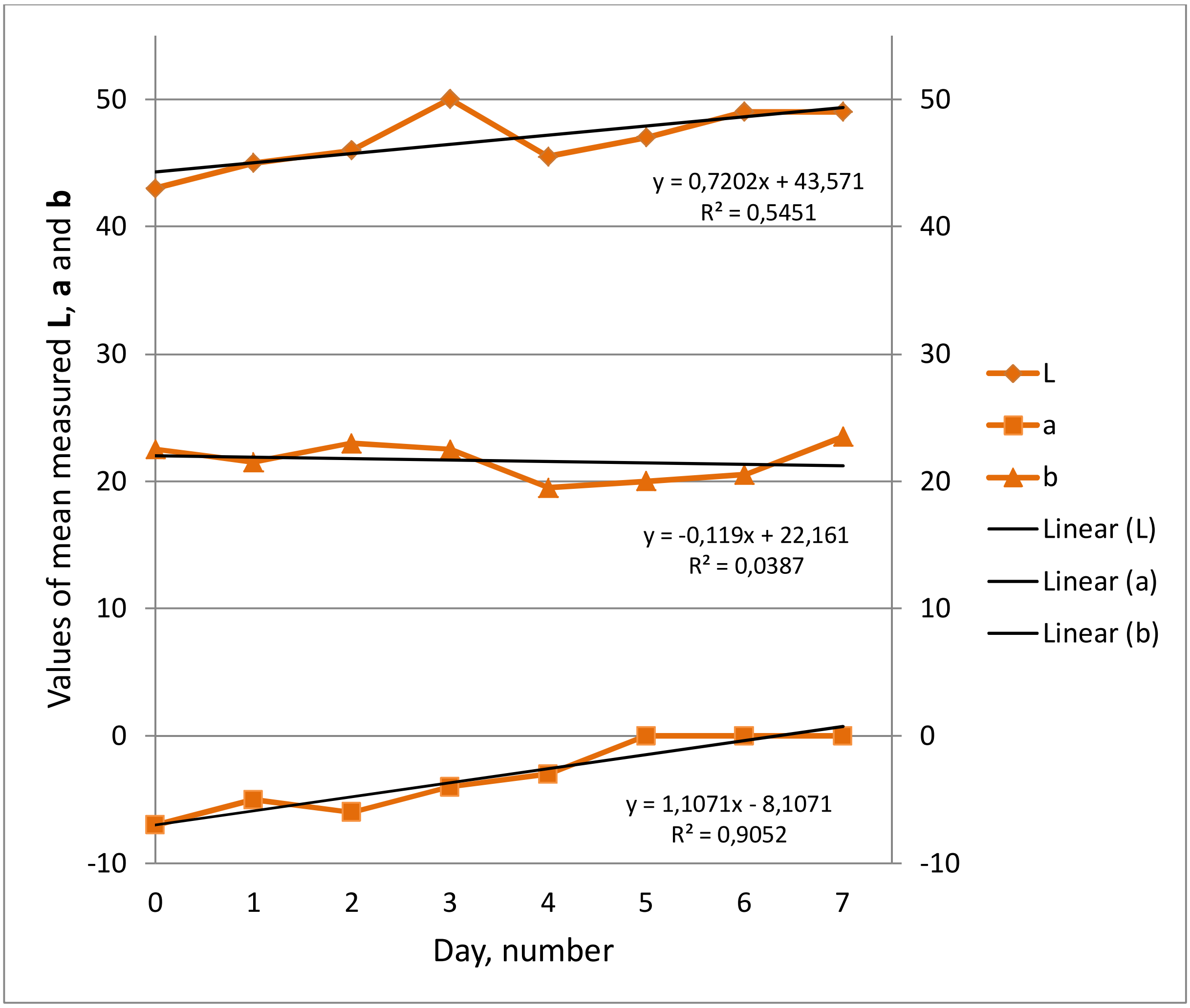
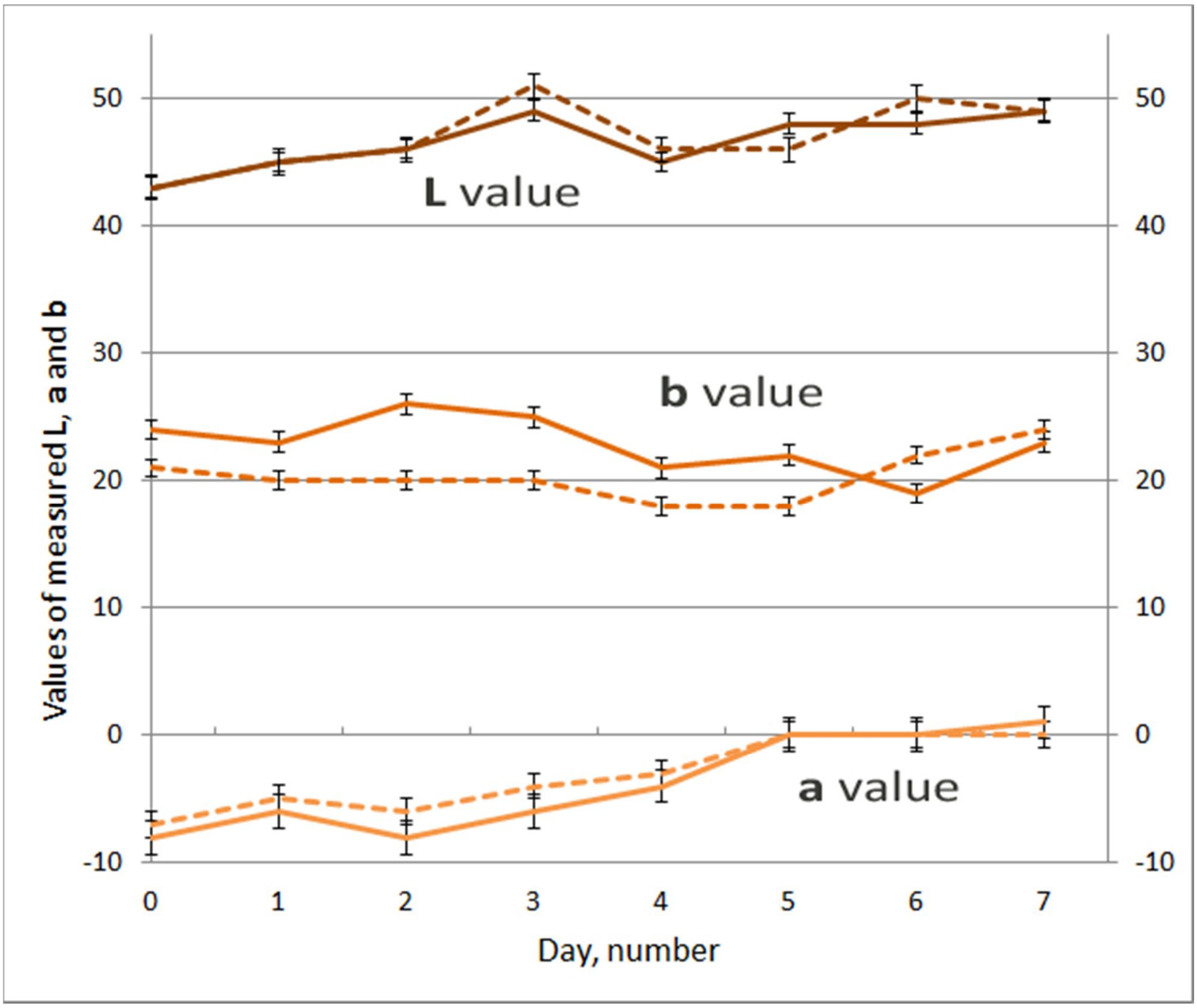


Figure 33

Results of color measurements of banana peel. Solid lines represent values on the inside curvatures and puncture lines – ones on the lateral sides of banana fruits



5.3 Gas chromatography – mass spectrometry

Eight GC/MS procedures were conducted, for pulp of bananas corresponding to each day of the experiment. The most representative and relevant to this work are results from days, no.: 0, 3 and 7, corresponding to (0) green unripe banana before the ripening process, color grade 2; (3) almost fully yellow ripe banana after the ripening process, color grade 4; (7) yellow fully ripe banana with black spot on the surface, color grade 7. Identification of spectra was performed for these three samples. Both chromatographic patterns and identifications of spectra are shown below in this section. All other chromatographic patterns are presented in the Appendix.

There are obvious changes in the aromatic composition, occurring due to the ripening process. The first sample (day 0) has no aromatic compounds, or they are not distinguished from the background noise. The specific aroma of a green banana – similar to cucumber or grass – is caused by the composition of the fruit peel. After the ripening process (day 3) as a result of biochemical reactions in the fruit a bunch of aromatic compounds is produced. The aroma of a ripe banana is characterized by 4 main compounds (section 1.5.), and all of these compounds were found in studied fruits: (1) amyl acetate, (2) Butyl isobutyrate, (3) hexyl butyrate, (4) 3-Hexen-1-ol. Although the ripe banana already has its character aroma, the biochemical reactions are hastened, and more aromatic compounds occur. A list of 18 aromatic compounds was completed according to the mass spectrometry. The aroma of a ripe banana and a fully ripe banana slightly differ from each other, but chemical composition differs significantly (4 compounds versus 18).

Figure 34

Gas chromatographic patterns of the SPME extracts of banana pulp; 2nd, 4th and 7th color grades, respectively (see Appendix for detailed patterns)

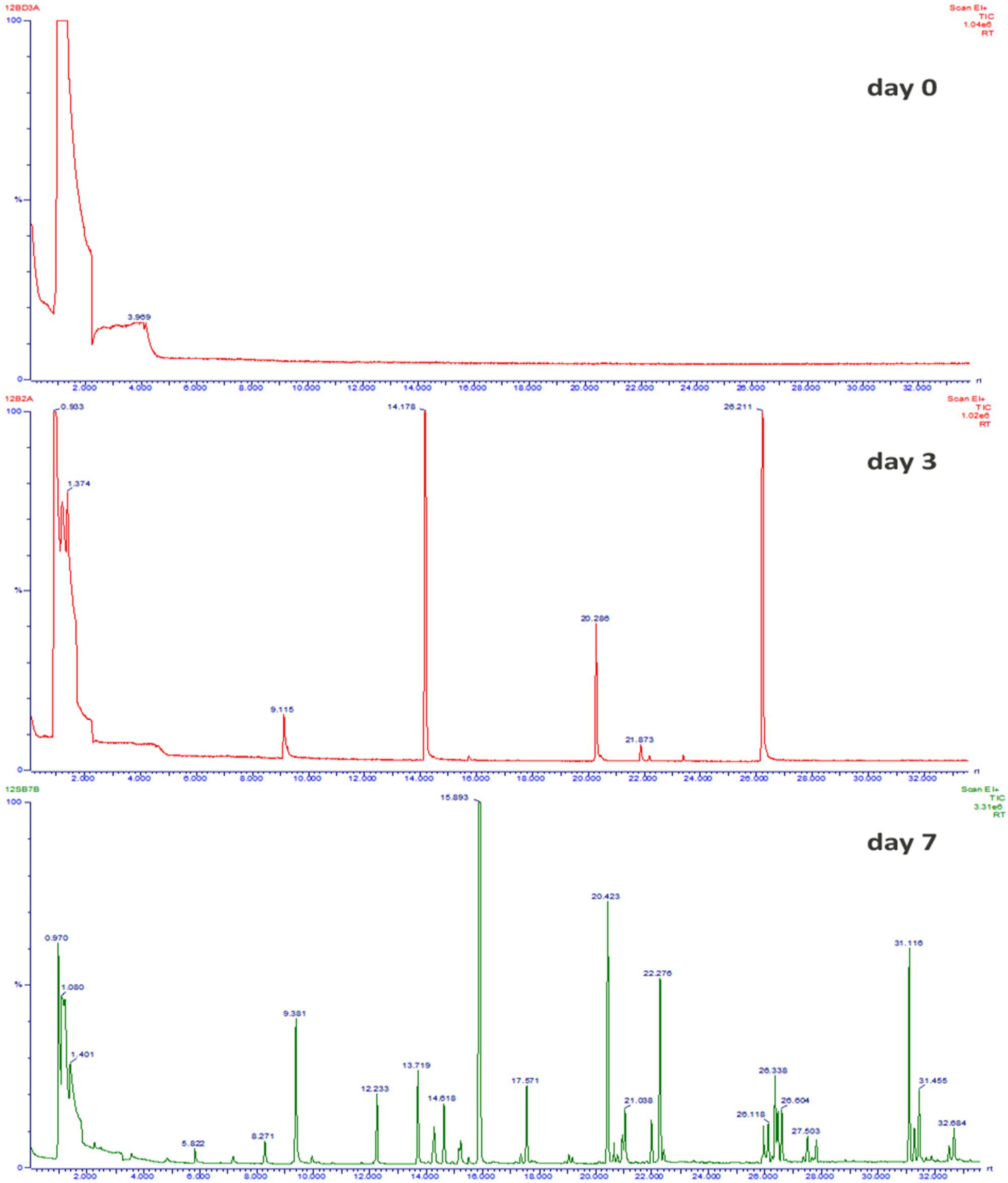


Table 10

Identification of spectra. Bananas color grade 2 (day 0): green unripe banana before the ripening process

Retention time, min	Compound
0.000-4.000	Noise

Table 11

Identification of spectra. Bananas color grade 4 (day 3): almost fully ripe yellow banana after the ripening process

Retention time, min	Compound
0.000-4.000	Noise
9.115	Amyl acetate
14.178	Butyl isobutyrate
20.286	Hexyl butyrate
21.873	3-Hexen-1-ol
26.211	cis-3-Hexenyl and trans-3-Hexenyl

The used method of GC/MS allows to identify the chemical compounds, but not to define the amount. Further investigations are required to discover contributions of each chemical compound to the aroma of the product.

Table 12

Identification of spectra. Bananas color grade 7 (day 7): fully ripe banana with brown dots on the surface

Retention time, min	Compound
0.000 - 4.000	Noise
5.822	Isobutyl acetate
8.271	Butyl acetate
9.381	Amyl acetate
12.233	Pentanol
13.719	Isobutyl butyrate
14.224	Butyl isobutyrate
14.307	Hexyl acetate
14.618	Butyl butyrate
15.893	Isobutyl isovalerate
15.893	Isoamyl isobutyrate
17.571	Amyl valerate
20.423	Hexyl butyrate
20.635	cis-3-Hexenol acetate
20.750	trans-3-Hexenol acetate
22.276	3-Hexen-1-ol
26.422	cis-3-Hexenyl
26.587	trans-3-Hexenyl
31.455	Hexenyl butyrate

VI. CONCLUSIONS

- Treating mature unripe bananas with 650 ppm ethylene at 19-20°C activates the process of ripening with gradual obtaining the characteristic consumer qualities, including color, fragrance and others.
- The studied ripening facility ensures the proper way of ripening desert bananas, although the real 'in-use' technology differs from the recommended ones: in (a) temperature, (b) ethylene concentration and exposure and (3) relative humidity. Improvements of the conditions in the ripening camera might increase quality of the final product and decrease the operational costs. Further experiments are required to prove the reasonability of ripening facility upgrade.
- The ripening facility should be equipped with a moisturizer to adjust relative humidity of the air inside the ripening room. This solution might reduce mass losses of bananas during ripening.
- The color changes of banana peel during ripening are caused generally be the chlorophyll degradation.
- The severest impact on the dessert banana quality is in the retail network. Fast changes of the air temperature from decreased to elevated cause chilling injuries and increased respiration rate, respectively, which significantly shorten the shelf-life of a banana. Maintaining of the optimal conditions for fruits during storing should be provided in retails.

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