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# Long-term storage of sugar beet in North-West Europe

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IRS IRBAB KBIVB IfZ NBR Nordic Beet Research

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# PREFACE

This report was produced by the members of COBRI (COordination Beet Research International) representing the sugar beet research institutes in Denmark/Sweden (NBR, Holeby), Germany (IfZ, Göttingen), Belgium (IRBAB/KBIVB, Tienen) and the Netherlands (IRS, Bergen op Zoom), results of long-term storage trials in Northern Germany by courtesy of Andreas Windt, Nordzucker AG Braunschweig.

The aim of the report is to bring together all existing knowledge about sugar beet storage that may be important in improving the long-term storage of sugar beet under North-West European conditions.


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# SUMMARY


In the countries of Western Europe, sugar factory operations have been extended to mid-January and therefore sugar beet have to be stored for about two months. This report presents a review of current knowledge and research into methods to lower sugar losses and optimise the conditions for long-term storage.

Sugar losses during storage can be quantified as respiration losses in air-tight vessels, under controlled conditions or in field clamps. For quality assessment, the standard analyses (sugar, potassium, sodium and amino nitrogen) should be extended to include at least analysis of invert sugars (glucose + fructose). Additional information can be obtained from visual assessment of beet injuries (especially root tip losses) before storage, and of sprouts, frozen parts, moulds and rot after storage.

During storage, sugar is degraded by enzymes. In the first days after harvest, sugar losses occur due to wound healing and thereafter respiration declines. Further sugar losses mainly depend on the storage temperature. Storage at 2 to 8 °C is regarded as optimal. In addition to the sugar losses, strong accumulation of invert sugar occurs, which severely affects processing. Sugar losses are markedly enhanced when sprouting, rotting and infection by bacteria and fungi occur. Rotten and, in particular, frost-damaged beet cannot be stored further and have to be processed immediately. Mould formation and the subsequent rotting and reduction in quality drastically increase above an accumulated thermal time of 270 degree days (base temperature 0 °C).

Sugar beet varieties differ in storability, possibly due to their susceptibility to damage and/or infection by moulds and rot. Storage losses are also strongly dependent on the beet growing conditions (location/soil, stress during the season, harvesting conditions). Root injuries during harvesting and clamping should be minimised, as they markedly increase rotting and thereby sugar losses. Complete removal of leaves, possibly in combination with slight topping, gives the lowest sugar losses during long-term storage, as over-topped beet are avoided. Treatment with lime during clamping can reduce pathogen infections.

Recommendations for optimal harvest and clamp management include protecting clamped beet from precipitation. Clean, dry beet allow gas exchange, which prevents heat accumulation and lowers the infection potential of moulds and rots. Frost damage should be avoided by harvesting the beet in time and covering the clamp with e.g. plastic sheeting, fleece, straw or canvas, which can provide some protection against frost.


# 1. INTRODUCTION

In North-West Europe, sugar beet harvest has to be finished before the beet are damaged by frost. Figure 1.1 shows the risk of temperatures below 0 °C, -3 °C and -5 °C in the Netherlands from mid-October to mid-January. Table 1.1 shows the variation in temperature over five years in the most southerly beet growing area of Sweden. The risk of low temperatures, expressed as number of days per month with mean daily temperature below -5 °C and below 0 °C and the number of days per month with night frost, is significant but very variable between years. In November and December, cold days with temperatures below 0 °C are often interspersed with warmer days with mean daily temperatures above +5 °C.

The number of days with frost in December in the different sugar beet areas of North-West Europe are shown in Figure 1.2, in which 2010 represents a year with a severe winter and 2011 a year with a mild winter. The risk of frost damage is high if sugar beet are still in the soil in December. The risk of poor soil conditions for harvest operations also increases later in the season. In general, this means that the harvest period starts in September and ends in mid- or late November. Before the reform of the sugar market in 2006 (Council Regulation (EC) No 318/2006), the processing of sugar beet was usually finished before Christmas. However, during the sugar beet reform many sugar factories were closed and the processing period was extended to mid-January. This means that more sugar beet now have to be stored for a longer period. In fact, the maximum storage period has doubled, from about one month to more than two months (Figure 1.3).

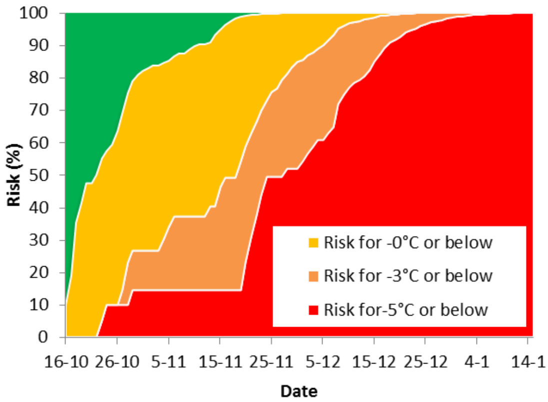



**Figure 1.1:** Risk of temperatures below 0 °C, -3 °C and -5 °C in the central Netherlands from mid-October to mid-January, 1993-2013. (Source: KNMI, 2013).

**Table 1.1:** Number of days per month with mean temperatures below -5 °C, below 0 °C and above 5 °C and number of days per month with night frost; locations near the southern coast of Sweden. Data from Jordberga weather station, November-January 2006-2010. (Source: Nordic Sugar, Agricenter Sweden, 2011).

| November | Number of days | | | |
|---|---|---|---|---|
| Year | <-5 °C | < 0 °C | night frost | >5 °C |
| 2006 | 0 | 2 | 4 | 24 |
| 2007 | 0 | 2 | 9 | 13 |
| 2008 | 1 | 5 | 7 | 18 |
| 2009 | 0 | 0 | 0 | 27 |
| 2010 | 2 | 7 | 10 | 10 |

| December | Number of days | | | |
|---|---|---|---|---|
| Year | <-5 °C | < 0 °C | night frost | >5 °C |
| 2006 | 0 | 0 | 5 | 25 |
| 2007 | 0 | 4 | 10 | 9 |
| 2008 | 0 | 5 | 14 | 3 |
| 2009 | 2 | 11 | 18 | 6 |
| 2010 | 12 | 29 | 31 | 0 |

| January | Number of days | | | |
|---|---|---|---|---|
| Year | <-5-0 °C | < 0 °C | night frost | >5 °C |
| 2006 | 1 | 5 | 8 | 19 |
| 2007 | 0 | 4 | 9 | 8 |
| 2008 | 2 | 12 | 17 | 0 |
| 2009 | 8 | 29 | 30 | 0 |
| 2010 | 2 | 18 | 24 | 0 |

Sugar losses occur and the quality of the sugar beet decreases during storage. The extent of the decrease depends on the condition of the harvested beet, the storage conditions and the length of the storage period. Guidelines are needed to minimise the sugar losses and the decrease in quality. For this reason, much research has been done to investigate the effect of different conditions and measures on the storability of sugar beet. Back in the 1970s, intensive research was carried out to establish the effect of different factors on sugar losses and the decrease in quality during storage (Vukov and Hangyal, 1985). Since then, a great deal of research on sugar beet has been carried out on laboratory scale and on farms to further investigate factors that may be important for the storability of sugar beet. In recent years research has focused on the factors affecting sugar beet during long-term storage and covering strategies for optimal storage.

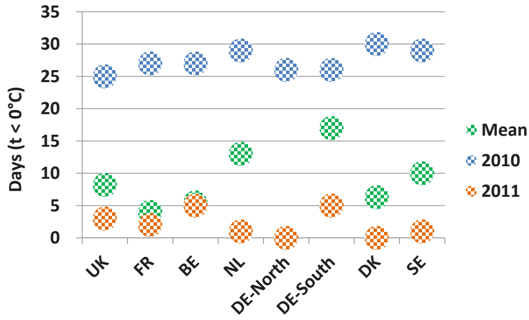



**Figure 1.2:** Number of days in December with frost in eight sugar beet growing areas in North-West Europe. In 2010 the winter was very cold and in 2011 the December was mild. (Source: Legrand et al., 2012).

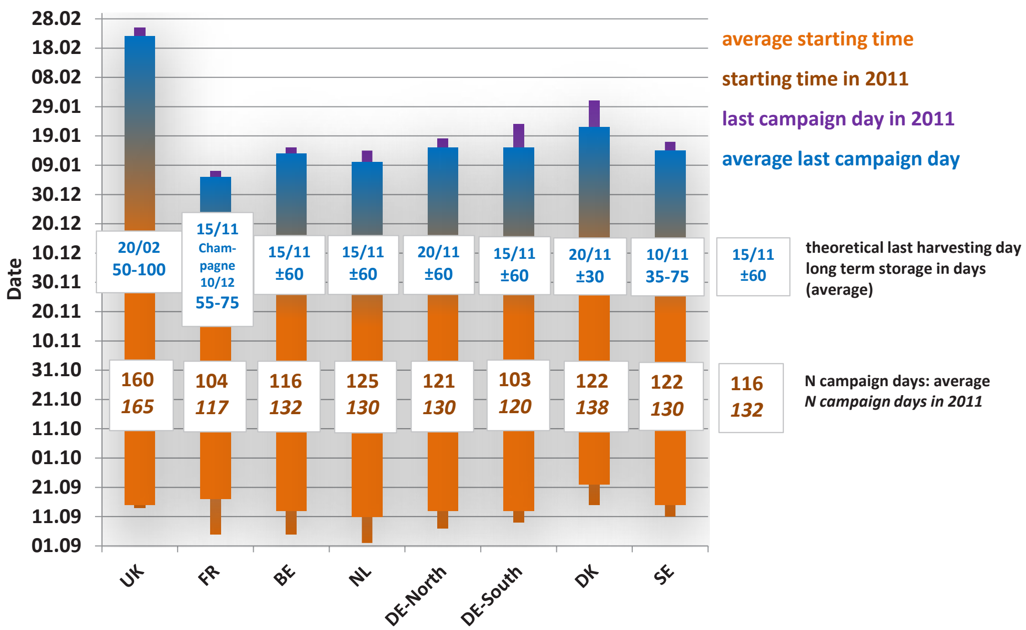



**Figure 1.3:** Start and end of the beet harvesting campaign and number of campaign days in 2011, which was a year with record yields in all countries shown, and average for 2007-2011 in eight sugar beet growing areas in North-West Europe. The theoretical last harvesting date and the average long-term storage (days) are also indicated. (Source: Legrand et al., 2012).

# 2. BACKGROUND TO QUALITY REDUCTION DURING STORAGE

## 2.1 Quality assessment

Assessment of the technical quality of sugar beet in Europe is based on several parameters, sugar content being the most important. However, the percentage of sugar that can be extracted as granulated sugar during processing is influenced by several non-sucrose compounds in the beet. These compounds are characterised by melassigenic properties, effects on the alkalinity of the extracted juice and possibly colour formation during processing. To estimate the amount of non-extractable sugar, several equations have been developed in Europe. To allow assessment of internal beet quality on a large scale at a reasonable analytical cost, these equations contain only a few parameters. Most equations are based on the concentrations of potassium, sodium and amino nitrogen. Some also take into account the amount of reducing sugars in the beet (Huijbregts, 2003).

Several factors are responsible for the decrease in beet quality during storage (Kenter and Hoffmann, 2006). First of all, sucrose decreases due to respiration, wound healing and the possible development of moulds. At the same time, the concentration of reducing sugars (mainly invert sugars: glucose + fructose) increases. Endogenous sugar beet enzymes contribute to invert sugar formation by inducing acid invertase expression as a wound response to infection (Rosenkranz et al., 2001). This gives an additional decrease in quality, because during processing invert sugars decrease the alkalinity of the juice by converting to acids and furthermore increase colour formation. The formation of raffinose during storage can also reduce the quality of the beet (Kenter and Hoffmann, 2009). Raffinose has a dramatic effect on both sucrose crystallisation rate and sucrose crystal morphology (Dutton and Huijbregts, 2006). The concentration of soluble nitrogen may also increase through degradation of proteins, which also decreases the alkalinity. Even more negative effects on beet processing can be caused by rotting beet and rotten beet parts. Part of the rotten material is removed during washing of the beet, thus contaminating the wash water. The remaining parts affect processing because of the very low sugar content and high concentrations of invert sugars and organic acids.

Frost damage also affects beet quality severely. Processing of thawed beet is possible before they deteriorate, although the washing water is more contaminated with sugar due to the leakage of sugar through the open cell walls. For this reason, in Denmark and the Netherlands farmers are not permitted to deliver frost-damaged beet (de Nie et al.,1985). Deteriorated beet are difficult to process. In particular, the formation of polysaccharides such as dextran and levan causes great problems during beet processing (de Bruijn, 2000; Hein et al., 2012).

## 2.2 Respiration

Respiration accounts for 70-80% of the sucrose losses that take place during storage (Wyse, 1970). Sucrose is the most important carbohydrate source for the formation of respiratory carbon dioxide (Barbour and Wang, 1961). Figure 2.1 shows a simplified representation of the conversions under aerobic conditions (Koster and Jorritsma, 1980).

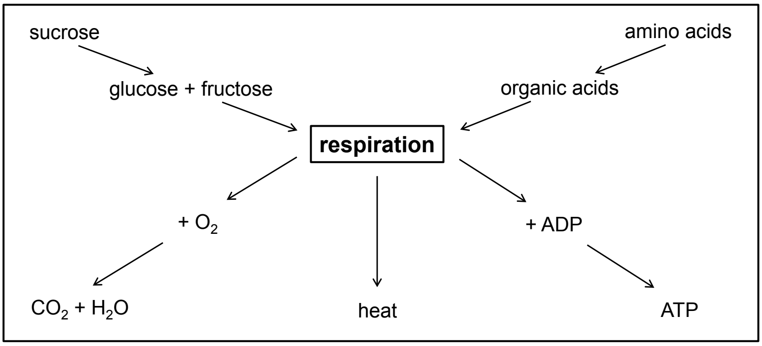



**Figure 2.1:** The most important conversions that take place during sugar beet respiration in storage. (Source: Koster and Jorritsma, 1980).

The respiration process starts with cleavage of sucrose into hexose sugars, most likely catalysed by sucrose synthase (Echeverria, 1998; Etxeberria and Gonzalez, 2003). However, sucrolysis by alkaline and acid invertases is possible (Wyse, 1974; Berghall et al., 1997). Enzyme activity depends on temperature. The highest enzymatic activities are reported to occur at about 40 °C (Klotz and Finger, 2001). Respiration requires an adequate supply of oxygen to convert sucrose into carbon dioxide and water. The energy made available during this exothermic reaction is partly stored as an energy-rich molecule, ATP (adenosine triphosphate). The rest is converted to heat. Amino acids also contribute to respiration via deamination to organic acids. Under oxygen-limiting conditions ethanol is formed by fermentation. This results in even larger sugar losses, since anaerobic respiration requires 15- to 16-fold more sucrose to generate an equivalent amount of ATP than aerobic respiration (Zhang and Greenway, 1994).

## 2.3 Wound healing

Storage respiration is exacerbated by root injuries, which cause the respiration rate to increase within the next 24 hours. During the following 1-2 weeks in storage, the respiration declines as root injuries heal (Ibrahim et al., 2001).

## 2.4 Sprouts

Intact vegetative buds with high metabolic activity and leaf regrowth contribute to the respiration rate in storage. Sprouting in roots defoliated by flailing may contribute more to the respiration rate than sprouting in scalped or topped roots (Steensen and Augustinussen, 2003; Hoffmann, 2012).

## 2.5 Root rot

Root rot diseases in sugar beet caused by *Rhizoctonia solani* (AG 2-2 IIIB and AG 2-2 IV), *R. crocorum, Aphanomyces cochlioides, Phoma betae, Macrophomina phaseolina, Fusarium oxysporum f.sp. radicis-betae, Fusarium culmorum, Pythium aphanidermatum, Phytophthora drechsleri, Rhizopus stolonifer, R. arrhizus* and *Sclerotium rolfsii* cause significant losses wherever sugar beet are grown. However, not all of these soil-borne pathogens have been reported in all sugar beet producing areas. Many of these pathogens cause post-harvest losses in storage clamps (Jacobsen, 2006).

Root rot caused by *Rhizoctonia* spp. is wet, which makes the roots impossible to store. In contrast, rots caused by *Aphanomyces cochlioides* are dry and affected beet may be stored for some time, but with a higher rate of respiration due to the deformations caused by this oomycete. In some years, usually after drought in the field, characteristic rots caused by *Fusarium culmorum* may occur. As with *Rhizoctonia* spp., the affected beet are not suitable for storage. Root rot may also occur in the clamp during long-term storage as a result of infection by moulds, bacteria and stem nematodes (*Ditylenchus dipsaci*).

## 2.6 Bacteria

Under the growing conditions in North-West Europe, bacterial infections are of minor importance. However, during storage they are important, as they occur in damaged beet. If beet roots are deteriorating, for instance after being affected by frost, bacteria can considerably decrease the processing quality of the sugar beet by producing polysaccharides (Augustinussen and Smed, 1990). This makes the processing of beet very difficult (de Bruijn, 2000; Hein et al., 2012). A contributor to beet deterioration in many countries, particularly when warm and humid conditions prevail, is infection by the heterofermentative *Leuconostoc mesenteroides* lactic acid bacteria, which produce dextran (Eggleston and Huet, 2012). Among the bacterial infections, the most aggressive is the bacterial soft rot (*Erwinia serbinowi*). Other types of bacterial rot and their most common species are: root rot or crown gummosis (*Erwinia bussei, Bacillus betae, B. larecans*); collar rot (*Pseudomonas syringae*) and wet rot (*Erwinia carotovora*) (Zahradníček , 1993).

## 2.7 Moulds

During storage, moulds may develop where the beet tissue is damaged. The removal of crown tissue, root tip losses and surface injuries form entry points where moulds may start. The development of moulds is related to storage time and temperature. A conservation threshold has been calculated beyond which storage moulds begin to develop. This threshold takes into account the storage time and the storage temperature. It is expressed in accumulated degree days (accumulated thermal time in degree centigrade days with a base of 0 °C). According to French research, the threshold for accumulated thermal time is 250 degree days (Rapp, 2009). In this, accumulated degree days is calculated as the daily maximum temperature outside the clamp plus the daily minimum temperature outside the clamp divided by two $(T_{max}+T_{min})/2$). Legrand and Wauters (2012) assume a threshold of 270 degree days based on the outside temperature, which corresponds to 300-350 degree days when the temperature inside the clamp is taken as reference. After an accumulated thermal time of 270 degree days, sugar losses can be exponential due to the development of storage moulds.

After long-term storage (116 days) in an experiment in the Netherlands, a white fungus had spread all over the clamp (Figure 2.2). This fungus was identified as *Monilia. Penicillium, Alternaria* and *Aspergillus* were also identified (Huijbregts, 2005). In Belgium, the main moulds identified in beet clamps are *Penicillium, Botrytis, Trichoderma, Rhizoctonia* and *Fusarium* (Legrand and Wauters, 2012). The most common moulds isolated from beet in long-term storage clamps in Sweden are *Botrytis* and *Penicillium* (Figure 2.3) but also *Fusarium* and *Sclerotinia* may be found (Olsson, 2008). In the Czech Republic, moulds commonly found on

**Figure 2.2:** *Monilia* in a sugar beet clamp after 116 days of storage. (Photo: IRS).

**Figure 2.3:** Mould damage to sugar beet in long-term storage. (Photo: NBR).

stored beet are *Penicillium expansum, Botrytis cinerea, Alternaria tenuis, Fusarium betae, Phoma betae, Rhizopus nigricans, Mucor hiemalis, Aspergillus niger, Cladosporium herbarum* and *Rhizoctonia violacea* (Zahradníček, 1996).

Only under extremely warm and wet storage conditions do beet roots contaminated with *Fusarium* form mycotoxins. Screening for mycotoxins in sugar beet brei infected with *Fusarium* and stored for 59 days at 100% humidity and temperatures of up to 15 °C, corresponding to 695 degree days, has revealed small quantities of deoxynivalenol (DON), zearalenone (ZEA) and 15-acetyl deoxynivalenol (Huijbregts, 2009a; Huijbregts, 2010a). However, these toxins are not normally found in beet pulp because they are water-soluble and are removed during diffusion.

Moulds increase sugar losses during storage. Even a slight infection by *Penicillium* and *Botrytis* can increase respiration rates and greatly enhance the content of invert sugars (Wyse, 1980). The reduction in sugar content and formation of invert sugars is closely related to the infection with moulds and rots when sugar beet are stored (Hoffmann, 2012) and the quality begins to decline. Therefore, the main threat to beet quality during long-term storage is rotting as a result of mould infections.

## 2.8 Frost damage

Frost damage can occur if sugar beet are stored below the freezing point, which is about -3 °C based on the point of inflection in frost experiments (Figure 2.4). During a frost period, core beet temperature only decreases below the freezing point when the beet is totally frozen. The consequences of frost damage depend very much on the storage conditions afterwards. Experiments in a temperature cabinet showed considerable frost damage at exposure times of 3 hours at -10 °C (Figure 2.4). After thawing and storage at +10 °C for two weeks the pH decreased and invert sugars and polysaccharides (dextran and levan) were formed, as shown in Table 2.1 (Heijbroek and Huijbregts, 1984). Processing quality is thus considerably reduced after frost damage and thawing as beets deteriorate very quickly (Kenter and Hoffmann, 2006). Table 2.1 also shows the results of staining with Ponceau Red to distinguish between reversibly and irreversibly damaged beet tissue (see section 3.2.4). The storage temperature after thawing is of considerable importance for the degree of deterioration. In the temperature cabinet study cited above, roots exposed even to -10 °C for 12 hours did not show any increase in the content of polysaccharides or invert sugars, or a decrease in pH, after two weeks when stored at +4 °C, although visible damage evident as a glassy appearance did not disappear during that period and the tissues were stained positively by Ponceau Red (Table 2.2).

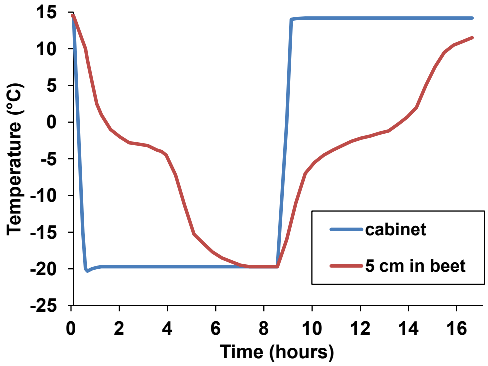



**Figure 2.4:** Temperature changes in the centre of sugar beet during rapid freezing and thawing in a temperature cabinet. (Source: Heijbroek and Huijbregts, 1984).

**Table 2.2:** Influence of rapid freezing (more than 0.5 °C per minute) on sugar beet before and after storage for two weeks at +4 °C. (Source: Heijbroek and Huijbregts, 1984).

| Frost | | Proportion of affected tissues before storage (%) | Stained by Ponceau Red | Changes in frozen parts after storage | | |
|---|---|---|---|---|---|---|
| Temp. (°C) | Time (hours) | | | pH | Invert sugars | Poly-saccharides |
| -10 | 1.5 | 0 | | 0 | - | - |
| | 3 | 60 | | -0.1 | - | - |
| | 4.5 | 80 | x | -0.1 | - | - |
| | 6 | 100 | xx | 0 | - | - |
| | 12 | 100 | xx | 0 | - | - |
| -5 | 3 | 0 | ø | 0 | - | - |
| | 6 | 0 | ø | 0 | - | - |
| | 12 | 80* | ø | 0 | - | - |
| | 24 | 100* | x | 0 | - | - |
| | 36 | 100* | xx | 0 | - | - |
| | 48 | 100* | xx | 0 | ± | ± |

ø = No staining
x = Partly stained
xx = Totally stained
* = Brown necrosis around the vascular bundles

\- = No increase
± = Little increase

## 2.9 Dirt tare

Dirt tare has to be avoided because it increases the gross weight that has to be transported to the factory. Further it has to be washed off and stored in ponds. In addition insufficient cleaning in the factory may increase the ash content of the pulp. Dirt tare also influences the storability of the sugar beet by reducing the ventilation in the clamp, resulting in higher temperatures and consequently higher sugar losses (Tabil et al., 2003). In general, the proportion of dirt tare is so low that it does not affect the clamp as a whole. However, in practice problems often arise in parts of the clamp, typically where the sugar beet have been unloaded. In these spots dirt accumulates, forming compacted cores which restrict ventilation and gas exchange. As a consequence, storage temperature increases because of the accumulated heat, resulting in enhanced deterioration of the beet.

# 3. ANALYTICAL METHODS

## 3.1 Storage experiments

### 3.1.1 Respiration Measurements

Sugar losses during storage are mainly caused by respiration and the development of moulds after reaching the threshold of accumulated thermal time, which is about 300 degree days. For this reason it is possible to estimate sugar losses by measuring the carbon dioxide production or oxygen consumption during storage. Beet samples are stored in metal or plastic cylindrical vessels and placed in a room with controlled temperature. Air supplied from a compressor flows into these vessels near the bottom. At the top, the air is diverted to the measuring equipment, as shown in Figure 3.1.

Based on the air flow and carbon dioxide production or oxygen consumption, the sugar losses can be calculated. A detailed description of these measurements is given by Koster et al. (1980). This methodology makes it possible to estimate the sugar losses during the storage period for different treatments, such as choice of variety, topping and defoliation, under controlled conditions. Even relatively small differences can be monitored due to the high precision of the measurement technique.

Sugar losses can be expressed in several ways:
- grams of sugar per 100 g sugar (%) per day
- grams of sugar per kg sugar per day
- grams of sugar per ton of beet per day

Under good storage conditions, sugar losses from machine-harvested beet are about 0.1% per day, corresponding to 1 gram per kg sugar per day or 170 grams per ton of beet per day for sugar beet containing 17% sugar. This was first demonstrated in investigations in the 1960s and 1970s (Oldfield et al., 1980), and has been confirmed in many further studies since then (e.g. Kenter et al., 2006). If the calculation is based on carbon dioxide production, sugar losses can be converted to grams of sugar per 100 grams of sugar per day by the equation:

**Figure 3.1:** Equipment used at IRBAB for measuring the respiration losses from sugar beet during storage. (Photo: IRBAB).

Sugar loss ($g\ sugar \times 100\ g^{-1}\ sugar \times d^{-1}$)

$$= 24 \times 60 \times 0.01 \times \%CO_2 \times 0.001 \times flow \times f \times 10 \times (\%S)^{-1} \times w^{-1} \times 44.01 \times 0.648 \times 22.4^{-1} \times (1 + 0.00367\ t)^{-1}$$

where:
24 = hours per day
60 = minutes per hour
$0.01 \times \%CO_2$ = litres $CO_2$ per litre air
$0.001 \times$ flow = litres per minute (if flow = in ml/min.)
%S = sugar content before storage
f = correction factor if the flow measurement depends on $\%CO_2$: $f = (100-a \times \%CO_2)/100$ , with a = constant of flow meter
w = net beet weight in kilograms
t = temperature (°C)
$44.01 \times 0.648 \times 22.4^{-1} \times (1+0.00367t)^{-1}$ = conversion of litre $CO_2$ to grams of sugar

Figure 3.2 shows the typical course of respiration losses over time. Higher sugar losses occur during the first days due to wound healing, and after about 300 °C days due to the development of moulds. In another approach, the beet quality after storage can be compared with the beet quality of a reference sample before storage to estimate the decrease in quality.

*Note: Sugar losses occur not only due to carbon dioxide production, but also due to the accumulation of invert sugars and raffinose.*

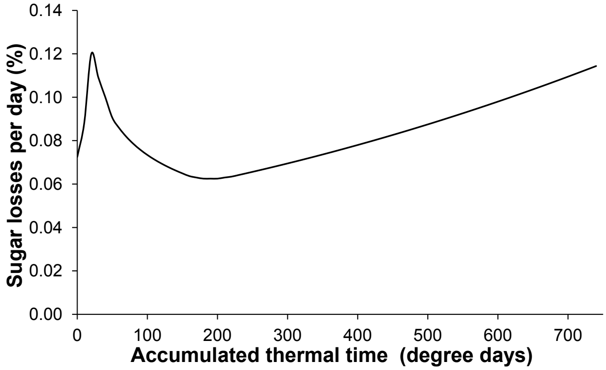



**Figure 3.2:** A typical curve for sugar losses caused by respiration during storage of sugar beet. (Source: Huijbregts, 2009b).

## 3.1.2 Storage under controlled conditions

In order to determine sugar losses and the decrease in quality under specific conditions, sugar beet samples are stored in nets, sacks or boxes (Figures 3.3 and 3.4). Reference samples are analysed before storage for at least sugar content and soil tare. The stored beet samples are weighed before storage (gross weight). Net weight before storage (net weight in) is calculated from the gross weight using the soil tare percentage of the reference samples. After storage, the samples are analysed and the results are compared with the quality of the reference samples. Sugar losses in percentage per day are calculated using the equation:

sugar losses in percentage per day =
100 x (net weight in x sugar content reference – net weight out x sugar content out) x (net weight in x sugar content reference)$^{-1}$ x number of storage days$^{-1}$

These tests can be performed in barns or outdoors as long as the beet are protected against frost. For experiments at specific temperatures, cold stores or climate rooms have to be used. Humidity should be near 100% to prevent a reduction in root weight by transpiration (water loss). If root transpiration is too high, the water loss will interfere with the sugar content decrease.

**Figure 3.3**: Sacks of sugar beet stored in boxes. (Photo: NBR)

**Figure 3.4**: Sugar beet stored in plastic boxes in a controlled environment. (Photos: NBR).

### 3.1.3 Clamp experiments

Two types of clamp experiments are generally used. The first is based on full-scale clamping trials using in and out values of weight, soil tare and beet quality to calculate the sugar losses and the reduction in quality during storage. The second method is based on net samples stored in the clamp in order to calculate the sugar losses and decrease in quality of the whole clamp (Figure 3.5). The net samples are placed between beet loads of the same material. Reference samples are analysed before storage. The stored beet samples are weighed before and after storage to calculate the loss of weight. After storage, the samples are analysed and the results are compared with the quality of the reference samples. The sugar losses are calculated as described in section 3.1.2. Temperature should be recorded outside and at several places inside the clamp. As an indication of sugar losses, the accumulated thermal time based on temperatures above zero within the clamp is used (Jaggard et al., 1997). As the temperature varies considerably within a clamp, sugar losses and quality changes also depend strongly on the position in the clamp. Therefore, beet samples should cover the whole cross-sectional area to give a representative picture of the clamp (Figure 3.6).

**Figure 3.5:** Nets filled with samples of sugar beet being stored inside the clamp. (Photo: IRS).

**Figure 3.6:** Net bags filled with samples of sugar beet being stored inside all over the cross-section of the clamp. (Photo: Nordzucker).

Starting in 2004 in Northern Germany trials testing different covering materials have been conducted with focus on the effect of storage temperature, storage period, size of the clamp, and also kind of topping (defoliated vs. "normal"). Sugar losses were determined in bags which were placed in the clamp (Figure 3.6). Investigations in Sweden and Northern Germany have shown that temperature records are crucial for understanding the changes in a clamp, especially if the aim is to evaluate clamp management. Figures 3.7, 3.8 and 3.9 show different ways of evaluating the temperature change in a clamp. In Swedish investigations during 2011-2012, different frost protection methods were evaluated by measuring temperature, as shown in Figure 3.9.

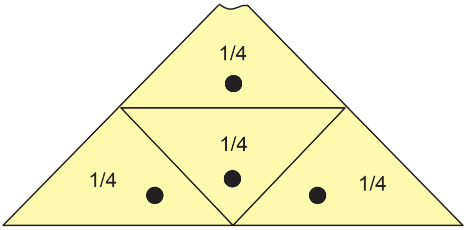



**Figure 3.7:** Positions for temperature measurement in a clamp to get a representative temperature value for the various parts of the clamp. (Source: Olsson, 2009a).

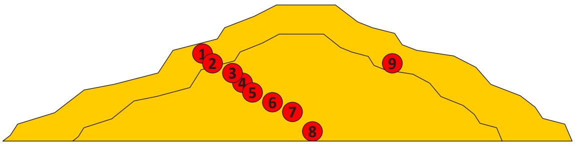
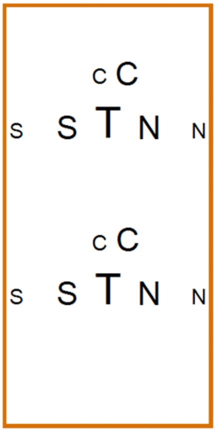



**Figure 3.8**: Position of temperature logger in a clamp to get a representative value. (Source: Nordzucker).




Thermometers in the clamp:

S 0.2-0.5 m from the ground on the south side, just below the outer layer of beet

S In the middle on the south side, just below the outer layer of beet

T On the top, just below the outer layer of beet

N In the middle on the north side, just below the outer layer of beet

N 0.2-0.5 m from the ground on the north side, just below the outer layer of beet

C Centre, 0.5 m down

C Centre, 2 m down

**Figure 3.9:** Placement of thermometers in a clamp when testing different frost protection materials during long-term storage. (Source: NBR 2013, unpublished material).

## 3.2 Analyses

### 3.2.1 Standard quality parameters: sugar (Pol), potassium, sodium, amino nitrogen

Reference samples and post-storage samples have to be processed without delay. After washing, the beets are sawn and the homogeneous beet brei is analysed directly or immediately shock-frozen and stored below -20 °C until analysis. After extraction and clarification of the beet brei, sugar content is determined by polarimetry, potassium and sodium by flame photometry and amino nitrogen by fluorimetry or colorimetry (ICUMSA, 2009).

### 3.2.2 Additional quality parameters: sucrose, invert sugars, raffinose, soluble nitrogen

If the beet have deteriorated to some extent, the polarimetric sugar determination deviates from the sucrose content due to the presence of other components with polarising properties (Bergkvist, 1971). For correct determination of the sugar content, direct sucrose determination is possible. This can be done using an enzymatic method (Karlzen and Tjebes, 1988) or by HPLC (Huijbregts et al., 2006). With HPLC, invert sugars (glucose, fructose), raffinose, glutamine and betaine can be determined simultaneously in filtrates of sugar beet brei (see Figure 3.10).

However, the HPLC method is time-consuming and expensive. Enzymatic methods can be used for the determination of invert sugar and raffinose (Hollaus et al., 1977; ICUMSA, 2011). More recently, a method has been introduced to measure glucose online in the tarehouse using immobilised enzymes (Huijbregts, 2013a). This measurement can be used as an indication of the formation of invert sugars during storage. An IIRB study on the long-term storability of different sugar beet genotypes showed a close correlation between glucose and invert sugars (Figure 3.11). From various storage experiments from 2003 to 2011 Schnepel and Hoffmann (2013) derived a formula for the calculation of the invert sugar concentration from the glucose concentration of the beets.

Soluble nitrogen in the filtrates can be analysed after lyophilisation and dry micro-Dumas combustion by gas chromatography (Hoffmann et al., 2009).

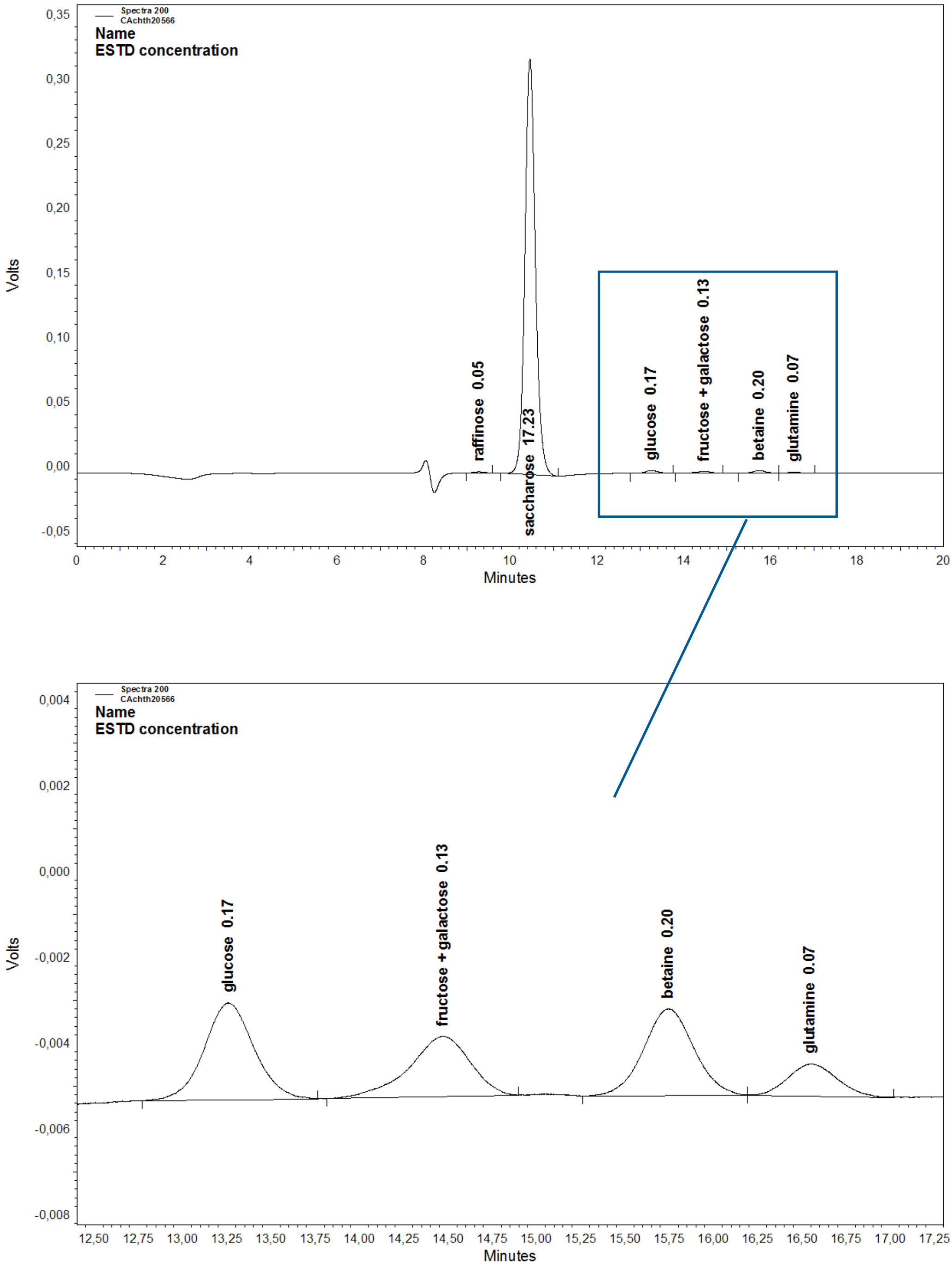



**Figure 3.10**: HPLC analysis of raffinose, sucrose, glucose, fructose, betaine and glutamine in sugar beet extract. (Source: Huijbregts et al., 2006).

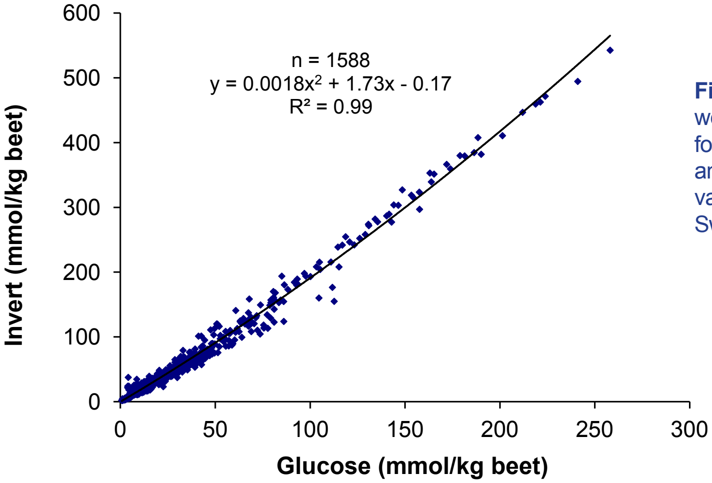



**Figure 3.11**: Relationship between glucose and invert sugars for sugar beet genotypes before and after long-term storage under various conditions. (Source: van Swaaij and Huijbregts, 2010).

### 3.2.3 Scores for sprouts, frozen parts, moulds, rot

Additional scoring of sugar beet after storage can be carried out before and after washing the samples. Before washing, each beet in a sample, or only some of the beet in large samples, are visually judged for the number and length of sprouts. To quantify infection with moulds, the affected surface can be estimated using the same scale as is used for diseases (Figure 3.12). This visual assessment can also be done on different parts of the beet such as the crown tissue and the tap root or the whole beet root surface, as this affects the severity of the infection.

The proportion of frozen parts and rots can be better estimated after the beet sample has been washed, using the same scoring system as in Figure 3.12. The percentage of rot can be estimated in a more quantitative way by cutting off the rotten beet parts and weighing the beet and the rotten beet parts separately. Note, however, that infections by mould and the subsequent rot may be underestimated and the amount of dirt tare overestimated as the affected tissue may be washed off. Regarding the assessments and the scoring systems, there are established scales for tap root breakage and topping (Jorritsma and Oldfield, 1969; Brinkmann, 1986). Scoring systems regarding sprouts, frozen beet parts, moulds and root rot may vary between countries.

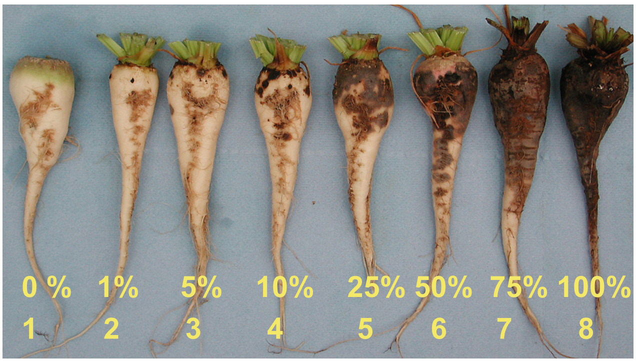



**Figure 3.12**: Scoring system for assessing sugar beet after storage. Scores and their corresponding percentages of the root infected by mould, rotted or damaged by frost. (Source: Büttner et al., 2004).

### 3.2.4 Detection of reversible and irreversible frost damage

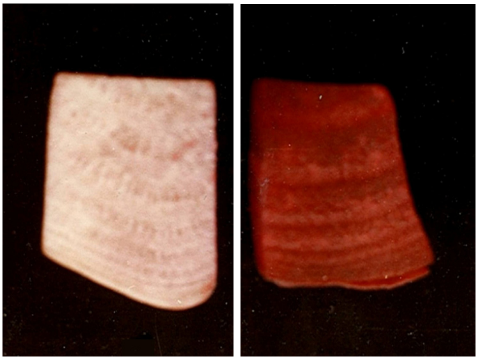


**Figure 3.13**: Staining with Ponceau Red. No staining of healthy sugar beet tissue (left) and complete staining of tissue subjected to freezing temperatures (-20 °C) for 30 minutes (right). (Photo: IRS).

If beet have been damaged by frost, it is important to know whether the damage is irreversible. In that case, the beet must be processed before the deterioration starts (Kenter and Hoffmann, 2006). To distinguish between reversible and irreversible damage, a method has been developed using Ponceau Red for staining (Huij-bregts et al., 1981).

Beet slices with a thickness of 3 mm are placed in a 0.4% Ponceau Red (R6) aqueous solution. After 15 minutes, the slices are washed with water for 5 minutes and the colour is determined visually or by reflection measurements at λ=600 nm with a densitometer. Figure 3.13 shows the difference between a healthy beet part and a beet part with irreversible frost damage after staining with Ponceau Red. Irreversibly damaged roots are stained dark red. However, tests have shown that parts of the damaged tissues which are able to recover within two weeks may also react positively (Heijbroek and Huijbregts, 1984).

# 4. FACTORS AFFECTING STORABILITY

## 4.1 Beet material

### 4.1.1 Beet growing conditions

Stress factors during growth may affect the storability of sugar beet. The effect of drought stress on storability was demonstrated in 2003 in Germany (Kenter and Hoffmann, 2008). During storage, the concentrations of amino N, betaine, total soluble N and invert sugar increased. These effects were found to be more pronounced at high storage temperature and in beet which showed visible symptoms of drought stress in the field. Thus, water shortage impairs not only the quality, but also the storage properties of sugar beet. For beet with symptoms of drought stress, the storage period should be kept as short as possible.

Trials in Germany have also shown that storability is impaired by visual root injuries and by *Rhizoctonia solani*, both of which cause an increase in sucrose losses and in accumulation of melassigenic substances such as amino-N and invert sugar (Kenter et al., 2006). Strausbaugh et al. (2011) found that the *Rhizoctonia*-bacterial root rot complex can negatively affect neighbouring healthy roots during storage, leading to additional sucrose losses. A positive correlation between loss of sugar during storage and the frequency of *Aphanomyces* in the soil was found in an investigation involving 47 fields in Sweden during 2006-2009 (Persson and Olsson, 2009). The beet were hand-lifted in order to obtain roots with as little damage as possible and then stored for 60-70 days under cold or warm conditions (5-10 ºC and 10-15 ºC, respectively).

Campbell and Klotz (2006a) and Klotz and Campbell (2009) associated post-harvest storage losses with *Aphanomyces* root rot. Liming of the soil can have a positive effect on the storability of sugar beet infected by *Aphanomyces* because it may suppress the infection in acid soils (Roelfsema, 2011). *Fusarium* infection also affects post-harvest respiration rate, sucrose concentration and the formation of invert sugar in stored sugar beet (Campbell et al., 2011). In 2011 and 2012, roots from liming trials at eight different locations in Sweden were stored for 70 days. The beet were grown in soil with a pH level around 7, amended with different amounts of limestone (8 and 32 ton/ha corresponding to 4 and 8 ton/ha CaO) and factory lime (16 ton/ha corresponding to 4 ton CaO/ha), applied in the autumn before the sugar beet crop. Sugar losses after storage tended to decrease with 8 and 32 ton lime stone/ha compared with beet grown in unlimed soil (Olsson and Persson, NBR, unpublished). Poor soil structure or a pan layer can lead to fangy roots. This gives higher storage losses due to damaged roots and root tip breakages during harvest.

Since the 1980s, differences in sugar losses between sites during storage have been observed in practice, although growing conditions seem to be similar. This phenomenon is not entirely understood but is believed to be related to differences in the microbiological composition of the soil. In an investigation in Sweden in 2005, beet samples from eight different sites were stored in a controlled environment with two different temperatures (5 and 25 ºC) for 33 and 25 days. The results showed, with one exception, correlations between mechanical injuries, symptoms of fungi and bacteria and sugar losses. One site with high sugar losses showed very little mechanical damage (Persson, 2005). In a more extensive investigation during 2006-2009, where beets from the same variety were hand harvested at different sites, occurrence of soil borne fungi in the soil was found to be correlated to the sugar losses. Sugar losses increased with increasing root rot index of *Aphanomyces* in the soil. The soil at each site was also analysed with respect to acidity and nutrient status. There was no correlation between any of the chemical soil factors and sugar losses (Persson and Olsson, 2009). Later investigations showed a 50-100% difference in sugar losses during long-term storage of the same varieties grown at two different sites with varying soil characteristics (Olsson, 2011).

*Conclusion: Healthy beet give the lowest sugar losses during storage. Stress conditions during the growing season should be avoided by preventing drought, nutrient and pest stresses and by suppressing diseases. Rotten beet should not be stored.*

### 4.1.2 Variety

Differences in the storability of varieties have been extensively studied in the past. In most cases only small differences in sugar losses were reported (Wyse, 1970; Koster et al., 1980; Vanstallen, 1980; Vukov and Hangyal, 1985; Kenter et al., 2006; Kenter and Hoffmann, 2006). A study on biomass beet (high root yield, low sugar content) showed similar sugar losses during storage for the sugar beet varieties tested (Huijbregts, 2008). However, Wyse et al. (1978) found up to 2.5-fold differences in respiration rate among varieties, suggesting that sufficient genetic variability exists among sugar beet genotypes to sustain a breeding programme designed to develop low-respiring breeding lines. In 2008/09 and 2009/10, storage trials with 12 sugar beet genotypes were carried out under different conditions in six countries (van Swaaij and Huijbregts, 2010). Genotypes showed significant differences in sugar losses, but there was a strong interaction with year and site. Furthermore, differences between the genotypes occurred as regards the decrease in beet quality during storage, not only as a reduction in sugar content, but also as an increase in invert sugar and soluble nitrogen.

**Table 4.1**: Sugar losses after long-term storage of different varieties of sugar beet grown at one site in 2007-2009 and at two sites in 2010-2012. (Source: Olsson, 2012b).

| Variety | Type* | 2007 | 2008 | 2009 | 2010 | 2010 | 2011 | 2011 | 2012 | 2012 |
|---|---|---|---|---|---|---|---|---|---|---|
| Site | | Äd | Äd | Äd | Vra | Hvi | Vra | Hvi | Vra | Hvi |
| Days x Temp. | | 70d*4.6 | 75d*6.6 | 73d*10.2 | 68d*8 | 61d*8 | 64d*11 | 63d*11 | 60d*11 | 60d*11 |
| Accumulated day degrees | | 322 | 493 | 746 | 517 | 453 | 685 | 674 | 653 | 653 |
| **Average loss % sugar/day** | | **0.10** | **0.10** | **0.16** | **0.08** | **0.11** | **0.14** | **0.17** | **0.11** | **0.13** |
| Julietta | NT | | yellow | green | green | green | green | green | yellow | green |
| Rasta | N | red | red | red | yellow | yellow | yellow | red | yellow | red |
| Theresa KWS | NT | green | green | yellow | yellow | yellow | green | green | | |
| Nexus | N | | red | green | yellow | green | yellow | yellow | | |
| Rosalinda KWS | N | | | yellow | red | yellow | green | green | | yellow |
| Mixer | N | | | green | yellow | yellow | yellow | yellow | yellow | red |
| Sabrina KWS | N | | | | green | yellow | green | yellow | yellow | yellow |
| Cactus | NT | | | | | | yellow | yellow | yellow | yellow |
| SY Muse | N | | | | | | red | yellow | yellow | red |
| Sy Stinger | N | | | | | | yellow | yellow | yellow | green |
| Alexina KWS | NT | | | | | | | | yellow | yellow |

(green) Low loss level, statistically different to high loss level on LSD 5 % level
(yellow) Average loss level for tested varieties
(red) High loss level, statistically different to low loss level on LSD 5 % level
* NT = nematode tolerant N = not nematode tolerant

Experiments during recent years have shown that differences do indeed exist between varieties when sugar beet are stored for a long period (Kenter and Hoffmann, 2009). Storage experiments in Belgium with several varieties showed that until the threshold level of 270 °C days was reached, the differences between varieties were small, i.e. losses were less than 5% of sugar weight (Legrand and Wauters, 2012). Beyond that threshold, the tests showed that harvesting conditions, causing root tip breakage, lateral injuries and over-topping, and the aggressiveness of the cleaning system were crucial for the extent of sugar losses during storage. The more aggressive the harvesting, the more pronounced were the sugar losses. It was also shown that with aggressive harvesting, the differences in sugar losses between varieties increased during long-term storage. These results suggest that differences in storability between varieties are only partly caused by differences in internal carbohydrate turnover. A more important factor seems to be the difference in susceptibility to mechanical injuries and to infection by moulds and rot.

Long-term storage experiments under controlled conditions at temperatures between 8 and 16 °C during 2007-2012 also showed differences between varieties (Table 4.1). Although the ranking in the storability of varieties changed between years and locations, it was obvious that some varieties had a better storability and were therefore more suitable for long-term storage (Olsson, 2009b; Olsson, 2011; Olsson, 2012b).

Although differences in storability between varieties may exist, it is difficult to incorporate this trait into variety selection due to the extensive testing procedure. A joint IIRB study showed only weak relationships between sugar losses and initial sugar content (r = -0.66), initial betaine content (r = -0.62) and root tip breakage (r = +0.66) (van Swaaij and Huijbregts, 2010). After storage, significant correlations were found between sugar losses and the incidence of mould (r = +0.87), rot (r = +0.88) and the content of invert sugars (r = +0.89).

*Conclusion: There are differences in storability between sugar beet varieties. Susceptibility to mechanical damage and/or infection by mould and rot seem to be of major importance for these differences in storability.*

### 4.1.3 Beet size

Theoretically, large roots will have smaller sugar losses during storage because of the smaller surface to volume ratio, but in a respiration experiment with roots of different weight (on average 385, 797 and 1313 g/beet), the large roots had only 10% lower respiration losses than the smallest roots (Huijbregts, 2008). However in practice, differences may be larger due to better ventilation between large beet when stored in a clamp (Tabil et al., 2003).

*Conclusion: Small sugar beet may have somewhat higher sugar losses during storage than large beet.*

## 4.2 Harvesting and clamping conditions

### 4.2.1 Root damage during harvesting and clamping

Increased sugar losses during storage as a consequence of beet injuries have been reported in several studies (Ingelsson, 2002; Steensen and Augustinussen, 2002a; Kenter et al., 2006). In a joint study by IRBAB and IRS, the effect of growth conditions and variety on damage susceptibility was studied (van Swaaij et al., 2003). In another study investigating the effect of injuries caused by a rotating turbine on sugar losses during storage (Huijbregts, 2008), after aggressive cleaning by the turbine the sugar losses increased 3-fold compared with the untreated reference during a storage period of three weeks (Figure 4.1). In long-term storage the differences will probably increase due to the development of moulds on the injured tissue.

The losses caused by a harvester with turbines (Holmer) were then compared with those caused by a harvester with axial rollers (Ploeger) (Huijbregts, 2008). Under optimal conditions both systems caused similar sugar losses during short-term storage. Tests on the effect of cleaning intensity on sugar losses with the harvester with axial rollers showed somewhat lower losses with less intensive cleaning and higher losses with more intensive cleaning compared with the optimal cleaning (Figure 4.2).

Ingelsson (2002) also showed that intensive cleaning can cause high sugar losses during storage. The amount of injured beet was twice as high and the damaged beet surface three times higher after intensive cleaning compared with more gentle cleaning. The temperatures in the clamp during 7 weeks of storage did not differ on average, but in parts of the clamp with intensively cleaned beet the temperatures were higher than in parts of the clamp with more gently cleaned beet. After storage, intensively cleaned beet had significantly more sprouts, most likely due to heat production by the damaged beet, and more heat-damaged beet, mould infections and root rot than more gently cleaned beet. The sugar losses after storage were also significantly higher, on average 0.19% per day compared with 0.14%.

Olsson (2008) showed that most mechanical damage to sugar beet is caused by the harvester. Although loading and unloading may increase existing surface cracks and root tip breakages, about 80-90% of the injuries originate from the harvester. It is a well-known fact that the root tip is a direct point of entry for fungal attack and subsequent root rot. The degree of fungal attack and sugar losses after long-term storage of sugar beet subjected to different levels

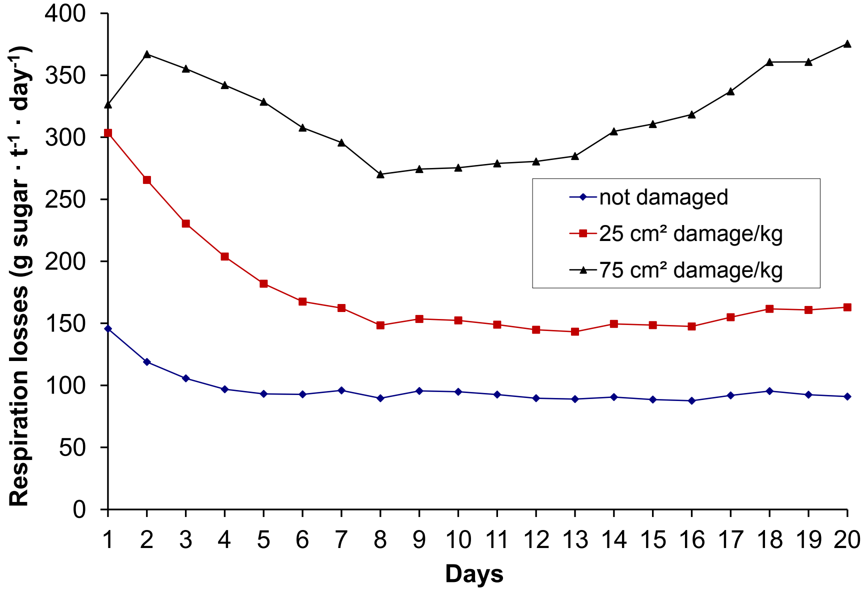



**Figure 4.1**: Effect of beet injuries caused by a cleaning turbine on sugar losses during storage of sugar beet at 10 °C. The losses are calculated from $CO_2$ production. (Source: Huijbregts, 2008).

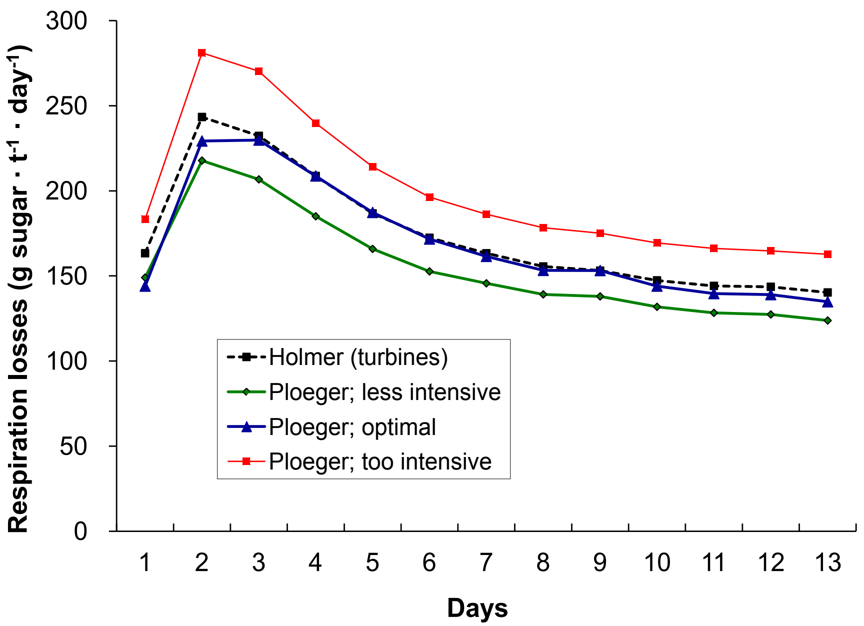



**Figure 4.2**: Effect of a Holmer harvester with turbines and a Ploeger harvester with axial rollers used at different cleaning intensities on respiration losses of sugar beet during storage at 10 °C. The respiration is calculated from $CO_2$ production. (Source: Huijbregts, 2008).

**Figure 4.3**: Sugar beet harvested with a normal system (top) and with a low impact harvesting system (bottom) in long-term storage trials in Sweden in 2006-2008. (Photo: NBR). (Source: Olsson, 2008).

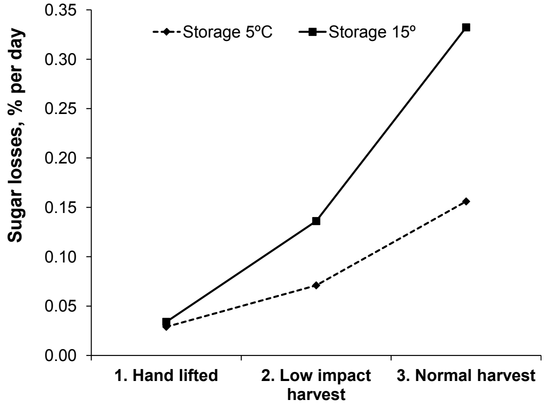



**Figure 4.4**: Effect of different levels of damage during harvest on sugar losses during long-term storage of sugar beet. (Source: Olsson, 2008).

of damage during harvesting (mild and normal) were investigated in nine trials in Sweden (Olsson, 2008). Hand-lifted beet were included as reference (Figure 4.3).

The more gently harvested sugar beet had significantly less damaged surface area than the normally harvested sugar beet (1.5 and 6.6 $cm^2$, respectively). After 61-70 days of storage, normal harvesting resulted in more of the root tip area being infected by fungi and higher daily sugar losses than low impact harvesting. The differences were significant at both low (5 ºC) and high (15 ºC) storage temperature (Figure 4.4).

At 5 ºC, the daily sugar losses were almost twice as high from normally harvested sugar beet than from the more gently harvested sugar beet. At 15 ºC, the difference was even greater. For sugar beet harvested by hand, the sugar losses were less than 0.05% per day at both storage temperatures and thus the higher temperature did not increase the sugar losses. However, increasing the storage temperature from 5 to 15 ºC almost doubled the daily sugar losses from low impact harvested and normally harvested sugar beet as also shown by Kenter et al. (2006). In another experiment, it was concluded that the decrease in sugar content during storage of low impact harvested sugar beet was only 70% of that after normal harvesting. This indicates significant potential for low impact harvesting to decrease sugar losses during storage. The observed differences in storability of the beet materials were mainly due to varying degrees of root tip fractures and fissures (Olsson, 2010a).

During Beet Europe 2010, the storability of sugar beet harvested with different harvesters was compared (Table 4.2) (Huijbregts, 2010b). Harvesting systems with the lowest root tip losses (hand harvesting and a Grimme Maxtron 620 harvester) gave the lowest rot score and also low sugar losses. Sprouts did not correlate with the sugar losses.

*Conclusion: Root injuries during harvesting and clamping should be minimised. During uprooting and cleaning, some surface damage and root tip losses are unavoidable. A balance has to be found between soil removal and beet injuries.*

**Table 4.2**: Impact of different harvesters on harvest quality and storage losses. Sugar beet stored at 100% humidity: first 3 weeks 10 °C, next 2 weeks 15 °C, last 2 weeks 10 °C. (Source: Huijbregts, 2010b).

| Harvester | Topping quality (%) | | | Root tip losses | Sprouts* | Moulds** | Rot** | Weight losses | Sugar losses |
|---|---|---|---|---|---|---|---|---|---|
| | Petioles | Good | Overtopped and angled | (t ha$^{-1}$) | | | | (%) | (% d$^{-1}$) |
| Agrifac Big Six | 14.9 | 71.5 | 13.7 | 2.7 | 8 | 2.8 | 2.3 | 2.2 | 0.10 |
| Agrifac Quatro | 11.5 | 84.6 | 4.0 | 2.5 | 8 | 2.1 | 2.1 | 1.1 | 0.08 |
| Grimme Maxtron 620 | 17.1 | 68.5 | 14.4 | 1.5 | 5 | 1.5 | 1.3 | 2.3 | 0.08 |
| Grimme Rexor 620 | 23.3 | 69.6 | 7.0 | 2.3 | 6 | 2.0 | 2.3 | 3.5 | 0.13 |
| Grimme Rootster 604 | 9.7 | 89.4 | 0.9 | 2.5 | 8 | 2.0 | 2.5 | 1.7 | 0.12 |
| Holmer Terra Dos T3 Plus | 12.0 | 77.9 | 10.1 | 2.0 | >10 | 1.9 | 2.1 | 3.4 | 0.14 |
| Ropa euro-Tiger V8-3 | 17.6 | 79.1 | 3.3 | 1.9 | 8 | 1.4 | 2.0 | 2.5 | 0.12 |
| Vervaet Beet Eater 617 | 14.1 | 80.8 | 5.1 | 2.8 | 7 | 2.3 | 2.3 | 2.7 | 0.12 |
| Vervaet Beet Eater 625 | 8.2 | 88.9 | 3.0 | 3.1 | 6 | 2.3 | 2.8 | 1.7 | 0.12 |
| Hand-harvesting | 13.4 | 84.1 | 2.5 | 0.1 | >10 | 1.1 | 1.4 | 0.2 | 0.05 |
| Lsd (5%) | | | | | | | | 2.3 | 0.05 |

* average number of sprouts per beet.
** visual observation 0 = 0% moulds/rot; 9 = 100% moulds/rot.

## 4.2.2 Defoliation and topping

A number of investigations have been carried out to estimate the effect of defoliation and topping on the storability of sugar beet (Wyse, 1980; Koster et al., 1980; Vandergeten, 1988; Destombes and Noé, 1989; van der Linden and Huijbregts, 2001; Steensen and Augustinussen, 2002b, 2003; Hoffmann, 2012). Wyse (1980) found that in long-term storage (105 and 130 days), the respiration rate of topped beet increased significantly over that of untopped beet. Figure 4.5 gives an example of a storage experiment with machine harvested sugar beet with different topping settings (Huijbregts, 2009b). For the first three weeks, until about 200 degree days, the effect of topping on sugar losses was small. After this period the differences in sugar losses between topping settings increased. Over-topped beet had more sugar losses after long-term storage. This may be due to the development of moulds at the cutting surface of over-topped beet (Figure 4.6).

Defoliated beet may produce more sprouts during storage, especially at relatively high temperatures. However, in a storage experiment comparing conventional topping with defoliation by a test machine comprising three axles with rubber-studded flails, no visual differences were observed in sprouting between topping and defoliation (van der Linden and Huijbregts, 2001). Sprouting seemed somewhat less with defoliation in combination with minimal topping. The effect on storability was small.

Hoffmann (2012) showed that overtopped beet had the highest weight losses and sugar losses, as well as the strongest accumulation of invert sugar. Defoliated beet had slightly higher sugar losses than topped beet perhaps due to sprouting. A close relationship was found between invert sugar accumulation and infection by mould and storage rots which was highest for overtopped beets. Steensen and Augustinussen (2003) showed that during a storage period of approx. 5 weeks, the respiration rate of flail-topped beet and of non-

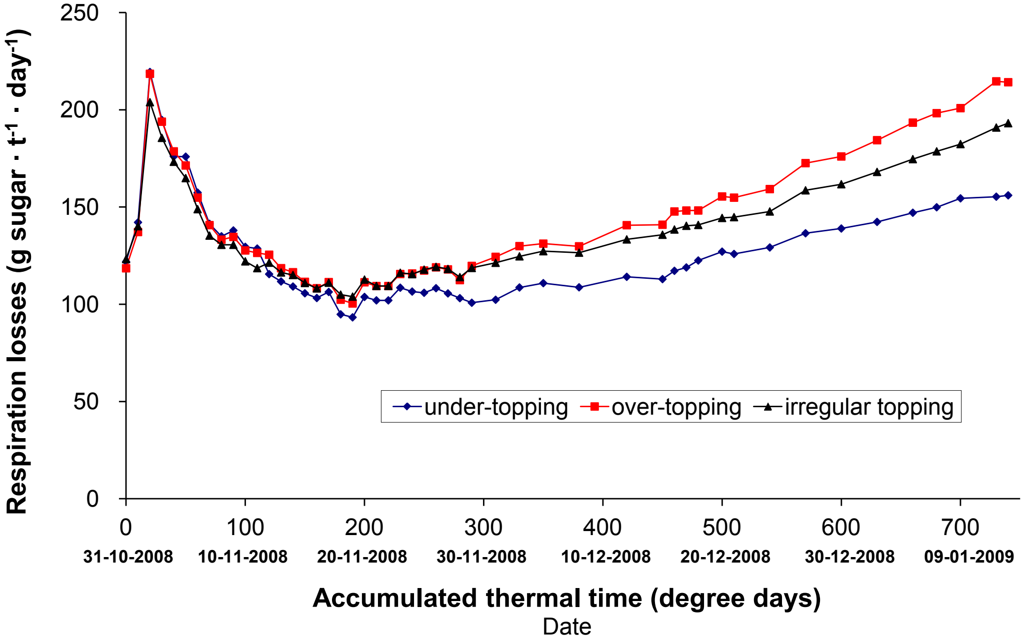



**Figure 4.5**: Effect of mode of topping (setting of the scalpers) on sugar losses during storage of sugar beet at 10 °C. Losses are calculated from $CO_2$ production. At the end of November, the threshold of accumulated thermal time (300 degree days) was reached. (Source: Huijbregts, 2009b).

**Figure 4.6**: Infection by moulds (left) resulting in rotting (right), especially at the broken tip and at the cutting surface of over-topped sugar beet. (Photos: Suiker Unie).

scalped beet was slightly higher than that of conventionally topped beet and of scalped beet. The invert sugar content increased considerably, the increase being significantly higher in the flail-topped treatments than in the conventional treatments.

In a clamp experiment, Huijbregts (2013b) investigated the effect of leaf residues. The clamp was split in four parts to compare the storage of beet with remaining green stalks and leaves with well-defoliated/small topped beet, both with and without covering with fleece. During frost the whole clamp was covered with an additional plastic sheet. The temperature in the clamp was highest (on average 11.6 °C) in the clamp part where beet with green stalky material were covered with fleece, and lowest (on average 8.8 °C) in the uncovered part with defoliated/small topped beet. The decrease in sugar content was highest for beet with leaves and without fleece and lowest for beet without leaves and with fleece. The increase in glucose was highest under the fleece. Sugar losses were higher for beet with leaves, on average 0.23% per day, than for beet without leaves, 0.18% per day. Incomplete defoliation should therefore be avoided. Petioles and leaves in a clamp reduce ventilation and produce heat during rotting (Tabil et al., 2003). This can lead to higher storage temperatures and subsequently higher sugar losses.

*Conclusion: Complete removal of leaves, possibly in combination with minimal topping but avoiding over-topping, gives the lowest sugar losses during long-term storage.*

### 4.2.3 Weather conditions during harvesting and storage

As the storage losses during long-term storage depend on the accumulated degree days, the initial temperature is important. Harvesting under cold conditions, but with temperatures above 0 °C, are preferable for long-term storage. High temperatures at the start of the storage may give high respiration losses and subsequently enhanced heat production, causing even higher temperatures in the clamp.

It has been shown that very moist conditions in the clamp, which can occur when beet are being clamped in rain, increase the sugar losses. The effect of rainfall on storage losses was investigated in 2010-2011 by adding water to sugar beet during storage (Olsson, 2011). The results showed an increase in sugar losses from 9.1% in boxes with dry storage conditions to 11.5% with simulated rainfall (Figure 4.7).

**Figure 4.7**: Simulating rainfall in long-term sugar beet storage trials in Sweden. (Photo: NBR).

*Conclusion: Harvesting under dry and cold, but frost-free conditions is preferable for long-term storage.*

## 4.3 Storage conditions

### 4.3.1 Storage temperature and period

Storage temperature is a very important factor for the storability of sugar beet. Several studies have shown the effect of temperature on sugar losses during storage (Burba, 1976; Devillers, 1981; Kenter et al., 2006; Huijbregts, 2008). As an example, Figure 4.8 shows the effect of storage temperature on sugar losses for beet with different levels of injuries. The effect of temperature on sugar losses is related not only to the degree of surface damage of the sugar beet, but also to the storage period. Legrand and Wauters (2012) observed that percentage sugar losses increased with the accumulated thermal time reached under different constant storage temperatures (Figure 4.9). Olsson (2011) also showed that sugar losses during storage were correlated to the number of degree days to which the beet were exposed during storage (Figure 4.10). Legrand and Wauters (2012) concluded that the sugar losses during the first period of storage were mainly caused by wound healing of harvesting injuries and by respiration of the sugar beet themselves. Later in storage, they were caused by the development of storage moulds, which increased root weight losses and sugar losses. The losses due to the storage moulds were exponential from a threshold level of 270 °C days (Figure 4.11).

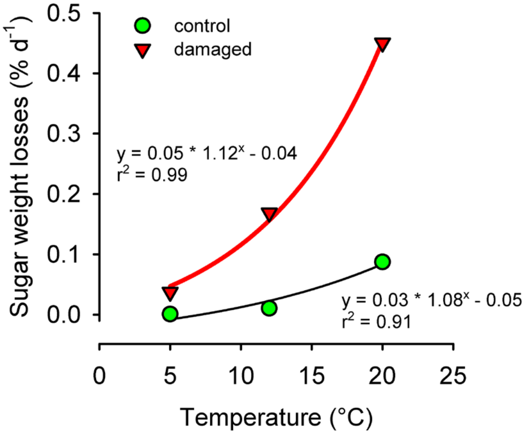



**Figure 4.8**: Impact of beet damage on sugar losses during storage; 27 days of storage, control = undamaged beets, 100 % = amount of sugar at the beginning of storage. (Source: Kenter et al., 2006).

A threshold value was also shown by Olsson (2011). For storage periods of 100-300 degree days the daily sugar losses were 0.05% sugar. It was concluded that this might be the baseline for good storage of sugar beet. Above 300 degree days the sugar losses started to increase exponentially and reached 0.13-0.15% sugar per day at 400-700 degrees days, which is a level of losses often seen in practice. After more than 60 days of storage at 16 °C (> 1000 degree days), 0.5% of the sugar was lost every day, or in total around 30% during the storage period. In most cases the beet then did no longer meet the delivery standards as there was not only a decrease in sugar content, but also an increase in K+Na content and a decrease in purity, which indicates serious beet deterioration. Olsson (2009a) concluded that in clamps with problems it is difficult to maintain optimal storage conditions during long-term storage.

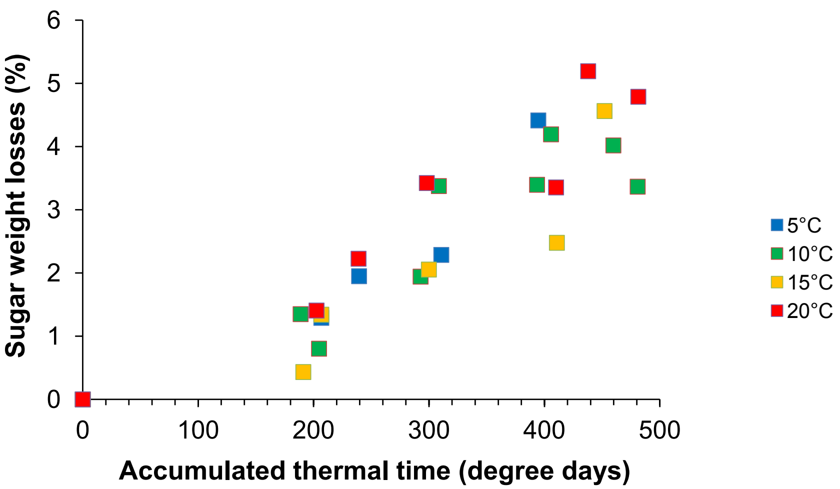



**Figure 4.9**: Sugar losses in relation to the accumulated thermal time at different constant temperatures of sugar beet storage (5, 10, 15 and 20 °C). (Source: Legrand and Wauters, 2012).

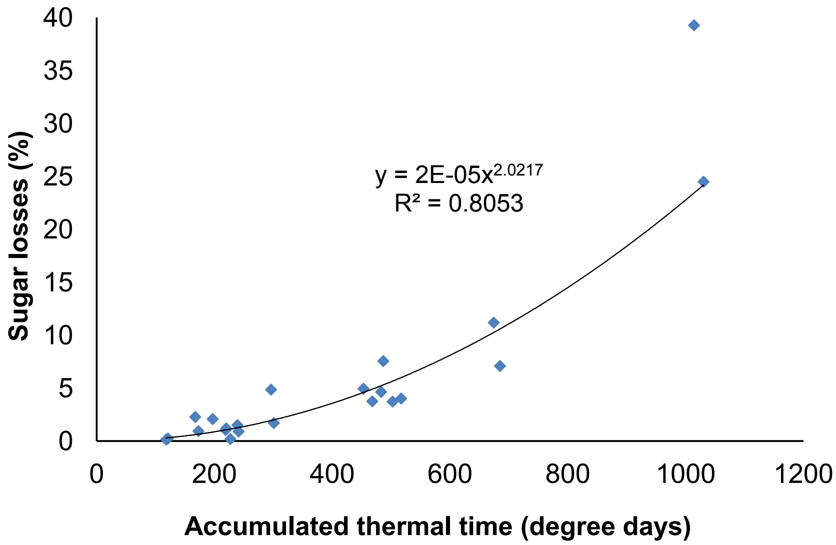



**Figure 4.10**: Sugar losses as a function of accumulated degree days. Results from long-term storage of four sugar beet varieties in 22 trials during 2010-2011. (Source: Olsson, 2011).

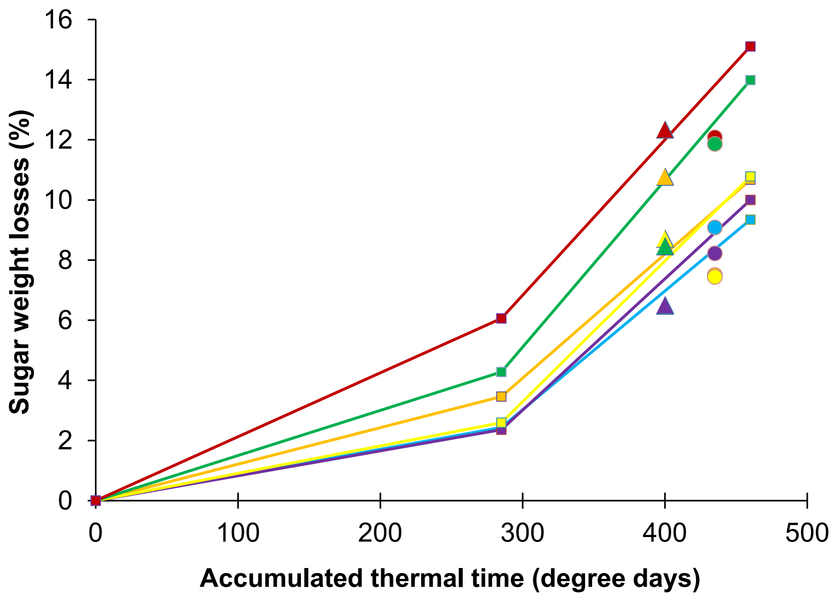



**Figure 4.11**: Sugar losses of six varieties of sugar beet (indicated by different colours), mechanically harvested on 03-11-2011 and stored under different storage conditions: Lines and square markers: storage in boxes (3 replicates of 50 kg); round markers: storage in bags in a clamp (4 replicates of 25 kg); triangular markers: storage in a clamp (1 × 15 tons). (Source: Legrand and Wauters, 2012).

*Conclusion: Sugar beet should be stored at low temperatures but above 0 °C. During long-term storage, mould formation and subsequent rot and reduction in quality may drastically increase above an accumulated thermal time of around 270 degree days.*

### 4.3.2 Humidity

Andales et al. (1980) found that relative humidity had a highly significant effect on weight losses by sugar beet. The weight loss was nearly a linear function of storage time at high relative humidity, but was a quadratic function of time at low relative humidity. In contrast, humidity had little influence on sugar losses. Under practical conditions in North-West Europe, the relative humidity in clamps is above 90% due to the production of water during respiration and restricted ventilation. Mass losses are thus often low. In storage trials ventilation should be restricted, as otherwise high mass losses may occur (van Swaaij and Huijbregts, 2010).

However, as described in section 4.2.3, very moist conditions in the clamp, which can result when the clamp is not protected against rainfall, increase sugar losses. The clamp can be protected from rainwater while maintaining gas exchange by using for instance polypropylene fleece. This can also reduce mould infections due to lower relative humidity. Another advantage is drying of the soil in the clamp, which makes it easier to remove it by a cleaner loader. However, covering the clamp immediately after harvest under relatively warm conditions may give an unwanted increase in the storage temperature (Figure 4.12).

*Conclusion: Stored beet should be protected against rainfall but with sufficient ventilation to prevent an increase in temperature.*

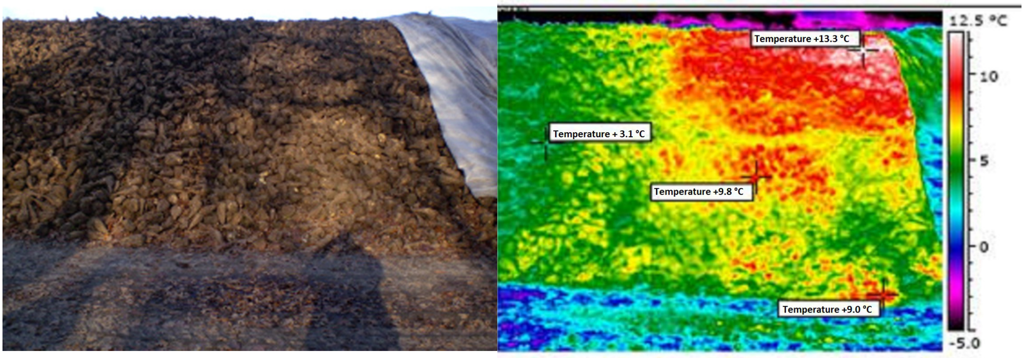



**Figure 4.12**: Photograph (left) and infrared picture (right) of a clamp. The left side of the clamp was uncovered and the right side covered by Toptex®, which was removed just before the picture was taken. (Photos: IRS).

### 4.3.3 Frost damage

Frost damage to sugar beet before and during storage has to be avoided, as outlined in section 2.8. In countries in North-West Europe, the ambient temperature in the storage period, i.e. from early November to mid-January, can vary considerably, from above 10 °C to below -10 °C (see also Figure 1.3). This means that without frost protection clamped beet may be totally frozen during a frost period and thaw out subsequently when the ambient temperature rises above 0 °C. Kenter and Hoffmann (2006) showed that after thawing a decline in the concentration of sucrose and a concomitant increase in all non-sucrose substances analysed was detectable after only three days. The loss in quality increased considerably with storage temperature.

Augustinussen and Smed (1990) showed that when sugar beet were exposed to temperatures lower than -5 °C for a 24-hour period, the damage can be serious. Immediately after thawing a small loss of sugar was found. When the beet were stored at 8-10 °C after thawing the respiration increased, sucrose was degraded to invert sugar and dextran was produced. The reduction in beet quality depended on the length of the storage period after thawing and the storage temperature.

Huijbregts (2009b) compared yield and quality of late-harvested beet that had been exposed to a short period of frost (-3 to -9 °C), and beet harvested before the frost and subsequently stored. The sugar beet showed hardly any frost damage at harvest. However, sugar content had significantly decreased, by 0.44% in absolute terms, between the last harvest on 29 November and 7 January (Figure 4.13).

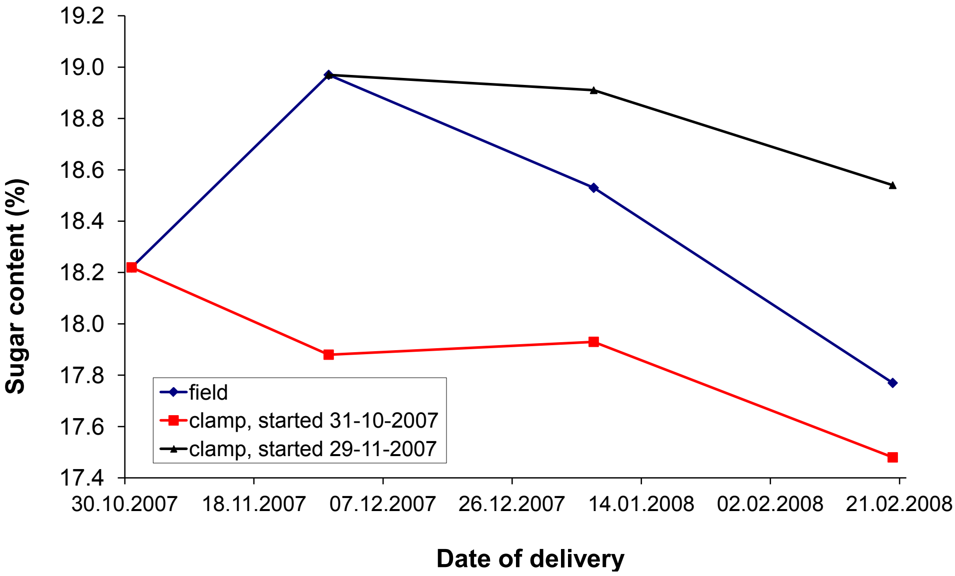



**Figure 4.13**: Change in the sugar content of sugar beet in the field and in the clamp, 31-10- 2007 to 20-02-2008. LSD (5%): field 0.40% and clamp 0.20%. (Source: Huijbregts, 2009b).

The sugar beet still in the field showed a significant increase in the concentration of raffinose, but not glucose and fructose. In a clamp, frost-damaged beet can deteriorate very rapidly. Beet should be harvested before they are irreversibly damaged by frost. During storage, beet should be protected against frost to minimise sugar losses and quality decreases. Frozen beet should be kept cool and processed as soon as possible to prevent deterioration. See section 2.8 for more information about deterioration after thawing.

*Conclusion: Frost damage to sugar beet should be avoided by harvesting in time and by providing protection against frost during storage.*

### 4.3.4 Treatments

Various chemical compounds, a controlled atmosphere and surface coatings have been suggested as means of reducing storage losses, but their commercial application appears to be quite limited (Campbell and Klotz, 2006b). It is possible to reduce sugar losses and to improve sugar beet quality after storage by preventing mould infections using fungicides (Vandergeten, 1988; Schulz and Dietrich, 1992).

Reduction of sugar losses by providing a controlled atmosphere with an increased carbon dioxide content and/or reduced oxygen content has been studied (Wyse, 1973; Huijbregts, 1983, 1984). No beneficial effect on beet quality after storage could be found by increasing the carbon dioxide content, although carbon dioxide production decreased. Decreasing the oxygen content to 12% in combination with 6% carbon dioxide did not have a significant effect on beet quality after storage. Decreasing the oxygen content to 3-5% reduced sugar losses. However, when beet were stored for extended periods below 10% oxygen and at 21 °C, they degraded more rapidly than those held above 10% oxygen.

Zahradníček (1996) provided recommendations on doses and strengths of lime to counteract sugar beet rot during storage. Other chemical and physical methods of protection have also been outlined. Olsson (2012a) found lower sugar losses with sugar beet treated with lime before storage. During storage for 63-64 days at 11 °C, liming reduced the sugar losses from 9.1 to 6.6%, most likely because liming reduced the incidence of mould (Figure 4.14).

*Conclusion: Effective commercial treatments to improve sugar beet storage are not available. However, treatment with lime may reduce sugar losses.*

**Figure 4.14**: Storage trial with sugar beet treated with lime in amounts corresponding to 1% of beet weight. (Photos: NBR).

# 5. OPTIMAL HARVEST AND CLAMP MANAGEMENT

## 5.1 Aim

Sugar losses and decreases in quality during storage should be minimised. Frost-free, cold and dry storage of healthy, well-defoliated, clean beet with minimal topping and little injuries result in the lowest losses. To fulfil these requirements, good harvesting conditions are needed and clamp shape and covering strategy must be chosen carefully in order to keep the beet frost-free, cold and dry.

## 5.2 Harvest

The quality of beet harvested ‘just in time’ may be better than the quality of stored beet. Invert sugar concentration remains low in the field if no irreversible frost damage occurs, while invert sugars increase during storage (Huijbregts, 2008). However, harvesting after mid-November ‘just in time’ before delivery can give an unacceptably high risk of harvesting under bad conditions and frost damage.

In 2006-2009, the optimal harvest date for late delivery was investigated in Sweden (Olsson, 2009a). Although it was shown that the sugar content and sugar yield decreased and the total loss of beet material increased when the harvest date was delayed from 1 November to 20 November or 10 December, it was still more profitable to shorten the storage period. However, the later the harvest the higher the risk of frost, as became evident in 2010, when harvesting around 10 December was not possible due to frost.

Under wet conditions, the risk of damage to the soil structure by heavy harvesters and, in particular, transport machinery is higher. This can have negative consequences for the following crops. In line with national soil protection goals, soil compaction must be avoided (Tijink and Spoor, 2004; Horn and Fleige, 2009). Harvesting under good conditions provides a number of advantages, such as less damage to soil structure, less soil tare, lower beet losses, fewer beet injuries and subsequently less sugar losses during storage. In general, harvesting a week earlier under ideal conditions results in a higher profit than harvesting under poor conditions just before delivery. Table 5.1 shows the effect under Dutch conditions.

**Table 5.1**: Root yield, extra growth, extra losses, soil tare, tare penalty and financial profit when harvesting sugar beet under good conditions compared with harvesting one week later under poor conditions. (Source: Huijbregts, 2012a).

| Harvest time | Harvest conditions | Root yield (t/ha) | Sugar content (%) | Extra growth* (€/ha) | Extra beet losses* (€/ha) | Storage losses (€/ha) | Soil tare (%) | Tare penalty* (€/ha) | Financial profit* (€/ha) |
|---|---|---|---|---|---|---|---|---|---|
| November 8 | good | 75.0 | 17.3 | - | - | 18 | 5 | 51 | 2.992 |
| November 15 | poor | 75.6 | 17.4 | 49 | 30 | - | 15 | 173 | 2.906 |

* Calculations based on €35 per ton beet, tare penalty €12.70 per ton. Growth and sugar content calculated with SUMO and data from the 2006/2010 campaigns. Extra beet losses by intensive cleaning under poor conditions based on €30 per hectare according to Beet Europe 2010.

**Table 5.2**: Sugar losses and financial profit of sugar beet harvested under good and poor conditions. (Source: Huijbregts, 2012a).

| Harvest time | Harvest conditions | Financial profit delivery 15/11* (€/ha) | Sugar losses delivery 15/01** (t/ha) | Financial profit delivery 15/01*** (€/ha) |
|---|---|---|---|---|
| November 8 | good | 2.992 | 0.46 | 3.293 |
| November 15 | poor | 2.906 | 0.91 | 3.087 |

* See Table 5.1

** Calculated with sugar losses during storage of 100 and 200 g per day per ton beet (0.06 and 0.12 % sugar per day) with good and poor harvesting conditions, respectively.

*** Financial profit for delivery on 15 January, including deduction of € 6.77 per ton for late delivery.

If beet have to be stored, differences in financial profit between harvest under good conditions and harvest under poor conditions will increase due to the higher sugar losses during storage of damaged beet (Table 5.2). In general, weather and soil conditions get worse during the course of the beet campaign. On clay soils in particular, this means a higher amount of soil tare and more beet injuries and beet losses. To a smaller extent this also applies to sandy soils, but on sandy soils the harvest period depends more on the risk of frost.

## 5.3 Clamp shape

To prevent increasing storage temperature at relatively high ambient temperatures, it is important that the clamp is not too high. For an A-shape clamp of less than 10 metres width the height should not exceed 3 metres. The height of a domed clamp wider than 10 metres should not exceed 2 metres. The width of the clamp may be restricted by the type of cleaner loader in use. If polypropylene fleece is used to keep the beet dry, it is important that the slope of the clamp is sufficient to drain off the water. This is not a problem on an A-shape clamp, but for a square-based clamp the top should be domed, without pits. If the incline is sufficient, about one-third of rainfall runs through and the rest runs off. With only a few degrees of incline the opposite occurs, with at least 75% of rain permeating.


**Figure 5.1**: Equipment to make the sugar beet clamp domed and pit-free. (Photo: NBR).

**Figure 5.2**: Large storage clamps for sugar beet with large straw bales as walls. (Photos: NBR).

**Figure 5.3**: Pallets can be placed under large straw bales forming the walls of sugar beet clamps to promote ventilation. To prevent frost, smaller bales can be placed in front of the pallets. (Source: Olsson, 2010c).

Special equipment can be used to construct a clamp without pits (Figure 5.1). Flattening must be carried out with minimal damage to the beet (Olsson, 2010c). Storing sugar beet between bales of straw or walls of concrete with soil, has the advantage that the beet are already protected against frost (Figure 5.2). To prevent restricted ventilation, the height should not exceed 2 metres (Ebelin, 2000). Placing pallets under the bales of straw can improve the ventilation, but also increases the risk of frost damage. This can be avoided by placing small bales in front of the pallets when frost is expected (Figure 5.3).

## 5.4 Covering strategies

All covering strategies that keep the beet dry, cool and frost-free are good. To keep the beet dry, covering with a sheet that allows gas exchange but protects against precipitation is recommended. Several types of material have been tested (Günther, 1995; Westerdorff and Wollenweber, 1997; Huijbregts, 2008; Olsson, 2009a). Huijbregts (2008) compared different covering strategies. Incidental covering with plastic sheeting in frost periods was compared

**Figure 5.4**: Mechanical covering of a sugar beet clamp and securing of the fleece. (Photos: Nordzucker).

**Figure 5.5**: Straw directly put on the clamp (Storage trials in Northern Germany, photo: Nordzucker).

**Figure 5.6**: Blowing straw onto a net on a sugar beet clamp (Photo: NBR).

with permanent covering with polypropylene fleece (Toptex®) and with canvas with top ventilation (by a polypropylene fleece strip or netting at the top). With permanent covering, weight losses were higher. However, no significant difference was found in sugar losses, resulting in higher sugar content after storage using Toptex®. It should be noted that the storage period was only 5 to 6 weeks, with in all cases an accumulated thermal time of less than 300 degree days. In the Netherlands, an average weight loss of rather more than 1% per month has been reported using polypropylene fleece, with storage periods varying from one to almost four months (Huijbregts, 2008).

In general, geotextile (polypropylene fleece, for example Toptex® 110 g/m$^2$) is a good compromise between air ventilation and rainfall protection under North-West European weather conditions. However, the frost protection it provides is poor, especially under windy conditions. On A-shape clamps, the fleece can be put on and removed mechanically (Figure 5.4). Straw can also be used for insulation and can be placed on the clamp mechanically (Figure 5.5). Disadvantages are the reduction in insulation when the straw is wet and mixing with the beet in the surface layer. Both disadvantages may be overcome by placing the straw between two sheets (Figure 5.6).

If clamping occurs at relatively high ambient temperatures the beet should not be covered, in order to allow maximum ventilation and remove the heat produced by the beet (partly damaged during harvest and clamping). As soon as the temperature in the clamp falls below 8-10 °C, covering with a sheet permeable to air but not to water is recommended to protect the clamp against rainfall. Airtight sheets should be used if additional protection against frost is needed. During a frost period, the clamp may be completely covered with airtight sheets but these have to be (partially) removed as soon as the clamp temperature rises after a frost period. As a compromise, protection against frost may be provided by only using a partial additional covering of the clamp flanks with airtight sheets. Airtight sheets fitted with Velcro (trade name: Jupette®, see Figure 5.7) can be easily attached to polypropylene sheets (Legrand, 2012).

As varying degrees of frost are common in Sweden, the best clamp management has been a topic of investigation for many years. In practice, temperature control is strongly recommended and as the ambient temperature can vary greatly, the farmer has to be prepared to increase and decrease the ventilation accordingly. Straw is often an important material, in combination with fleece and/or plastics (Figure 5.8).

**Figure 5.7**: Fleece with a partial additional covering of airtight canvas fitted with Velcro (Jupette®) covering a sugar beet clamp. (Photo: Pype Agro Geotextiles).

**Figure 5.8**: Sugar beet clamp with the top covered with fleece and then a plastic sheet before straw is blown on. (Photos: NBR).

From long-term storage trials during 2006-2009, it was concluded that straw in combination with a plastic sheet gave distinctly better protection than straw in combination with Toptex®. However, securing the plastic in position was a problem. It was also concluded that in freezing temperatures with wind chill, a completely windproof cover was absolutely essential on the windward side of the clamp (Olsson, 2009a). In 2009 and 2010 a combination of plastic netting followed by straw and a plastic sheet was tested (Figure 5.9), and was found to function satisfactorily (Olsson, 2010a, 2010b). In investigations in 2012, Toptex® in combination with Jupette® (Figure 5.10) gave the best results, in comparison with 30-40 cm of straw, straw in combination with Toptex®, Toptex® alone and Toptex®, straw and plastic sheeting (NBR, unpublished results 2013).

In Northern Germany trials concerning the effect of eight different cover strategies on sugar losses during long-term storage were conducted from 2007 to 2012 (Figure 5.11). Temperature and wind speed were measured. The bags were removed after 60 days, and in a second

**Figure 5.9**: Sugar beet clamp covered with netting, followed by straw and then a plastic sheet held in place by pallets (bottom left) and bales of straw (bottom right). (Photos: NBR).

**Figure 5.10**: Sugar beet clamp covered with Toptex®, with Jupette® at the sides and a small ventilation strip with only Toptex® at the top. (Photos: NBR).

part of the clamp after 90 days. It could be shown that under optimal storage conditions losses are only about 80 g sugar per ton of beet per day, but can increase up to 600 g per ton per day under very warm conditions.

The uncovered beets (treatment 1 and 7) always showed the highest sugar losses (Figure 5.12). But under Northern German weather conditions also coverage with straw (in addition to Toptex®) resulted in high losses (treatment 3).

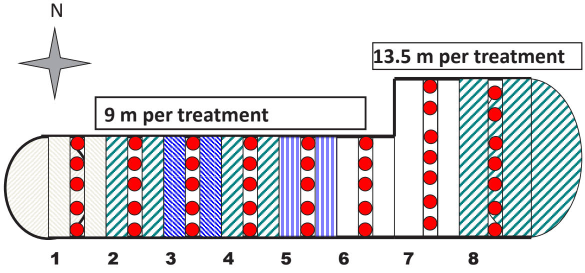



**Figure 5.11**: Sugar beet clamp testing 8 different cover strategies. (Source: Nordzucker).

Two major conclusions were drawn: as the thickness of the straw layer and changes due to wind cannot be exactly controlled, zones with too much and too low coverage occur. In most cases too much heat is kept in the clamp because of thick straw layers. On the other hand water is accumulated inside the clamp because of reduced ventilation. The high moisture content transports the frost temperature right into the clamp. In all these storage experiments it turned out that the coverage with fleece (Toptex®) seems to be the best cover strategy to prevent high sugar losses during long-term storage.

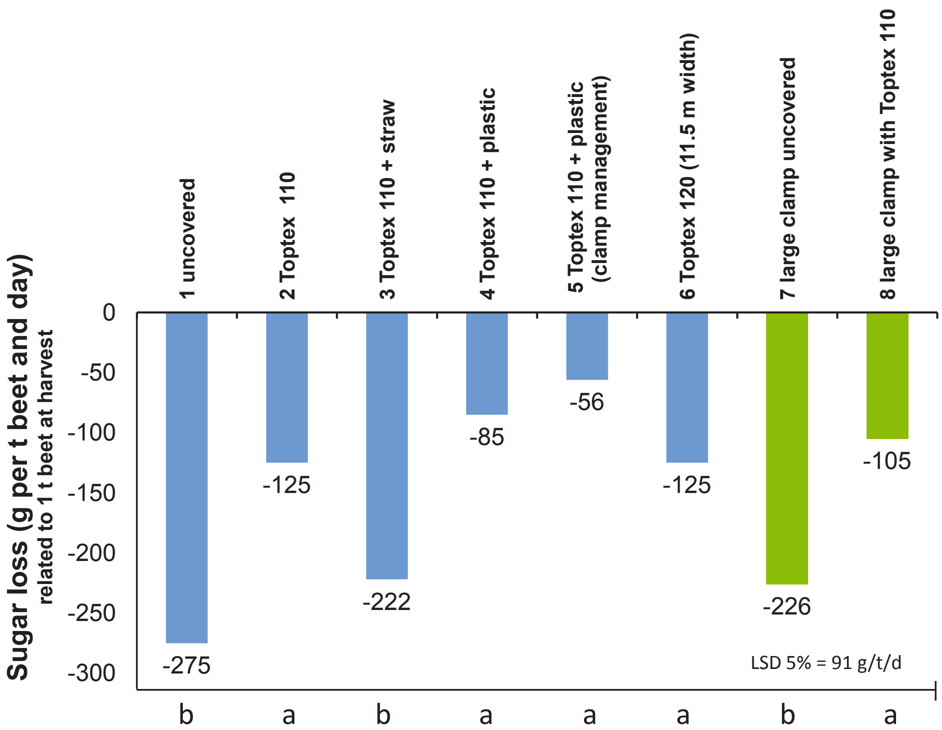



**Figure 5.12**: Impact of different cover strategies on sugar losses at long-term storage; end of storage period 18.02.2010. (Source: Nordzucker).

# 6. GUIDELINES FOR OPTIMAL LONG-TERM STORAGE

In most countries in North-West Europe, long-term storage of sugar beet started after the reform of the sugar market in 2006. However, even before the reform of the sugar market long-term storage was usual in England and for that reason practical guidelines for long-term storage had been developed in that country (Brown and Armstrong, 2002).To achieve optimal storage, measures have to be taken even before sowing and during the growing season, harvest and storage.

The guidelines presented below provide a starting point to minimising losses during long-term storage of sugar beet under North-West European conditions.

## 6.1 Pre-harvest

- Prepare a uniform seed bed to achieve a uniform plant population
- Sow a variety with good storability properties (if data are available)
- Use appropriate measures to prevent traffic-induced soil compaction (fangy beet), drought, nutrient deficiency and pests and diseases, in order to enable the sugar beet to grow without stress and to get healthy sugar beet at harvest.

## 6.2 During harvest

- Harvest under good conditions
- Harvest before beet are damaged by frost
- Remove all leaf material and avoid overtopping
- Clean the beet with minimal damage

## 6.3 During storage

- Store the beet on a site that can be reached by lorries and loading equipment under all conditions
- Use a dry flat base with good drainage of water
- Minimise beet damage during unloading
- Construct the clamp preferably in an A-shape, in such a way that covering material can be easily applied and fixed in place
- Restrict the height of the clamp to about 3 metres for A-shape clamps and 2 metres for domed clamps to get sufficient ventilation and to prevent additional damage when piling the beet up
- Cover the clamp with fleece about one week after harvesting (when the heat production has decreased) in order to protect it against precipitation
- Protect the beet in time against frost with additional (windproof) material
- Prevent a rise in temperature in the clamp by supplying sufficient ventilation at ambient temperatures above 0 °C
- Monitor the clamp temperature and adjust the covering system if necessary to keep the beet frost free, cool and dry.

See Figures 6.1 and 6.2 for examples of covering strategies.

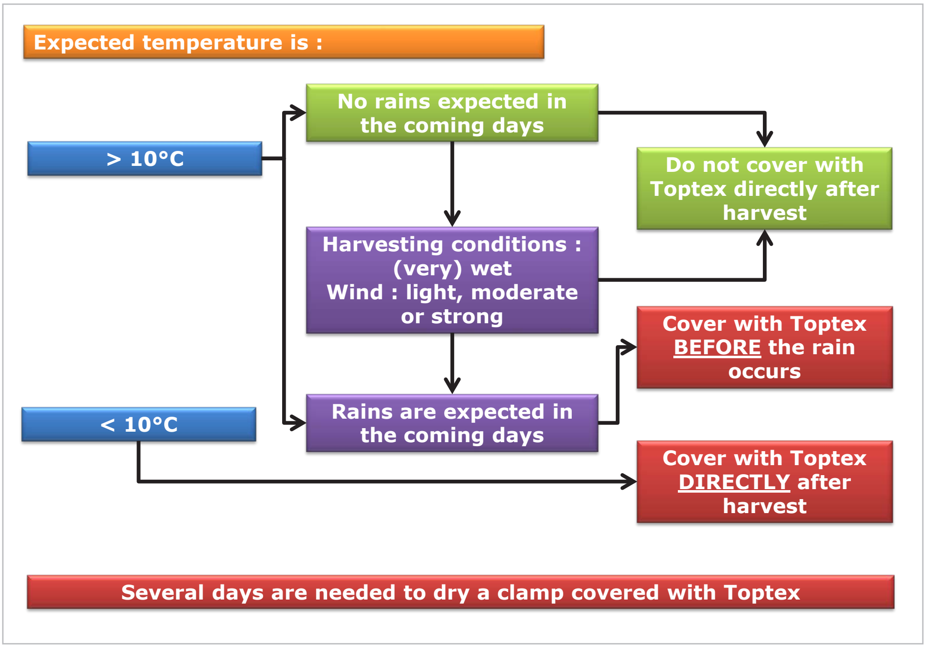



**Figure 6.1**: Covering strategy for sugar beet clamps at ambient temperature above 0 °C. (Source: Legrand, 2012).

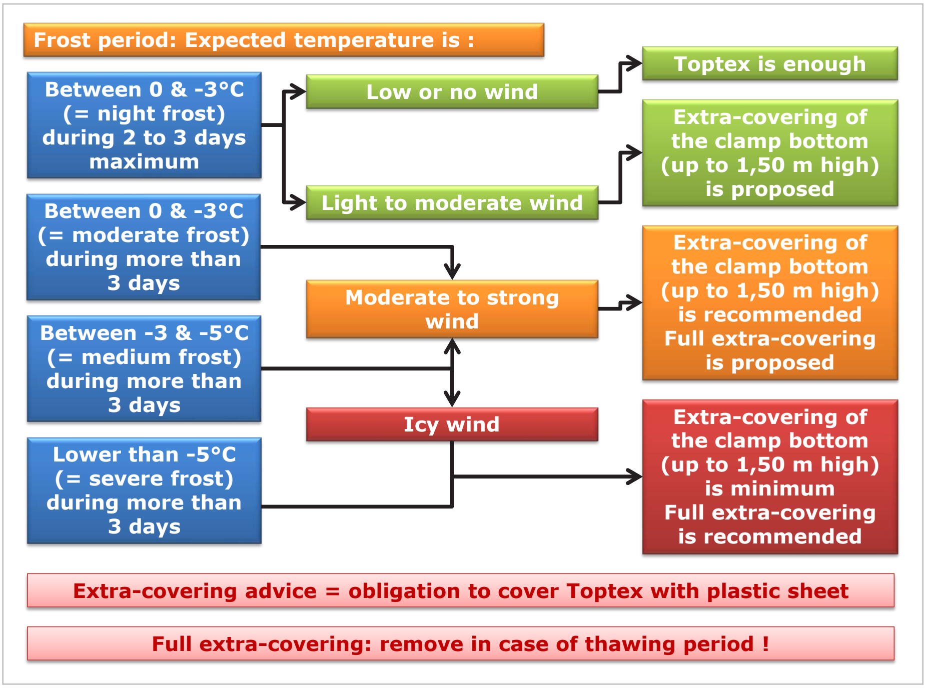



**Figure 6.2**: Covering strategy for sugar beet clamps at ambient temperatures below 0 °C. (Source: Legrand, 2012).

If temperatures are below -6 °C for at least three hours over at least two days, covering with fleece and windproof material over the fleece is insufficient. Additional insulation can be provided by placing insulating material, such as straw, between the two layers. Table 6.1 provides a summary of the properties of covering systems to keep clamped beet frost-free, cool and dry.

**Table 6.1**: Properties of some covering systems for sugar beet clamps to keep the beet frost-free, cool and dry. (Source: Huijbregts, 2012b).

| Material | Frost protection | Ventilation | Precipitation protection | Handiness at windy conditions | Remarks |
|---|---|---|---|---|---|
| Not covered | – – | ++ | – – | | only above 0°C |
| Plastic | 0 | – – | ++ | – – | at frost, thickness at least 0.2 mm |
| Fleece | – | + | 0/+[1] | + | for example Toptex 110 g/m$^2$; cover 1-2 weeks after clamping |
| CSV COVAS canvas | 0 | + | + | + | top 3 m netting for ventilation; covering before frost |
| Fleece + CSV COVAS canvas | + | 0 | ++ | + | fleece 1-2 weeks after clamping + canvas before 1st frost period |
| Fleece + blister padding | + | 0 | 0/+[1] | 0 | blister padding at the side under fleece |
| Fleece + canvas (with Velcro) | + | + | 0/+[1] | + | canvas on fleece; covering before frost |

++ = very good; + = good; 0 = moderate; – = bad; – – = very bad
[1] good for A-shape clamp

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## IMPRINT

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In the countries of Western Europe, sugar factory operations have been extended to mid-January and therefore sugar beet have to be stored for about two months. This report presents a review of current knowledge and research into methods to lower sugar losses and optimise the conditions for long-term storage.