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Storage of fruits, vegetables and potatoes - a Nordic/Baltic Workshop

Quality Hotell Strand, Gjøvik, 3.-4. April 2013

Editors: Arne Hermansen & Eldrid Lein Molteberg

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Preface

Bioforsk has the pleasure to welcome you to the Nordic Baltic workshop on "Storage of fruits, potatoes and vegetables" at Gjøvik 3.-4. April 2013. This workshop is mainly directed towards advisors, including the industry involved in these commodities, and scientist from the Nordic Baltic countries. In total we are about 50 participants from the Nordic countries, the Netherlands, UK, Italy and Slovenia.

A major part of the Norwegian production of fruits, potatoes and vegetables is stored. The annual post-harvest loss is worth roughly 1 billion NOK. This represents enormous values for society. Limiting factors for optimal quality of these commodities are usually diseases and loss of texture and weight. They may also lose flavour and nutritional value. Quality after storage is greatly influenced by the choice and stability of the storage conditions, while many of the problems originate during the growing season.

This workshop is an activity in Bioforsk project "Improved quality of Norwegian fruits, potatoes and vegetables after long- and short-term storage" (2010-2014) (www.bioforsk.no/postharvest). The project partners are Bioforsk, Nofima and UMB, with the industry partners Gartnerhallen, BamaGruppen, Findus Norge, FellesJuice, HOFF, Graminor, NordGrønt, Norgesgrønt, Maarud and KiMs. The project is financed by Research Levy on Agricultural Products/the Agricultural Agreement Research Fund (FFL/JA) together with the industry partners.

The workshop will include presentations from this project, as well as input from invited European experts. The topics covered are storage physiology, postharvest pathology and storage techniques, primarily within the model commodities carrots, apples and potatoes as well as minimally processed vegetables

We wish to thank our workshop sponsor Research Council of Norway (NFR). In addition, we are also thankful to the other financial contributors to the Bioforsk project mentioned above.

We hope this workshop will be an interesting meeting point for scientists and advisors to exchange results and experiences and discuss further challenges regarding post-harvest issues.

Arne Hermansen & Eldrid Lein Molteberg

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Progress in physiology and techniques for storage and packaging of vegetables

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This presentation will introduce first the latest observations made on the field of fresh-cut leafy vegetables. Secondly new long storage technique for white cabbage will be introduced. Finally some word will be spent to present the new cooling software ‘Quest II’ applied for reefer transport.
Fresh cut-leafy vegetables are produces available all the year around in the supermarket. To be able to answer the purchase’s demand, the processing company needs to collect raw material from different locations. Through the season, the process company tunes its processing parameters in order to reach the minimum shelf life period of 7-8 days. According to the season and the product origin, the behaviour of the fresh-cut lettuce to storage conditions changes substantially.
During the autumn 2012, the quality decays of Dutch fresh-cut iceberg lettuce were investigated every week for a period of 5 weeks. This period, also called transition period, is critical for the process company. On the basis of the quality behaviour of the lettuce, the processing company will move forward or postpone the transition period. Huge stakes result from the timing of this decision as extra cost due to transport and quality problems are directly linked to th9is period.

- The overall quality is one of the most important quality criteria during the purchase act. Consumers judge the freshness of the fresh-cut lettuce through colour and shape. The main discolorations observed are pink due to oxidation of phenolic compounds and brown due to fermentation and senescence’s processes. The rate of brown discoloration is also depending of the season.
- Pink discoloration is one of the most important quality criteria. The sensibility to pink discoloration of fresh-cut iceberg lettuce was determined under control atmosphere storage. The intensity and the appearance rate are correlated to the harvesting week. Later to the end of the season is the Dutch crop harvested, more sensible is the tissue to oxidation. The sensibility to pink discoloration was not visible when fresh-cut iceberg lettuce is packed under optimal MAP conditions.
- One week of storage between harvesting and processing harms the quality of processed produces. When the whole crop is first stored at 2°C for one week, the fresh-cut iceberg lettuce is judged less attractive on production day. The quality decays follows afterwards the same “curve” than one observed for lettuce processed directly after harvest.

A new Dynamic Control System (DCS) has been optimised for the long storage of white cabbage. Temperature pull down is controlled, the CA condition are applied when the cabbage is at steady stage temperature. Then the minimum oxygen concentration is adjusted by controlling the ethanol concentration within the storage facilities. Thanks to this new storage control, fungi development is gotten under control, firmness and colour preservation are also better when storage with DCS. The energy consumption of storage under DCS is lower than ones under ULO.
Additionally to the storage of fresh produces, a good control over the transport condition is essential. New software called Quest 2 has been developed for reefer transport. This software is based on better control of temperature fluctuation. The technology rests on cooling demand required by the product in one side and the cooling capacity on the other side. Thanks to this new cooling control, the pulldown period is significantly reduced, the possible dehydration of the produce is minimized and a significant reduction of energy is reached.

Post-harvest physiology and innovative storage techniques for apple fruits

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The demand for improved quality and safety of apple fruit after storage has led to innovative handling methods that produce different effects, depending on the framework of conditions set. The most important variables that determine the success of fruit storage are many, and they interact in a complex network of relationships: i) The quality of fruit production, i.e. a well balanced and fully developed fruit ii) The maturity stage of the climacteric fruit, that has the ability to ripen even after having been separated from the mother-plant, but that could only age in the case of being picked too mature iii) The appropriate use of low temperature in the first adaptation phase of the fruit aiming to avoid disorders caused by chilling stress iv) The skillful use of the lowest temperature tolerated by the fruit allowing to slow down the quality-consuming metabolic activity that keeps the fruit alive, in order to loose as less as possible of the eating quality v) The appropriate setting of the optimal humidity and air circulation, avoiding at the same time too high water loss caused by too 'dry air' but avoiding also physiological disorders such as flesh browning derived by the impaired gas diffusion of the fruit in presence of high water saturation of the air vi) Controlling the atmosphere composition regarding the O_2, CO_2 content is a step that allows to reduce the metabolic activity further vii) Controlled atmosphere moreover a) influences the action of the ripening hormone ethylene, which could additionally be scrubbed away from the atmosphere, b) reduces oxidative processes during storage vii) Influencing directly the action and production of the ripening hormone in the fruit was a vision, that become true by the use of 1-methylcyclopropene/SmartFresh℠.

Furthermore, in the future non-destructive technology and chemometry could provide us information on the storage potential as a decision supporting tool for storage handling and marketing strategies. In the effort to deliver appealing and healthy fruits for a long period after harvest, even the most innovative storage technologies require appropriate handling in the respect of the complex network of variables that are acting during the post-harvest chain on the way to the consumer.

Storage physiology and storage techniques for potatoes

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Approximately 6 million tonnes of potatoes are produced each year in Great Britain, with 3.5 - 4.0 million tonnes of this being stored. Storage occurs in purpose built stores, as well as converted buildings. Utilisation is split approximately equally between processing and fresh (pre-pack) market outlets.

Bulk and box storage formats are used. Supply to the fresh market is pretty much exclusively from box storage, where ease of segregation and traceability are the main drivers. For the processing sector both bulk and box storage systems are used. Long-term storage for processing often is still carried out in boxes, for the avoidance of pressure bruising. Virtually all box stores in GB are of the 'overhead throw' (space-cooling) type with non-positive ventilation.

Treatment of stores with sprout suppressant growth regulators is common for the fresh (pre-pack) market, using storage temperatures of 2 - 4°C, and very common in the processing sector where storage temperatures typically are 6 - 12°C. Chlorpropham (CIPC) remains the most important sprout suppressant in both sectors however, additional restrictions on its use in certain store types ('overhead throw') may occur in the future.

In the fresh (pre-pack) sector ethylene has been used succesfully as a sprout suppressant since 2004, sometimes in combination with CIPC. Ethylene is not used in the processing sector, because of effects on reducing sugar content but this is the subject of on-going research.

Spearmint oil (Biox-M), applied as a hot-fog, received a full registration for sprout suppression in 2012 and is being used in a small number of fresh (pre-pack) stores. Cost currently precludes its use for processing.

Current areas of research include:

- Improving use of CIPC
- Alternative sprout suppressants
- Factors involved in senescent sweetening in processing crops
- Factors influencing Blackheart defect
- Selection of varieties for processing

Studies on maturity levels, ventilation strategies and storage pathogens related to potato storage in Norway

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Maturity levels of plants and tubers

The relationship between maturity factors of the potato plants and the quality of the potatoes during storage was studied in the two growing seasons 2010 and 2012.

Maturity can be defined as physiological, physical and chemical maturity. The aim of this study is to find the optimal maturity at harvest in order to achieve the best storage result.

Different maturity levels were obtained by fertilizing with different levels of nitrogen and planting at different dates. Typical maturity indicators (dry matter content, skin set, vine senescence and sugar levels) were measured at the end of the growing season on potatoes with three different maturity levels at harvest. We found that dry matter reach a maximum level at the time of harvest, while skin set and vine maturity increased until the date of vine killing.

When combining the maturity levels at the end of the 2010 season with the quality of the potatoes during storage, none of the maturity indicators were able to predict storage quality. The potatoes from 2012 are still in storage.

Effect of ventilation strategies

Two different ventilation strategies were studied: The “Findus strategy” with low air volumes per hour and the “Agrovent strategy” with intervals of high air volumes per hour.

We used the potato material with three different maturity levels (described above) and the quality was analyzed three times during storage. In 2010-2011 different ventilation strategies did not significantly affect potato quality after small-scale storage (8 kg). There were significant differences in quality between potatoes with different maturity levels, and the more mature potatoes gave the best quality potatoes during and after storage.

Storage pathogens

After the growing seasons 2010, 2011 and 2012, potato samples from the most important potato growing areas in Norway were collected. The aim was to investigate the presence of various species of the storage pathogens *Fusarium* and *Boeremia* in Norway. We found 7 species of *Fusarium* and one species of *Boeremia*. This information will later be related to collected information about the area where the potatoes were sampled, the potato variety, crop rotation and other information about the samples.

Effect of foliar fertilization of calcium and nitrogen in cell division period on fruit quality, ripening and storability of apple

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Trees of cv. Discovery and cv. Aroma were treated with calcium or nitrogen or both in two doses in cell division period in 2012 season. Apples were assessed prior to harvest for fruit growth and ripening, and for fruit quality parameters at harvest and during the storage period. Development of physiological and fungal decay was assessed both during cold storage and after simulated shelf life. Ripening was assessed nondestructively by a portable spectrometer giving an I_{AD} index (index of the absorption difference between 670 and 720nm giving chlorophyll activity). Mineral content was analyzed two weeks after last spraying and at harvest. In cv. Aroma the content of nitrogen was higher in fruits sprayed with additional nitrogen. No other significant differences in mineral contents early in season or at harvest were found.
Growth of the apples measured as increase in diameter per week and development in I_{AD} index was not affected by the nitrogen and calcium treatments in cell division period.
Fruit quality at harvest and during storage period indicated that apples from unsprayed trees were riper than apples from sprayed trees, especially those that got full dose of nitrogen or the combination of both full dose of nitrogen and calcium. Analyses of the aroma compounds indicated also delayed maturity in apples high in nitrogen and calcium. Esters known to be important to fruity ripe apple flavor tended to be higher in fruit from control trees, while compounds related to “green unripe apples” were lower in these apples.
Apples from the north side of the trees were less ripe than from the south side in mean of all treatments and within most of the treatments. I_{AD} index both before harvest, at harvest and during storage period differed even though it was aimed to pick as similar apples as possible.
Amount of physiological and fungal decay after storage was low and no differences between the treatments were found during storage period and shelf life, until mid December for cv. Discovery and mid January for cv. Aroma.
In a separate experiment cv. Aroma apples were sorted at harvest by I_{AD} index (DA-value) into three groups; below 0.65, between 0.66 and 0.80 and above 0.81. High index indicates unripe apples. The index will decrease as the apples ripen. Apples of all groups were assessed for quality parameters at harvest and after storage in CA-bags (2% O_2 and 6% CO_2) for three, four or five months at 2 °C and after simulated shelf life up to 14 days at 20 °C each time. At the same times the apples were assessed for physiological and fungal decay. The apples stored in controlled atmosphere were compared to apples stored in natural atmosphere at 1 and 3 °C.
The ripest apples developed earlier and more physiological decay. Differences in I_{AD} index could be found during the whole storage period. Measurement of I_{AD} index might be a useful tool to determine optimal harvest time for apples with good storability.

Effects of cultivar and pre-harvest factors on storability of carrots

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Storage diseases, mainly caused by pathogenic fungi, pose a great risk for post-harvest losses in carrots. The most important post-harvest diseases are liquorice rot caused by *Mycocentrospora acerina* and crater rot caused by *Fibularhizoctonia carotae*. Antifungal substances may play an important role in limiting such infection and in carrot roots these consist mainly of polyacetylenes and polyphenols. Previous studies have found that 6-methoxy-mellein and falcarindiol are amongst the most important antifungal substances in carrot (Davis & Lewis 1981). The polyacetylene falcarindiol is highly related to bitterness and primarily present in the peel, in contrast to the less bitter falcarinol that is present in the whole root. These compounds may vary with cultivars of carrot and also be influenced by preharvest conditions. The main focus in this work package is on effect of cultivars and pre-harvest properties, mainly maturity (developmental stage) and disease pressure, on storability of carrots.

In 2010 10 selected carrot cultivars were grown in a randomized block experiment inoculated with *M. acerina* and *F. carotae*. Disease pressure during the growing season and at harvest was assessed. After harvest the carrots were stored under normal controlled conditions at 0-1 °C for approximately 6 months. There were differences in the storability of the different cultivars. The cultivars Atomic red and Rothild were more severely attacked by *M. acerina* during storage compared to the other cultivars. Nelson had the lowest infection rate, significantly lower than Nantes, Natalja, Nominator, and Namdal but not significantly lower than Triton and Cosmic purple. There were no significant differences between cultivars regarding the content of falcarinol, whereas for falcarindiol and 6-methoxy-mellein we found significant differences between cultivars. Nelson had a significant lower content of 6-methoxy-mellein than Atomic red and of falcarindiol than Nantes, Nominator, Namdal, Rothild and Cosmic purple.

In 2011 and 2012 the cultivars Nelson and Nantes were sown at three different dates in a randomized block experiment. The plots were inoculated with *M. acerina* and *F. carotae*, and harvested at the same date in the autumn in order to obtain different maturity levels. There were significant differences in yield, healthy roots and the presence of *M. acerina* and *F.carotae* between the different maturity levels. There were no significant effects of contamination of *M. acerina* and *F. carotae* in the field on the content of polyacetylenes and sugar in the cultivar Nantes at harvest. There were no significant differences in total poyacetylen and total sugar between the most mature and the least mature roots. In 2011 the content of Sucrose was significantly higher, and Fructose and Glucose significantly lower for the roots with the longest growing time. The youngest roots contained significantly more falcarindiol compared to the oldest, whereas the opposite was observed for falcarindiol-3-acetat.

Reference

Davis, W.P. & Lewis, B.G. 1981. Antifungal activity in carrot roots in relation to storage infection by *Mycocentrospora acerina* (Hartig) Deighton. New Phytologist 88:109-119.

Sensory quality of cut root vegetables after packaging and storage under different conditions

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The following presentation summarises the first experiments from a Phd-project focusing on how to use root vegetables as a fresh-cut product. It will give an overview of the work that has been done until now, and further directions.

By using root vegetables in fresh-cut convenience products, these vegetables can be more accessible to the consumers. Rutabaga (*Brassica napus* ssp. *Rapifera*) and turnip (*Brassica rapa* ssp. *Rapa*) were chosen, and changes in sensory attributes during short-time storage were studied.

A pre-experiment using different combination of perforated films, product weight and temperature was done, where the aim was to create a diverse range of atmosphere developments at 5 and 10 ˚C. The concentrations of O_2 and CO_2 were measured during storage, and three atmosphere developments at 5 and 10 ˚C were used in the main experiment. The end O_2 levels chosen for rutabaga ranged from 14 to 1% O_2. For turnip the end % of O_2 ranged from 16 to 8 %.

The aim of the main experiment was to study the effects of storage time, temperature and passive modified atmosphere packaging (MAP) on sensory attributes. Rutabaga and turnip were peeled, cut into dices and washed. Chosen packaging combinations from the pre-experiment were used, and then stored for 5 and 10 days at 5 and 10 ˚C.

Sensory analysis was carried out during a two day session, and a reference sample, peeled, cut and washed the same day, was analysed together with stored samples.

In a following experiment, active MAP was included. To compare active MAP and passive MAP, the same packaging combinations were used, while for active MAP, the initial atmosphere inside the packages was set to 5% O_2. Sensory analyses were performed as described above. In addition, selected samples were heated before sensory analysis, to study the effect of storage conditions on fresh-cut root vegetables that are cooked.

Some attributes showed reduce intensity, like sour and green flavour and odour, and some attributes increased their intensity during storage, like sickeningly sweet taste and odour. These effects were mainly related to storage time and temperature. The appearance of rutabaga and turnip changed during storage. These changes were also related to time and temperature, but some effects of modified atmosphere were observed.

Changes in sensory attributes seen in these experiments can reflect possible changes during commercial distribution and storage of fresh-cut convenience products containing rutabaga and turnip. Future work can focus on to better understand these changes, and how to minimize them during storage.

Analyses of aroma compounds in fruits and vegetables

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Nowadays various GC/MS based head space techniques are in use. Of the methods applied, solid phase micro extraction (SPME) draw particular attention due to easy sample preparation. Having in mind preparation of fruits and vegetables for the analysis of aroma compounds, plant tissue is stabilized with the addition of salts like $CaCl_2$ or NaCl in order to inhibit enzyme activity that may alter aroma compounds. The current trend is to develop more gentle sample preparation that can be automatized for example automatized head space traps in dynamic air stream.

Here we are presenting the results of aroma compounds in apples as influenced by preharvest Ca application, postharvest application of 1-methylcyclopropen (1-MCP) and results of the aroma compounds in William pears as influenced by harvest date and storage conditions.

In our experiment, preharvest Ca applications had some minor effect on aroma compounds. Considering three varieties (Elstar, Discovery, Aroma) together, Ca treated apples had higher ratio (expressed as % of total aroma compounds) of hexanal, buthylacetate, 2-methylbuthylacetate, 6-methyl-5-hepten-2-one, hexyl acetate, hexyl propanoate, buthyl hexanoate and hexyl hexanoate. The same varieties contained lower ratio of ethyl acetate, ethyl butanoate, 2-hexenal, buthylpropanaote and buthyl propanoate. Significantly higher ratio of hexyl acetate was found in Elstar apples treated with Ca and significantly less buthylbutanoate was found in Discovery apples with preharvest Ca application.

Aroma compounds were determined in pears cv. Williams harvested at commercial picking date or 7 days before. Majority of compounds were found in lower concentration in fruits stored at –1°C or under ULO conditions. Interestingly no higher concentrations of anaerobic metabolites were found under ULO conditions neither at –1°C. More alpha farnesene was found immediately after storage as compared to shelf life. Methyl (2E,4Z9-deca-2,4-dienoate and ethyl (2E,4Z9-deca-2,4-dienoate are considered the most characteristic pear aroma compounds. Both compounds were found at lower concentrations immediately after storage but their concentration increased during shelf life. Later harvested fruits contained slightly more above mentioned characteristic compounds while temperature and atmosphere had minor impact.

Idared, Jonagold and Golden Delicious apples were harvested at their commercial maturity stage and treated with 1 μL L-1 1-MCP in a commercial storage house and stored for 6 months. The ratio of volatile compounds differed in the control and 1-MCP-treated fruits; significantly lower concentrations were determind in 1-MCP-treated fruits, as compared to the controls. The ratio of compounds with a fruity character was lower in the 1-MCP-treated fruits. The ratios of aroma compounds in Idared do not differ as much as in the aromatic cultivars Jonagold and Golden Delicious. The ratios of hexyl acetate for control and 1-MCP treated fruits were similar in Idared but considerably higher in 1-MCP treated Jonagold and Golden Delicious apples. Hexyl acetate is an ester that gives a character that resembles green sour apple. 1-MCP-treated fruits thus have less fruity and greener characters due to increased ratio of hexyl acetate. 1-hexanol is also more abundant in 1-MCP-treated apples and resembles green sharp and earthy odour. Another compound that resembles green, waxy, fruity, apple, spicy and tropical is hexyl 2-methylbutanoate and was found in greater amounts in 1-MCP-treated Jonagold and Golden Delicious apples. The above mentioned ratios of some of these key compounds were responsible for the more green overall sensory impressions of the 1-MCP-treated apples.

Effects of storage on antioxidants in fruits and berries

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Fruits and berries are perishable products that undergo metabolism, both pre- and postharvest. The need for maintaining good quality in fresh products of fruits and berries during storage is of great importance, since they often are stored for shorter or longer periods. These products are highly dependent on the storage environment to keep good quality due to respiration and transpiration. The two most important factors influencing postharvest life of horticultural crops are temperature and atmosphere. Decreasing storage temperature influences on the rate of respiration, texture, aroma and flavour and will decrease ethylene production and response rate of the tissues to ethylene. The response nevertheless, will vary widely between species, cultivars and maturity stage. In addition to lowering temperature during storage, decreasing the O_2 level and increasing the CO_2 level has been known for a long time to reduce metabolism in a larger extent than regular cold storage. Important quality factors for many consumers are appearance, texture, flavour and nutritional aspects, in addition to good keepability. For nutritional quality, bioactive compounds are of great importance in addition to vitamins. The most important antioxidants in fruits and berries are considered to be polyphenols and vitamin C, the latter contributing to a larger extent to the antioxidant activity in fruits and berries.

A large amount of research has been performed on fruits and berries and the effect of storage conditions on quality, including health related compounds. In general, temperature in addition to the control of O_2 and CO_2 levels in various ways have been shown to be the most important factors keeping the quality throughout the storage period. Results from storage experiments at the Norwegian University of Life Sciences (UMB) at Aas are presented to illustrate this. Storing 'Summerred' apples for four months at 1 and 5 °C in normal and controlled atmosphere (1-1.5 % O_2 and CO_2), results showed that storage conditions had little influence on the content of phenolic compounds. However, slightly higher values of cyanidin 3-galactoside were found in apples stored at 1 °C regardless of atmosphere, whereas the combination of 1 °C and controlled atmosphere gave higher values of chlorogenic acid. The antioxidant activity of the apples was not influenced by any of the storage conditions. Storing 'Discovery' apples for three months at 2 °C in normal and controlled atmosphere (2 % O_2 and CO_2) showed various results on apple quality. Atmosphere had no effect on antioxidant activity, but higher vitamin C content was observed in apples stored in controlled atmosphere. In a recent experiment at UMB with the cultivar 'Discovery', apples were stored in normal atmosphere for four months at 1, 3 and 5 °C. Apples stored at 1 °C had significantly higher content of vitamin C than apples stored at 5 °C. No temperature effects were observed on antioxidant activity or total phenolics.

These results indicate that storage at lower temperature and controlled atmosphere is beneficial for the general and nutritional quality in fruits and berries.

The impact of pre- and postharvest factors on chemical composition and storage losses in carrots

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The chemical composition of carrots (*Daucus carota* L) at harvest and during storage is influenced by cultivar, type of tissues examined, environmental conditions within a geographical area (sunshine radiation, temperature variation, soil type, soil moisture content and soil micro flora), agronomic conditions (sowing date, fertilisation, irrigation, harvest date and maturity stage at harvest) and post-harvest storage conditions (temperature, time and storage technology). It has been shown that certain chemical compounds such as polyacetylenes, 6-methoxymellein and terpenes have biological activity and thus may have protective properties against fungus that develop on carrots during storage. Carrots from Northern Europe can be stored for up to 6 to 8 months at 0–1 °C and above 98 % relative humidity with less than 2 percentage loss in fresh weight and changes in visual quality provided that the incidence of pathogens is low. The focus of the presentation is on storage losses in carrots and relations to the possible protective properties of polyacetylenes, 6-methoxymellein and terpenes.

An overview of the post-harvest potato diseases Dry Rot and Gangrene

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Gangrene, caused by *Boeremia foveata* and dry rot caused by various *Fusarium* spp. are potato tuber rots which can lead to severe losses in the store, blanking and uneven emergence in the field. Increased use of machinery to harvest tubers has resulted in a rise in importance of such wound pathogens. Dry rot is one of the most important fungal storage rots affecting potato: reports from the 1990's showed that in SE England 70% of ware crops and 100% of seed stocks were affected by the disease, and that the disease itself was present on as many as 1% of tubers, representing potential losses of up to 35,000 tonnes of stored potatoes annually in the UK.

Dry rot in the UK, and in other cool climates, can be predominantly attributed to *Fusarium coeruleum* and to a lesser extent *Fusarium sulphureum*. Gangrene is mainly of importance in northern Europe and can be of sporadic occurrence in susceptible cultivars after late harvest in cold, wet seasons.

For both diseases, reducing damage during harvesting and subsequent handling is a key element of a control strategy. Little research has been carried out on these storage rot pathogens in recent years. The symptoms, causal pathogens and epidemiology of dry rot and gangrene will be reviewed and appropriate control measures including possibilities for disease risk assessment, chemical control, cultivar choice, handling and storage conditions will be considered.

Skin blemish diseases in potato storage

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Skin blemish diseases adversely affect tuber appearance and hence are not attractive to consumers. The resulting economic loss to producers has been a challenge to provide good control or risk management strategies. Three blemish diseases, black dot caused by *Colletotrichum coccodes*, silver scurf caused by *Helminthosporium solani* and skin spot caused by *Polyscytalum pustulans*, increase in significance during storage and are the major subjects of this talk.

Decisions made during storage for example, drying and curing regimes and storage temperatures can affect disease levels. However, optimal disease control is achieved when all the risk factors, from seed selection, cultural factors and through to storage are considered holistically. Disease in storage will be considered through this holistic approach.
Advances in diagnostic methods will also be considered where they could improve risk management. For example the quantification of pathogen DNA from tubers or soil can be used to predict disease levels in field or storage.

Potato storage ventilation - introduction

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This abstract contains a short introduction to the subject, and is followed by presentations of 2 different ventilation systems

Aim and goal
The aim with storing potatoes is to keep and protect the product in such a way, that most possible of its desired properties are maintained and can be refound when destoring the crop. The goal is getting- or being able to supply customers with potatoes, of planned and even quality, during the desired storage period.

Requirements
As many factors make influence on the potato crop in the store, it's important to possess a storage system, which is capable of regulating and controlling the climate in the storeroom, primarily by temperature. In some circumstances it is also profitable to be able to regulate and control the relative humidity. Furthermore, on some locations and for some tasks, it requires a ventilation system combined with a cooling system, to solve the task.

To be specific about the storage- & ventilation system, it needs to be able to supply climate that ensures the destored crop:

- Is free of storage infected- or developed diseases
- Has minimum weight loss and no visible shrinkage
- Has minimum sprouting
- Has maintained the frying quality and the taste

Storage of potatoes -
- is an active process, which can be divided in to sub processes. All of those has their own characteristics and sets its own requirement for the storeroom and the ventilation system. The sub processes are:

1. Taking the crop into the store
2. Skin drying
3. Wound healing
4. Lowering the temperature to storage temperature
5. Maintaining the storage temperature
6. Warming up the crop, prior to grading or prior to any other handling

The design of the storage building and the ventlation system must ensure that fulfilment of the storage processes is possible.

Storing - key points
Managing a potato store is individual, from store to store – and day to day. What the right thing to do is right now is depending of the situation in the store concerned; considering the crop temperature, store temperature and ambient temperature. The key points when managing the store are:

- In order to reduce storage infected or – developed diseases, the tubers must be skin dried fast, which means drying must be finished no later than 24 hours after harvesting
- During storage, avoid condensation on the tubers at any time
- After lowering the temperature, it must be stable during the storage period
- The relative humidity must be highest possible, at any time during the storage

Tolsma ventilation system

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Tolsma ventilations can be both forced ventilation, for example bulk or box systems that brings the air in at floor level, or a room ventilation system. We normally prefer a room ventilation system for potatoes as it has a reversed circulation principle that are much better for drying potatoes and to avoid condensation.

Air capacity is vital for both drying, cooling down and maintaining the temperature of the potatoes. But what is even more important is to have control of the relation between the situation outside the storage and inside the storage. This can only be achieved with a precise measuring and continuously calculation and comparing of situation of the inside and the outside.

More so it is in many cases not always suitable temperature and humidity circumstances to allow good ventilation for the potatoes. In short we need to in some extent be able to heat the air we are using and some time cool down the air.

A Tolsma ventilation system can be programmed and equipped to handle “all” type of needs for the potatoes, It is therefore important to understand and know the goal for your actual storage.

Storage losses what is that? This has to be recognised as the losses depend on what you plan to do with your potatoes. Is it weight? Is it quality issues? What is quality for your potatoes? If we know this we can control it.

What is suitable humidity? 94%? 98%? We do not find it positive to keep an as high humidity as possible in the storage. As that normal causes many other problems that causes storage losses. We normally do not use humidifiers for potatoes. Instead we control the use of external air by using high air capacity in as few hours per day as possible and by restricting the drying out effect of the air used.

Refreshing and the CO_2 levels must be handled differently depending on the desired level in respect to the local climate circumstances. We handle this either with time interval or if needed with measuring of the CO_2 level.

The cycle of a ventilation year in our opinion is a bit different; Drying and maintaining the temperature of the potatoes 2-3 week. (In very rare occasion wound healing) after that fast cooling down to target the temperature, maintaining a stabile temperature, and if needed warming up before delivery.

Can a ventilations system cure deceases? No not really, but a modern system with a controlled high air capacity can dry up and isolate rotten and wet potatoes. (Depending on the amount)

Long time storage, September to August with maintained quality is that possible? Yes!

All these points and several more will be “ventilated” in our presentation of the Tolsma system. But as summery the key word is CONTROL.

Description of "Findusmetoden"

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This system of continuous ventilating potatoes with a low rate of humid air, resulted from a remarkable productive collaboration between mid-west American and Scandinavian technologist during the early 1970s. (Hylmö *et al* 1975). In the first period the development took place at the Findus company, therefore the name "Findusmetoden".

After ending the first period Alf Johansson started his own company, developing the system further with refrigeration and automatic control. It became the leading system in both Norway and Sweden, under the name of Alf Johansson-system in potato storage. The system is used both in bulk- and box potato stores. In Norway the most common is box potato store. Alf Johansson has also developed the system for vegetable storage, and obtained impressive results in both rapid cooling before selling in the fresh marked and in long time storage.

Cooling air is introduced at floor level while outlets are located as high up as possible in the store. The cold air continually floods the store, rise up from the floor, displacing the more buoyant warm air coming from the crop as it rises. Warm moist air is lighter than dry cold air, and the direction of the air movement will always be up and through the pile or box, even if the fan stops for some reason. Ensuring that only colder air meets warmer potatoes, sufficient drying of the crop occurs simultaneously at all levels in the pile or box, to ensure tuber skins remain dry.

The rising air continually spills out through the high level exit louvre, or goes back to the blending chamber through the recirculation louvre. The system is automatic, based on three temperature sensors. One sensor is measuring the temperature of the cold air into the store. Another sensor measures the outside air temperature and works together with the one that is measuring the temperature in the coldest potato in the store. If the outside air is too cold, - more than a fixed degree below the coldest potato for ventilation, the system introduces a part of used air to obtain the right temperature.

In continuous ventilation, humidification of the ventilation air is essential to avoid dehydration of the crop. The most simple method of humidification is to use a evaporative humidifier, where air is forced trough a water-soaked porous cellulose matrix. The air will pick up as much water as it can absorb, but not more.

Continuous low-rate humidified air ventilation system uses a wet bulb sensor for controlling whether the air is suitable for cooling. This works on the premise that ventilation air will approach its wet-bulb temperature once it passes trough a humidifier, so even if air is actually warmer than the crop, it can still have a cooling effect.

When cool outside air is not available, refrigeration can be used. Since ventilation is continuous, cooling of only a fraction of a degree may be enough.

Electronic environmental control and monitoring systems are an essential parts of potato storage. Based on the Alf Johansson system there are at least three different systems available in Norway, from rather simple monitoring to fully automatic control with PC-logging and SMS-warning.

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