RECENT DEVELOPMENTS IN POTATO STORAGE IN EUROPE
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ABSTRACT: Recent development trends and perspectives are to find alternative methods and materials like breeding new varieties, finding biological sprout suppressants, or investing in innovative storage facilities and technologies to meet consumer demands, climatic changes, and regulations. Paper discusses applicability of controlled atmosphere or modified atmosphere storage to potatoes. Forced application of ethylene in sealed store-rooms has been proved to control dormancy. Ozone is used to suppress bacteria in order to reduce the risk of spreading diseases. The use of volatile oil as sprout suppressant is of high interest to small scale organic growers. Main advantages of bin boxes compared to bulk storage are high variability and transportability, gentle handling, and ability to smaller partitioning of varieties. The free convective ventilation of big bin box stores needs special strategies to obtain homogeneous temperature. Absorption refrigerator can be used as cooling system for potato stores. The heat may be provided by a biogas generator plant. Modern climate controllers can be equipped with modules to control CO2 and air humidity. They can be extended with algorithms for potato surface drying and anti-condensing control. Newer control systems have options for weather forecast and online control or monitoring via mobile telephone.

KEYWORDS: potato storage, modified atmosphere storage, biological sprout suppressants, absorption refrigeration, experiences from Europe

INTRODUCTION
UNESCO (United Nations Educational, Scientific and Cultural Organization) declared the potato as the food of the future during the ‘international year of the potato 2008’ and stated the increasing value of the potato as the 3rd most important world food crop. The 17th Triennial Conference of the EAPR (European Association for Potato Research) was held in 2008 with the theme and title “The Potato in a Changing World”. The theme reflects the trend for the potato to be confronted with global changes of climate, rural land use, consumer needs and behaviour, energy and food crises.

World potato production has increased over the past decade at an annual average rate of 4.5 % (FAOSTAT) (Fig. 1). Mainly in the developing countries like China and India, the demand and consumption for potato production is growing as an alternative commodity to the traditional food crops such as cereals (rice and maize) (Wang and Zhang, 2004). However, the consumption is decreasing in the developed countries, especially in Europe (EUROSTAT) (Table 1). In the period from 1991 to 2007, potato production in developing countries increased from approx. 85 to 165 million tons, while in developed countries production decreased from about 185 to 155 million tons during the same period (FAOSTAT) (Fig. 2). The production in Europe reached 128 million tons in 2007. Roughly, half the production is consumed fresh or processed to convenience food (Keijbets, 2008). In recent years, there has been an increasing trend to potato processing as convenience foods for ease of consumption. This approach has a direct consequence on the potato storage features, because the consumers and processing companies are demanding potato of equally high quality during the whole year.
Global climate changes during recent decades with tendency to warm autumn and winter seasons in Central Europe led to the effect that traditional storage technique can no longer secure sufficient cooling and storage to prolong dormancy of potato tubers. On the other hand, the values of merchandized potato to consumers and processors have increased in recent years. The potato has changed from a cheap ‘mass’ nourishment to a ‘premium’ value produce with a highly stable quality standard, deliverable during the whole year. Temporary inadequacies of local production or delivery capabilities are compensated by imported produce. Consumers of fresh potatoes in the western hemisphere are increasingly prepared to accept higher prices for good quality. Processors are demanding high, equal and well-defined quality of tubers for continuous processing to ‘convenience products’ or snack food. The trend is recognized to reduced consumption of fresh potatoes and increased consumption of processed potatoes like French fries, chips etc. This trend will increase diet problems. The result of this is that campaigns are being started, e.g. in the UK to increase consumption of fresh potatoes amongst young families and primary school children.

Newer developments in research, technology, knowledge, and information exchange capabilities are helping to meet the changes in climate and consumer demands. Breeding of new varieties has been carried out, which are able to keep dormancy for longer time, or are able to lower the production of reduced sugars at low temperatures. Alternative suppressants of microbial diseases and sprouting, such as aromatic plants or gases, are approved and more are under development and test. Research is being conducted into energy saving techniques for cooling stores. Highly reliable and precise sensors and regulators accompanied with information technology for safer storage and better knowledge are being increasingly applied. Newer storage technology and management methods are now being operated.

Modern climate controllers can be equipped with modules and sensors to control relative air humidity and CO₂. The control software has been extended with algorithms for potato surface drying and condensation control. Newer control systems have now also been extended with options for weather forecasting and online control or remote monitoring via mobile telephone and internet.

The trends in changing worldwide markets and exchange, consumer demands, climate and growth of population are well reflected in the recent developments in potato research.
The demands of consumers and processors are also changing. This tendency is bringing about new demands for the quality standards of fresh potatoes for direct consumption or processing. Quality control for producers and marketers are crucial to fulfil official or processing company quality standards (OECD - Organisation for Economic Co-operation and Development). Newer classification and reporting software packages for quality controllers are developed and distributed. An electronic image catalogue of defects in fruits, vegetables and table potatoes has added a significant body of new images to the marketing standards and facilitates the interpretation of the regulations. This contributes to a harmonized explanation of marketing standards; hence, it serves as a tool for producers, marketers, and controllers (Geyer et al., 2009).

In recent years an increasing, although now almost stabilized demand for processed potatoes as convenience food has been recorded and this mainly in the form of French fries (‘pommes frites’; ‘chips’). During the same period, there was a decrease in the demand for fresh table potatoes. On the other hand, there is now an increasing willingness among consumers to spend more for higher quality produce, such as fresh potatoes with the rank of ‘premium quality’ given by the producers. Furthermore the need to be able to offer ‘premium quality’ potatoes of the same quality to consumers and industries throughout the year against the background of changing social and climatic circumstances is resulting in improvements to potato storage technology and management.

Since the developing countries are becoming emergent producers and exporters, the European market has become a more and more attractive destination for these countries to export potato at higher prices. As an example, 4500 kilograms of potatoes are to be exported to Germany (D) at a price of 1.50 USD per kilogram, marking the ‘first instance of potato exports from China to Europe’, according to a news report of the Ningxia Daily newspaper (Potatoreporteronline, 2009). Relevant European enterprises and experts found that the potatoes grown in Guyuan (P. R. China) are of the same quality as those grown in Europe. As long as local production and global transport costs are comparably low, this trend will lead to a strong competition with the European producers.

**PROCESSED POTATOES**

Consumption behaviour has changed over the past few decades, due to changes in society and opinion. Moving away from its former position as a cheap source of basic nutrition in the form of a fresh product, the potato is increasingly becoming a processed product in forms like ‘convenience food’.

### Table 1. Potato production (kilo t) in EU (EUROSTAT).

<table>
<thead>
<tr>
<th>Location/Year</th>
<th>2000</th>
<th>2002</th>
<th>2004</th>
<th>2006</th>
<th>2008</th>
<th>2010</th>
</tr>
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<td>82818</td>
<td>71441</td>
<td>71013</td>
<td>56791</td>
<td>61869</td>
<td>-</td>
</tr>
<tr>
<td>Poland</td>
<td>24232</td>
<td>15524</td>
<td>13999</td>
<td>8982</td>
<td>10462</td>
<td>9824</td>
</tr>
<tr>
<td>Germany</td>
<td>13193</td>
<td>11114</td>
<td>13044</td>
<td>10031</td>
<td>11369</td>
<td>9504</td>
</tr>
<tr>
<td>France</td>
<td>6434</td>
<td>6877</td>
<td>7255</td>
<td>6363</td>
<td>6808</td>
<td>6328</td>
</tr>
<tr>
<td>Netherlands</td>
<td>8127</td>
<td>7363</td>
<td>7488</td>
<td>6240</td>
<td>6993</td>
<td>6600</td>
</tr>
<tr>
<td>UK</td>
<td>6585</td>
<td>6967</td>
<td>6317</td>
<td>5727</td>
<td>6145</td>
<td>5838</td>
</tr>
</tbody>
</table>
10% of the global potato crop production, about 30 million MT per year is converted into consumer products such as French fries and potato chips (Keijbets, 2008). There is an increase mainly in the EU and North America for potatoes to reach the table in many homes not as a fresh product, but in processed form. This remarkable trend is also seen in developing countries.

Potato processing is highly mechanized and sophisticated. It depends strongly on assured delivery of raw potato during the whole year with reliable and guaranteed high quality. This trend leads to consequences in storage facilities as well as management. The potato tubers should be fresh, healthy, without blemish or damage, clean when coming out of storage. During frying, the tubers should not form acrylamide due to Maillard reaction which also causes browning (fry colour) (Matthäus et al., 2004). This may be because of the enhanced content of reduced sugars, a likely result from cold storage (Burch et al., 2008). Also, the formation of glycoalkaloids in the tubers at lower temperatures is a problem to avoid (Sengül et al., 2002). New varieties are being developed which permit storage at lower temperatures (4 °C) producing lower reduced sugar (Putz, 1997), or at higher temperatures with prolonged dormancy.

ORGANIC FRESH COMMODITIES

There is now a growing market for organic fresh commodities, especially in the European Union, the U.S.A. and Japan. In these and other countries, the production of organic food is regulated to maintain high quality and safety. Future growth is expected to range from 10-50% annually depending on the country (Keijbets, 2008). Organically grown potatoes are becoming suitable also for processing (Haase et al., 2007).

Other organic crops represent powerful competition for organic potatoes. This forces the producers to find alternative methods and materials to fulfil consumer demands and regulations such as developing new varieties, finding biological sprout suppressants, or investing in innovative storage facilities and technologies.

CONTROLLED ATMOSPHERE STORAGE

The use of controlled atmosphere (CA) or modified atmosphere (MA) storage has been introduced and is widely established in fruit and vegetable storage to enhance storability. Different methods and storage equipments are under investigation and discussion for their efficiency, economy, and effectiveness.

The main active components of ventilated air in potato storerooms that affect the storability are oxygen (O₂), carbon dioxide (CO₂) and ethene (ethylene, C₂H₄). Potato tubers are biologically active and respiring, with the result that the concentration balance of gas components (including water vapour) in air varies significantly during the storage period. Under normal storage control, a frequent exchange of air during ventilation is necessary, e.g. 2-3 times for approximately 15 minutes. The installation of CO₂ sensors to maintain CO₂ control is still under discussion and not yet well accepted because of high investment and maintenance costs. In applying CA/MA techniques, a sealed storeroom is necessary to avoid uncontrolled air exchange. This requirement is not easy to maintain in practical terms. However, the method of CA/MA storage is under discussion for its applicability even for potato storage.

The potential applicability of CA/MA technique for potato storage has been tested at a relatively early stage in Switzerland (Reust et al., 1984). The trials were made with 5 varieties at atmosphere composed of 2 % O₂, 1-12 % CO₂, a temperature fixed between 8-10 °C and relative humidity (RH) of 85-90 %. After these
Recent developments in potato storage in Europe

first trials the investigations were continued with var. Bintje only at 2-15 % O₂ and CO₂ fixed at 6%. A mass loss of 1-3 % occurred due to dehydration and loss of 2-12 % due to decay during 120-178 days storage time. Also, high accumulation of saccharose (sucrose) took place.

A recent investigation on the potentiality of different gaseous combinations was carried out by Angós et al. (2008) to reduce respiratory rates and to minimize colour changes and textural characteristics of the raw material. A series of studies were carried out under various oxygen (O₂) and carbon dioxide (CO₂) mixtures in variable concentrations. An atmosphere rich in CO₂ and with high concentrations of O₂ enhances the quality of the minimally processed potato, given that these factors reduce the processes of respiration and loss of nutrients, and its tendency for changing of colour (browning).

The investigations showed that high O₂ and CO₂ combinations in modified atmospheres significantly lowered respiration rates in minimally processed potatoes stored at 4 °C compared with potatoes stored under low O₂ and low to high CO₂ modified atmospheres. The best results were achieved using gas combinations of 80/10 and 80/20 (kPa/kPa; N₂ balance).

Khanbari and Thompson (1996) investigated three crisping potato cultivars (Record, Saturna and Hermes) at 5 or 10 °C in gas mixtures of 0.5 % CO₂ and 21.0 % O₂ for control and 0.4-9.4 % CO₂ all combined with 3.6 % O₂. There was almost complete sprout inhibition, low weight loss and maintenance of a healthy skin for all cultivars stored in 9.4 % CO₂ with 3.6 % O₂ at 5 °C for 25 weeks.

HUMIDIFICATION OF STORAGE AIR

Loss of water from potato tubers during storage causes loss of quality and weight, which means loss of valuable mass. The water is evaporated from the tuber surface into the ventilated air. The loss is proportional to the vapour pressure deficit between the intercellular space and the ambient humid air, (Gottschalk and Ezekiel, 2006). Higher humidity reduces this deficit; hence keeping a high relative humidity close to 100 % is expected to reduce the total mass loss during storage. Experiments to validate this assumption already began in the 1970s, (Nash, 1975). The need for reducing mass loss and gaining high quality (freshness) has prompted the installation of humidifiers in modern stores.

The application of humidifiers is a possible means for obtaining and keeping high humidity above 90 % RH. The main problem in the application of humidifiers like water sprayers or evaporators is the risk of condensation if the humid air is in contact with the tuber surface at temperature below the dew point temperature. Tuber surface moisture provides a suitable environment for diseases like Erwinia (Pringle and Robinson, 1996). Recent practice, however, has been focussed on the testing of humidification systems for controlling mass loss (Dellman, 2004). Some humidifiers spray a mist under high pressure (4 bar) into the room. Newer sprayers on the base of ultra-sonoric nozzles do not need compressors to produce high water pressure resulting in lower energy costs (Dellman, 2004). The humidifiers are activated when the humidity of the storage air is below 88-92 %.

Earlier investigations showed that intermittent humidification had no significant effect on RH in the room and on shrinkage. Recirculation in an artificially cooled room resulted in higher RH of 95 % and decrease in shrinkage by about 3.7 % over 5-6 months of storage, (Nash, 1975).
SPROUT CONTROL WITH ETHENE

Ethene (synonym: ethylene; C\(_2\)H\(_4\); molecular structure: CH\(_2\)–CH\(_2\)) is a natural metabolic product from fruit and vegetables. This gas regulates growth and ripening and is a special type of hormone that controls ripeness. For example, ethene concentrations of 0.1 - 1.0 ppm in fruit tissue increase oxygen and carbon dioxide production. With increasing senescence of the fruits, the metabolism intensity reduces and the production of ethene drops along with it.

Forced application of ethene in sealed storerooms has been advised to control sprout growth of potato tubers (Briddon, 2006). A review of licenses is currently in progress in the EU to approve pesticides with active ingredients like ethene. In the UK, ethene has been granted ‘Commodity Substance Approval’ by the Pesticides Safety Directorate. The effectiveness of ethene in the storage atmosphere for potato is still under investigations, for example in GB and NL. The advantages of using ethene are: firstly, there is no or low residue left because of the gaseous nature, secondly, ethene is a ‘natural’ substance which is acceptable to consumers, esp. of organic produce. In addition, the technology has been announced by the manufacturer as being simple to use with low operating costs. However, careful control is needed. Investigations in NL on the effectiveness of sprout suppression capability revealed a dependence on varieties, but this method seems to be a good option in the future.

Daniels-Lake et al. (2007) stated that ethene is an effective sprout inhibitor but, there is a risk of browning or fry colour in the use of ethene. Continuous ethene application of 4 μl/l after suberization inhibited sprout growth as effectively as CIPC, but enhanced fry colour darkening more than other treatments.

DISEASE CONTROL WITH OZONE

Another gaseous substance under investigation is ozone (trioxygen; O\(_3\)) used for pest control. Growing plants were exposed to airflow mixed with ozone using an open-top chamber and its influence on tuber condition has been investigated (Piikki et al., 2003). The average ozone concentrations at 1 m above the ground were between 27 and 39 nmol/mol. It was found that ozone exposure promoted tuber maturity, but had no effect on ascorbic acid content, and correlated inversely to malic and citric acid concentrations. The use of ozone for cleaning potatoes and vegetable is under investigation because of its anti-bacterial effect as for example on Escherichia coli and Salmonella spp. (Hassenberg and Idler, 2005). Washing water for cleaning lettuce was purified before adding ozone. The ozone concentration ranged between 0.020 and 0.036 ppm at temperature of 4.5 °C. It was found important to wash the produce as clean as possible before processing it with ozonized water.

The application of ozone to potato tubers before storage is expected as a method to suppress bacteria and to reduce the risk of spreading diseases. Results from investigations on the application of ozone as a pesticide (against Erwinia) carried out in NL seem positive. Dellman (2007) stated that ozone is an acceptable alternative to chlorine because it is unstable and decomposes rapidly to form oxygen. It is 350 times stronger and faster, while approximately 1/3,000 times shorter lived than chlorine. The gas is applied directly on the tubers that are transported on conveyors inside a tunnel before they are delivered to the store. The effectiveness is still being tested in NL in combination with ultraviolet (UV) light and water spray to obtain high air humidity that gives better results. It was proven that a combination of treatment with ozone, ultraviolet (UV) light and high
RH gives an effect to eliminate up to 99.5% of Erwinia bacteria. The investment cost of the ozone generator and tunnel amounts to approx. 60,000 €, (Dellman, 2007).

**NATURAL SPROUT INHIBITORS**

The most commonly used and approved sprout suppressants in the EU are isopropyl N-phenylcarbamate (IPC) and isopropyl N-(3-chlorophenyl) carbamate (CIPC). Although, chemicals based on these substances are approved for treatment of potatoes (NRA, 1997), IPC-CIPC (propham-chlorpropham) are recognized as harmful and toxic and there is limited evidence of a carcinogenic effect (ESIS, 2009). IPC-CIPC residues are limited in Germany to 10 mg/kg. Maleic hydrazide (MH) is prohibited in the EU. It is another substance with wide use mainly in U.S.A.

Besides the use of the traditional and certified CIPC based chemical sprout suppressant, volatile oil from aromatic plants has become of great interest as an alternative sprout suppressant, especially for organic small-scale growers. The use of CIPC based sprout suppressors is not allowed for organic and private (small-scale) growers in the EU.

A number of substances based on peppermint, spearmint, origanum, lavendula, and caraway oil are available. Oils extracted from all these plants have positive effects on sprout suppression and inhibit certain fungi and micro-organisms, (Gottschalk and Ezekiel, 2006). Application of crude extracts instead of oil had similar effects.

The monoterpenes S-(+)-carvone extracted from caraway consisting of 50-60% carvone has been found to be the most effective ethereal oil. Carvone having a concentration of 7.15 mmol·mol\(^{-1}\) was effective in suppressing sprout growth temporarily. Furthermore, carvone does not affect the colour of fried potatoes. It evaporates quickly; hence repeated application is necessary. Kalt *et al.* (1999) observed maximum sprout suppression with CIPC, followed by carvone, ethene and dimethylnaphtalene (DMN). Carvone is also effective as an insect repellent. In the EU, the market has therefore grown in recent years for approved natural sprout inhibitors and suppressants of certain fungi and micro-organism.

**ACRYLAMIDE**

Acrylamide is formed in food containing carbohydrates, amino acids and moisture content exposed at high temperature (>100 °C), *e.g.* during deep-frying. It is soluble in water, ethanol and ether. The forming process is accompanied by the Maillard-reaction (browning), (Pedreschi, 2007). Its role as a potentially toxic and carcinogenic substance probably found in higher concentrations in processed food such as French fries and chips *etc.* became public in 2002 (Swedish National Food Administration, NFA) (Tareke *et al.*, 2002). It is therefore assigned as carcinogenic by the International Agency for Research on Cancer (IARC, Group 2A, 1994). A concentration limit in food could not be defined yet, but it is assumed that lowest concentrations may represent health risks. Assumptions are made that daily intake for humans should be limited to 0.3 - 0.8 μg/kg bw on average, (Haase *et al.*, 2003). For example, a concentration of up to 10300 μg/kg bw was found in French fries and 3680 μg/kg bw in chips/crisps. It is therefore evident to avoid excessive consumption of fried potato products and prevent the formation of acrylamide during the different phases of storage and processing.

The presence of asparagine which is found in vegetable and potato is a base factor for forming of acrylamide (Haase *et al.*, 2003). It is assumed today that acrylamide is formed from asparagine while glucose and fructose contents have a catalytic effect. However, they
are also the limiting factor in practice. Low temperature storage (4 - 8 °C) may have effect on the acrylamide concentration of the final product, (Matthäus et al., 2004). One strategy to minimize the potential of acrylamide formation may be to choose varieties with low tendency to produce reducing sugar content at low temperatures (so-called ‘4 °C- varieties’, (Putz, 1997). The maturity state during harvest and chemical treatments are also influencing factors. For the forming of acrylamide, correlations between site, variety and reduced sugar content were determined (Haase et al., 2003). The tuber should be harvested and stored after full maturity development. Not fully matured tubers may have higher sugar contents which may probably not get reduced during a reformation procedure or may even increase during storage (Hertog et al., 1997).

Pre-treatments such as soaking or washing raw French fries in water for ½ hr or 3 hrs before cooking reduced acrylamide content to 23 - 48 % (Burch, 2008).

COOL STORAGE

Because of the global climatic changes, the use of fresh air as a cooling agent in potato storage has become more problematic. The increase of average environmental temperature during winter time in Europe in recent years makes it difficult or almost impossible to apply the traditional ways of cooling potato with cold outdoor air for long-term storage during a typical storage period, from late summer to early spring. As an alternative, refrigerated cooling which leads to increased storage costs (energy and equipment) has become more acceptable, since high and equal quality demands especially by processors justifies higher expenses because higher value return for premium quality potatoes can be expected.

Three variants of storage climate control for storing seed potato were investigated, (1) refrigerated cooling to cool and keeping cool, (2) mixed cooling with fresh air and refrigerated cooling if fresh air is too warm for cooling, and (3) fresh air cooling without refrigerators (Wulf, 2007). Comparative investigations between these three variants under CA for seven months each year for three storage periods 2003/2004 to 2005/2006 demonstrated that refrigerated cooling resulted in the lowest storage loss and lowest sprouting (Table 2). The results for rot and mass loss show no significant differences.

Refrigerated cooling reduced the influence of different growing site on sprouting and is also able to prevent condensation effects and reduces drying time.

**ABSORPTION REFRIGERATOR - ADIABATIC COOLING**

Thermal power plants using biogas as fuel have been constructed in recent years

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### Table 2. Sprouting and losses (in average % during 3 storage periods 2003-2006) for 3 cooling variants (Wulf, 2007).

<table>
<thead>
<tr>
<th>Variant (2) refrigerated cooling</th>
<th>Variant (2) mixed cooling</th>
<th>Variant (2) fresh cooling, without refrigeration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprouting</td>
<td>0.13 ±0.12</td>
<td>0.34 ±0.06</td>
</tr>
<tr>
<td>Mass loss</td>
<td>5.27 ±0.15</td>
<td>5.30 ±0.10</td>
</tr>
<tr>
<td>Rot loss</td>
<td>0.33 ±0.25</td>
<td>0.40 ±0.26</td>
</tr>
<tr>
<td>Total loss</td>
<td>5.85 ±0.25</td>
<td>6.20 ±0.26</td>
</tr>
</tbody>
</table>

Note: refrig = refrigerated
as a potential replacement for conventional power plants based on fossil fuel. These plants are for delivering heat and electricity. The building of smaller local power plants is one advantage of this technology. Many co-operatives and medium scale farmers have built or are planning to build power plants for processing renewable energy material or agricultural waste to biogas for combustion. Potato growers and processors are producing electricity and heat from potato processing waste and wastewater from potato washing. The heat is used to deliver warm water for washing or is delivered as heat to the local community. The production and delivery of electricity is generally preferred, since heat is not needed constantly at all times of the year, e.g. during the summer time. Surplus heat can be utilized to produce cold air for cooling potato stores, by using of absorption refrigerators.

Pollerberg (2007) tested the applicability and efficiency of absorption refrigerators for cooling of potato stores. Smaller refrigerators (<50kW) are mostly run using water as the refrigerant. Since the evaporation temperature of water as a refrigerant is too high (about 4°C) the use of a cooling system of this kind for potato storage is generally ruled out. Refrigerators using ammonia as the refrigerant is applicable because the evaporative temperature is much lower (about -60°C). Refrigerators of the kind with lower power requirements (<150kW) are currently in development and available solely for demonstration or educational purposes. Refrigerators with ammonia need a higher input temperature >120°C, with the result that biogas converters are a potentially more suitable supplier of the heat required than, for example, solar collecting systems.

Currently, investment costs are much higher for adsorption refrigerators (3000 €/kW) than for compressor refrigerators (300 - 500 €/kW), esp. for low cooling power <150 kW, but operating costs are less for the former (for absorber: 0.12 €/kWh or 10.6 €/ton; for compressor: 0.087 €/kWh or 7.9 €/ton; (Pollerberg, 2007). However, a fall in the investment costs for absorption refrigerators is expected within the near future.

**FREE CONVECTIVE VENTILATION**

Despite the fact that due to global warming the rise of average temperatures has significant consequences on cold storage of potatoes with ambient air, free convective drying, cooling and keeping of potatoes in big bin box stores are effective. The effects have been tested and verified by Hauschild et al. (2004). These types of stores do not need mechanical ventilation (fans) (Fig. 3). The air flow in the storehouse is controlled by dampers on the roof and on the ground. The airflow is developed according to free convection principle driven by buoyancy forces due to temperature differences within the boxes and the stack.

Sufficient air flow for drying and cooling of the boxes in late September/October was reported in principle. During long-term storage up to 5-6 months, a temperature difference of 2 K from bottom to top of the stack of up to seven boxes, each 1.2 m high, was regarded as satisfactory. Inadequate outdoor climatic conditions in late September/October can be compensated by using a mobile compressive refrigerator. The refrigerator is normally not used during winter, even when the winter seasons were unusually warm in recent years. Nevertheless, winter 2008/2009 was cold and long enough in Mid-Europe to maintain the adequate storage temperature.

A number of distributed sensors in the stack controls the potato temperature. The storehouse is divided into six sections, which can optionally be separated by removable curtains. These sections are controlled
independently by computing climate control equipment.

**BOX STORAGE AND CLIMATIZATION**

Potato storage in bin boxes has become more and more important in recent years. The main advantages compared to bulk storage are high flexibility and transportability, gentle handling, and ability to smaller partitioning of varieties. The relatively high investment costs for the bins can be compensated since bin storage can better assure high quality standards and values.

The ventilation of big bin box stores for potato needs special strategies to obtain homogeneous temperature distribution for all bins. For example, the free convective ventilation principle is used for a big bin store with 16 kilo t capacity in Germany (D) (Kern and Pötke, 2005). The airflow between the bins is caused by buoyancy forces when air temperature differences occur. The store room may be divided with curtains to ventilate individually separate sections, e.g. for different varieties or purposes. Based on the good experience gained using this storage type a new section was constructed recently to extend the storage capacity and to get higher flexibility and produce quality. A stationary absorption refrigerator can be used as the cooling system while no sufficient cooled ambient air is available. A biogas generator plant of the associated co-operative provides the heat for the refrigerator.

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**Fig. 3. Storehouse for up to 40 kilo t of potatoes in bin boxes with free convective airflow**
Airflow control by using an infrared (IR) thermographic camera for temperature measurement is under test (Geyer and Gottschalk, 2007). An adaptive control system based on IR-data is currently under development to save energy for the cooling system. Instead of using a high number of temperature sensors distributed in the boxes and storeroom, the IR-camera gives a view of the temperature distribution of the observed area (including boxes, potato, gaps between the boxes, air ducts etc). Temperature changes are visible as colour changes (Fig. 4). Interesting areas or spots within the visible image can be marked and the average temperatures of these regions are calculated by software and transferred to the control unit. Temperature changes reflect the change in airflow which is controlled by the damper positions (Fig. 4).

AUTOMATIC CLIMATE CONTROL

Successful automatic controls for maintaining the quality of potato need reliable facilities and equipment. Modern electronics and information technologies meet the demands for this equipment at reasonable investment, operating and maintaining cost.

Automatic temperature control started during the 1960s with the installation of simple thermostats. Before this time, the storekeepers usually checked the storage state regularly and adjusted the climate control equipment (fans, dampers etc) manually even during weekend throughout the storage period. Thermostats made this manual regulation unnecessary. However, the temperature needed to be monitored and the thermostat adjusted from time to time if necessary based on the experience and knowledge of the storekeepers. In modern electronic climate controllers, sophisticated climate control strategies are coded in the algorithm. The storekeeper can set all important parameters directly into the control unit according to the requirements for an optimal climate control for each particular storage period (drying, wound-healing, cooling, keeping, and warming).

The most important parameters are temperature (average or distributed), outside climate condition, fan on-off time, and energy consumption. As an option, measuring equipment for relative air humidity (RH) and CO₂ concentration inside the store can be added.

All data for describing the current climate status can be sent to the office via data-link.

Fig. 4. Photograph (left) and Infrared-thermo-camera view (right) of a potato box storage section
All settings can be handled via remote control from a central location such as the office.

The system can be designed in such a way that the remote control and data transfer can be done via internet and/or mobile phone. Alerts are prepared and sent to mobile phone as SMS (short messages). The need for frequent regular presence in the storehouse is no longer necessary. Of course, regular visual control of the potato conditions is still needed.

Newer controllers from NL take the weather forecast into consideration for enhanced control, the so-called ‘Weather in Control’ (Keesman et al., 2003). Online real-time weather forecast services are taken to predict ventilation and cooling for up to 10 days in advance. The system is also capable of making decisions on the use of lower electricity tariffs to reduce electrical energy consumption. Receding horizon optimal control (RHOC) is used as the methodology to augment the classical feedback controllers. Uncertainties in the weather forecast is minimised by using statistical data processing developed by Doeswijk et al. (2006).

**Equipment for automatic control**

Accurate control needs high precision and unfailing sensors. Platinum thermal resistive sensors (of Pt100 or Pt1000 type) with sufficiently high accuracy and reliability are mostly used. Humidity control helps to reduce mass loss of the tubers which is caused by desorption and evaporation. Therefore, humidity control is another option for modern climate controllers. Hair or synthetic fibre hygrometers may reach an accuracy of ± 3% but are no longer in use, because of high maintenance requirements. Modern sensors are based on electrical resistive or capacitive measurement of a hygroscopic polymer. The resistive sensor measures the moisture dependent electrical impedance of the polymer; the capacitive sensor measures the moisture dependent permeability of the polymer. The resistive sensor has low-cost and is useful in research, meanwhile the capacitive sensor is useful for stationary applications, e.g. in a storehouse. The disadvantage of both types is their high sensitivity for very high relative humidity (above 95 %). They are also fragile when exposed to condensed water. Their reliability is thus limited for extreme climatic situations. Newer sensor types based on CMOS technology are more robust against high RH. A psychrometric sensor based on Assmann-type is now available in D for stationary use. This type of sensor has high accuracy, full measuring range of 0-100 % RH, high reliability, and robustness. They are insensitive to condensation and mist, and need no calibration because it follows the physical ‘dry-bulb/wet-bulb’ principle in combination of the psychrometric chart after Mollier.

The recent development of low-cost temperature/humidity sensors based on CMOS technology gives the opportunity to distribute a higher number of sensors in the storeroom and the potato boxes or pile. Therefore, it is now possible to determine more different temperature profiles of the storeroom or pile. Mirror hygrometers are the most precise reference devices, but difficult to use especially in potato stores.

The different phases of climate control during storage need different air ventilation. Some modern controllers support therefore variable frequency drivers (VFD) to operate the fans with continuously controlled revolution speed. A VFD is an electronic device that varies the frequency and voltage for the fan motors, which revolves synchronously to the frequency. The appropriate airflow can thus be well adjusted to different operational modes such as drying, wound healing or best cooling etc. dependent on temperature difference between tubers and inlet air. Air ducts, boxes and potato heap causes pressure loss (‘head
loss’) and influences the working point of the fan. The pressure loss is proportional to the square of the airflow rate and the motor power is proportional to 3rd power of the airflow rate. Therefore, adjusting lower airflow rate helps both to save energy and reduce mass loss (Gottschalk and Ezekiel, 2006).

Modelling and model-based control

The climate control strategy is implemented as software and reflects experiences of a storekeeper and/or results from research about ‘optimal’ control. This software can be developed or implemented with ‘model-based’ algorithms. The algorithms may be adaptive or built as computer-based decision systems. The ‘risk-driven’ decision support system AssiStore™ was developed in GB to support storekeepers for enhanced storage management (Cunnington, 2008). From modelling the heat and mass transfer of ventilated potato tubers, it is known that variable airflow through potato bulks ensures well adapted acclimatization to reduce mass loss and shrinkage and accelerate drying.

Lukasse et al. (2007) developed another physical model for predicting climate dynamics in ventilated bulk-storage of agricultural produce. The model is a suitable simulator to assess the potential effects of changes in ambient climate, design, and controller tunings.

CONCLUSIONS

Global development and expanding markets will need continuous adjustments, which include adaptation to climate changes, consumption changes, rural area changes and yield, irrigation and fertilizing capabilities, health and food hygiene, sustainability and traceability. New varieties and product diversification, engineering innovation and information technology, and knowledge for better management during harvest, transport, storage, and marketing will all represent challenges for the future.

Further progress and expansion of information technology will facilitate the information exchange and will help to improve storage and transport management.

Global climate changes will necessitate relocation of the regions for potato production and change the import/export markets, with consequences to producers and exporters also in Europe. Expected higher prices for energy and transport will need better transport and storage management and equipment.

Food safety is an issue that is subject to ever more stringent controls and enforcement and will influence potato production, storage, transport, and marketing. Traceability is possible by using smart sensors and identification tags, such as ‘radio frequency identification’ (RFID). New packaging materials and types will help to improve storability and transportability. Environmental issues and the hazards of possible climate change enhance the need for effective collaboration in Europe.

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