



Control of Potato Storage Conditions for the Management of Post-harvest Losses due to Diseases

Harvested potato tubers are living organisms and hence interact with the surrounding environment. To maintain potato quality during storage, the storage environment must be adjusted to minimize tuber deterioration. Temperature, humidity and air movement can always affect the keeping quality of stored potatoes. Potatoes should always be kept in complete darkness to prevent greening. When potatoes are not properly stored, tuber losses due to fungal and bacterial infections can be high. To prevent this, storage conditions should be properly controlled depending on the type of potatoes stored.

TEMPERATURE

Temperature is the single most important factor in the keeping quality of stored potatoes. Respiration, sprouting, water loss, relative humidity, chemical composition and the development of storage diseases are all influenced by temperature.

Respiration consumes oxygen and releases carbon dioxide, volatile gases, water and heat. The rate of respiration is minimal at 7.2°C and increases above and below that temperature. For most varieties, temperatures below 3.0°C and above 15.0°C cause dramatic increases in respiration and are not recommended. With certain varieties, such as Shepody, holding temperatures as low as 2.0°C can be tolerated and may be required to control sprouting. Bruising, sprouting and immaturity also favor a high rate of respiration and should be avoided.

Length of dormancy during storage is determined by variety, temperature and the physiological age of the tubers, all of which vary from year to year. At temperatures below 4.0°C most potato varieties will remain dormant during a normal storage season (up to 8 months). Some varieties (such as Shepody) may require temperatures below 3.0°C to completely inhibit sprouting. At temperatures above 4.0°C the dormant period decreases as the temperature increases. Table and processing potatoes to be stored at temperatures above 4.0°C for more than a few months will require a sprout inhibitor. Maintaining uniform temperatures is critical as fluctuations shorten dormancy.

Temperature has an important relationship with relative humidity (RH). Warm air holds more moisture than cold air. Thus, even small changes in temperature can cause dramatic changes in relative humidity. For the same reason water loss from the tubers is greater at higher temperatures. Air at 10.0°C and 90% RH will



cause more "shrink" than air at 4.0°C and 90% RH. To avoid fluctuations in RH, which stress the tubers and can lead to condensation problems, maintaining a uniform temperature is essential.

The most important biochemical process affected by temperature is the accumulation of sugars, which influences the cooking and processing quality of potatoes. At temperatures below 7.2°C (depending on the variety - consult an agronomist), reducing sugars accumulate leading to dark chips and French fries when the potatoes are processed. At temperatures below 3.0°C the accumulation of sugars is so great that flavor and boiling and baking quality are affected. Potatoes that have sweetened due to low temperatures can be reconditioned to some degree, depending on variety, by raising the storage temperature to 13.0 - 15.5°C for 4-6 weeks before shipping. Assuming 1°C maximum differential between the bottom and the top of the pile, a maximum set temperature of 14.0°C will ensure that the top of the pile is no more than 15.5°C. Temperatures above 15.5°C are not recommended as they are stressful.

High temperatures can also affect sugar levels. Early in the storage season extending the curing period can help remove excess sucrose and reducing sugars as long as the potatoes are provided continuous fresh air supply. High sugar levels are most likely in immature potatoes and potatoes exposed to long periods of low soil temperatures. Handling will also affect sugars so bruising should be kept to a minimum, especially in immature crops. Extended storage at temperatures above 10.0°C can lead to a different kind of sugar accumulation, senescent sweetening. This occurs when potatoes age too quickly. Sugars leak from the starch granules, where they can not be reached during frying, to the cytoplasm, where they can. The loss of colour due to this process is irreversible. Senescent sweetening is most likely during short dormancy seasons - *i.e.* years when potatoes sprout sooner. Keeping CO₂ levels low by providing plenty of fresh air can delay or even prevent senescent sweetening when storing at higher temperatures.

The majority of storage diseases are partially or completely inhibited by storage temperatures below 7.2°C (depending on the variety – consult an agronomist). At temperatures above 10.0°C the growth and development of disease organisms increases dramatically augmenting the risk of total breakdown. Risk of breakdown is greatest just after the storage has been filled, especially during hot weather. Temperatures above 10.0°C should be avoided during long-term storage. The hatching of flies is also inhibited below 10.0°C, thus the presence of flies indicates that the temperature is too high somewhere in the storage and breakdown may become a problem.





Wound Healing and Curing Period

Storage of Healthy Potatoes: Wound healing and curing are essential for the development of a good skin to reduce water loss and minimize the danger of rots. If the potatoes are dry and in good condition, curing can begin soon after the storage is full. Cool, or warm, the pile to 13.0-15.5°C and maintain for 10-14 days along with a humidity of 92-97% RH. The curing period for processing potatoes may need to be extended to 4-5 weeks to improve colour. Colour samples should be taken weekly during curing of processing potatoes. Ventilate for 1-2 hours per day to supply fresh air while maintaining uniform conditions. The humidifier should be on during ventilation.

Storage of Problem Potatoes: Potatoes brought in very warm (greater than 20.0°C) or very cold (less than 7.0°C) should be cooled or warmed at a rate of 2.0-3.0°C per day until the curing temperature is reached. If the potatoes are otherwise dry and disease free, the humidifier can be turned on during this period. This is especially important during hot, dry harvest conditions when the risk of black spot bruising and subsequent infection by *Fusarium* is greatest.

Where the danger of soft rot exists, whether as a result of blight, frost, pinkeye, blackleg or excess moisture, the first priority is to dry the potatoes. For mild to moderate rot, ventilate continuously with a relative humidity of 85-95%. For severe rot, ventilate continuously with a relative humidity of 80-90%. Do not allow the humidity entering the pile to drop below 80%. In some cases, this may take several weeks or even months. In cases of severe frost or disease damage, cool the pile to 8.0-9.0°C and maintain at that temperature for 3-4 weeks before cooling down further to 3.0-4.0°C. The low temperatures will keep disease organisms in check while enhancing the drying process. (Note: if processing potatoes are involved, a decision will have to be made whether to accept the loss of colour due to low temperatures or the risk of rot at the higher temperatures needed to maintain colour. CONSULT YOUR LOCAL POTATO SPECIALIST).

Over the past 10 years or so, many growers have begun using heaters to aid in drying. Most modern, well-insulated potato storages don't require heat to keep the crop warm because the potatoes produce a significant amount of heat on their own. When dealing with rot, however, heaters above the pile will warm up the return air to the point that the control system must bring in extra fresh air to maintain the correct plenum temperature. The extra fresh air will typically reduce the relative humidity (assuming the humidifier is off) by 3-4%, which can cut drying times in half. It is important to size heaters to the ventilation system so that the return air is warmed 0.5-1.0 °C. Note that a heating system of this size will cost \$5-10/hr to operate, so they are not a cheap option, but well worth it when



dealing with rot. Your ventilation supplier can help you select the appropriate heater or heaters.

Another option to aid in drying is a dehumidifier. For a slightly higher capital cost than a properly sized heating system, a dehumidifier can help remove additional water equivalent to about 1/3 the amount removed by the heater, but at substantially reduced running costs. Plus they are portable enough to move between storages. Growers with portable refrigeration systems can use them as dehumidifiers by essentially turning them around; *i.e.* refrigerating the outside air.

Finally, it is important to keep in mind that in most years there will be a combination of potential problems. For that reason it may be a good idea to ventilate continuously for a few days prior to curing just to evaluate the quality of your crop while creating uniform pile conditions. If the crop is in reasonably good condition, the humidifier can be turned on during ventilation, otherwise it should be off or set to maintain no less than 80% RH.

Cooling and Holding Period:

Once the potatoes are cured, the rate of cooling and the final holding temperature depends on the end use of the crop:

Seed: Cool gradually at the rate of 1.0°C every 1-2 days to a holding temperature of 3.0-4.0°C. Cooling more rapidly can shock the tubers, leading to a shortened dormancy. It is important that once the final holding temperature is reached, it is maintained. It is better to wait until any danger of warm weather is past before cooling rather than cool the potatoes immediately after curing and have the temperature in the storage increase during a warm spell. Fluctuating temperatures also shorten dormancy.

Table Stock: Cool at a rate of 1.0°C every 3-4 days to a holding temperature of 4.5-5.5°C. Cooling too rapidly will shock the tubers causing an excess buildup of sugars which can affect cooking and eating quality.

Processing Stock: Processing potatoes have special requirements. It is of the utmost importance to prevent the buildup of sugars and avoid loss of processing quality. The first requirement is that the potatoes be cooled slowly at approximately 1.0°C per week. Rapid cooling tends to cause sugar accumulation. Secondly, for short to intermediate holding of processing potatoes, the holding temperature should not be below 7.2°C unless the variety is known to store well at lower temperatures. Potatoes to be processed into French fries before Christmas can be held at 10.0°C. Chip stock can be held at slightly higher temperatures, 10.0-12.0°C. For storage after Christmas, and up until the early





part of May, both chip and French fry stock can be held at 8.0-10.0°C. At these temperatures senescent sweetening should not be a problem. If a loss of colour is experienced, a 4-6 week reconditioning period at 13.0-15.5°C will help restore colour. Potatoes held for summer processing (May-July) should not be stored at temperatures above 10.0°C. To maintain tubers in the best possible condition, it may be beneficial to cool to 4.0-5.0°C, hold at that temperature until early May and then allow the bins to warm gradually to 13.0-15.5°C, 4-6 weeks prior to shipping. However, reconditioning out of cold storage does not always work and works better for some varieties (such as Shepody) than others where some risk is involved.

Grading and Handling Period

Potatoes should be warmed to at least 7.2°C, and preferably higher, before handling. Cold tubers are brittle and very susceptible to bruising and black spot. Ideally, the entire lot of potatoes to be moved should be warmed prior to handling. However, in large, single bin facilities it may not be practical to warm the entire storage, especially if small lots are involved. One solution is to slowly warm the storage to 7.2°C, move the potatoes to be shipped to a separate grading area and then gradually cool down the storage again. This will entail handling the potatoes twice but that is still preferable to handling very cold potatoes. Multi-bin storages with separate environment controls do not have this problem. If grading is done in the storage, avoid adding heat. Fluctuating temperatures encourage sprouting and change the RH of the air in the storage.

VENTILATION

Air Movement

Air movement includes both through-the-pile ventilation and over-the-pile ventilation (= recirculation). Through-the-pile ventilation is necessary to dry and cool the potatoes, supply fresh air, and remove carbon dioxide, volatiles and excess heat and moisture from the storage. Recirculation aids in maintaining uniform temperature conditions throughout the storage and sweeps moisture from the walls and ceiling.

The type and capacity of ventilation system will depend on storage design and the condition of the potatoes at harvest. A small storage (160 ton) with slatted walls and adequate air exchange with the outside can get by with natural ventilation provided it is used only for seed or table stock potatoes. However, even in these storages some form of air circulation is necessary. Without air movement warm air from the potatoes will accumulate above the pile. Under those conditions, it is possible for the top of the pile to be as much as 5.0°C





warmer than the bottom. To provide circulation, place at least one fan on top of the pile so that it circulates air around the storage. Better still, place a framed fan in a depression on top of the pile so that it pulls air from the floor and then have another fan for circulation. The in-pile fan can also be used to cool "hot spots" and therefore prevent serious breakdowns. (Note: in large, unventilated storages more than one in-pile fan will be necessary).

Any storage to be used for processing or larger than 160 ton in capacity will require some form of forced air ventilation system. Ventilation systems capable of blending outside air with inside air should be designed to move air at a rate of no less than 1.0 cfm/cwt (20 cfm/ton) of potatoes stored. Wet or field frosted potatoes or tubers affected by blight, pinkeye, blackleg, water soak or soft rot will benefit from higher rates of ventilation (2-2.5 cfm/cwt, 40-50 cfm/ton) for rapid cooling and drying. Mechanically harvested potatoes also benefit from higher rates since the bruising that occurs tends to increase the rate of respiration and therefore heat production. At ventilation capacities above 1.0 cfm/cwt the rate of water loss from the potato remains uniform, whereas the rate of drying increases. Thus, with high ventilation capacities, the potatoes are dried more quickly with less overall shrinkage. Ventilation systems that utilize exhaust fans only are designed to move less air because of the difficulty in controlling temperature at the intake during cold weather.

Ventilation schedules - how often to run the fans - and whether to use over or through-the-pile ventilation will be determined by the condition and end use of the stored potatoes. During cooling, an alternating cycle of continuous and intermittent ventilation works best. Whenever the temperature is to be dropped one degree, turn the ventilation system on and leave it on until the tubers at the top of the pile are at the desired temperature. Then, ventilate only as much as needed to maintain no more than 0.5-1.5°C difference between the bottom and the top of pile until it is time to drop the temperature another degree. In general, a schedule of one hour on - three hours off, or three hours in the morning and three hours in the evening will maintain the proper differential.

Once the pile is at holding temperature, ventilation should be kept to a minimum. Again, try to maintain a differential no greater than 0.5°C per 2 m of pile depth. In other words, for a 2 m pile the differential should be no more than 0.5°C, while for a 6 m pile the differential can be as much as 1.5°C. The amount of ventilation required to maintain the differential will be determined by holding temperature, variety and tuber condition. Seed potatoes, stored at or below 4.0°C will require less ventilation than potatoes to be maintained at 10.0°C simply because the warm potatoes produce more heat through respiration. Certain varieties of potatoes, and any potatoes that are immature or affected by disease, have higher rates of respiration and will require more ventilation. With small capacity





systems (10.4 l/sec/ton) the fans should not be on for less than 1 hour at a time to avoid layering of cold and warm air within the pile. Thus, timers that control fans on a few minutes per hour (or 1/2 hour) basis are not recommended. (Note: 24-hour timers also provide more flexibility in fan operation, such as allowing night cooling only during warm spells).

Storages equipped with frequency drives (VFDs) can use the drives to slow down the fans rather than setting fixed ventilation schedules. Fans running continuously at 50% speed will provide the same amount of air as running the fans at full speed for 12 hours out of 24, yet will consume considerably less electricity; ~ 15% vs. 50%. An added benefit is that ventilating continuously at slower speeds will maintain uniform pile temperatures without causing additional shrink. Once the pile is at the final holding temperature, set the drives at a speed that will maintain the correct differential between the bottom- and top-of-pile temperature as indicated above. Note, however, that when the fans are running at half speed the static pressure in the storage may not be enough to open the exhaust louvers, so it may be necessary to prop them open to ensure proper air exchange with the outside.

If the potatoes are in good shape and relatively little air is required to maintain temperatures, the air can be recirculated. Recirculation is advantageous in that it minimizes water loss from the tubers. Recirculation also allows for sweeping of excess moisture from the ceiling if that is a problem (although in well insulated storages with good air movement, condensation should not be a problem). Simply open the bypass and ventilate for the same amount of time as usual. If tuber temperatures remain constant, it is possible to continue to recirculate for the remainder of the storage season. However, it should be pointed out that recirculation tends to reduce the amount of fresh air brought into the storage, which could be a problem for potatoes destined for processing. Storages equipped with frequency drives generally don't require recirculation because the pile is ventilated continuously.

Humidity

Relative humidity (RH) in storage should be high to aid in prevention of shrinkage losses and pressure bruising. In general, a RH of 92-97% for dry, healthy potatoes and 85-90% for wet, leaky potatoes is recommended. A humidifier is an absolute must for ventilated storages, especially those with automatic systems. In fact, humidifiers will be of little benefit in unventilated storages since there is no way to deliver the humidified air to the potatoes. Many types of humidifiers are available but they are all designed to break water into tiny droplets so that evaporation will take place, and for that, moving air is required. Except when drying wet or rotted potatoes, or when it is raining outside, the humidifier should



always be on when the ventilation system is running, even if the humidity appears to be high.

Many modern potato storages are equipped with humidicell type humidifiers. In regions with low outside relative humidity (<30% RH), it may be necessary to install secondary humidifiers, such as pressurized nozzles or spinners, to bring relative humidity to the 92-97% range. Humidicells can also provide a substantial amount of evaporative cooling in dry regions, which can greatly aid cooling the potatoes. Certain control panels are equipped with settings that allow for the evaporative cooling effect and will raise the start temperature for ventilation. More humid regions, such as the Maritimes provinces, probably don't require secondary humidifiers, but can still take advantage of the evaporative cooling effect.

A storage with inadequate insulation or poor air circulation may experience excess moisture buildup. This can lead to water dripping on the pile which must be avoided at all costs in order to minimize the danger of rot. Adding extra insulation and placing fans above or on top of the potato pile will improve air circulation and help eliminate condensation problems.

Storage Monitoring

A good storage management program should include daily checks of the storage. Make sure that the ventilation controls and dampers are functioning correctly especially during very cold weather when the danger of ice buildup is greatest. Use an accurate thermometer to check the air and tuber temperatures at several locations in the storage. A thermometer or temperature probe located 50-100 cm below the top surface of the pile will give an indication of the highest temperature in the storage. Relative humidity can be checked at the same time with a humidity gauge or psychrometer. Be alert for the signs of soft rot development - a pungent smell, depressions in the pile, water in the ventilation ducts and hot spots in the pile. Early detection of soft rot is now possible with the use of infra-red thermometers. These devices, which look like radar guns, can be used to measure temperatures at the top of the pile. Areas of potential breakdown will show up as "hot spots", often as much as three weeks before other symptoms are noticeable. Records of all storage conditions should be kept daily so that if problems arise there is some way of determining the cause.

In recent years it has become increasingly evident that potatoes are very sensitive to changes in the storage atmosphere. This is especially true of processing crops which can accumulate sugars if the CO₂ level in the storage is too high. Current recommendations call for CO₂ levels to be below 2500 PPM (0.25%) for most French fry varieties, and even lower (1500-2000 PPM) for



chipping potatoes and certain French fry varieties. Growers are advised to include CO₂ measurement as part of their daily storage checks, or to purchase a CO₂ sensor for their control panel to maintain desired CO₂ levels. If the storage is equipped with heaters, they can be turned on to help bring in extra fresh air.

Acknowledgement

Contribution of John Walsh, Potato Storage Specialist with McCain Foods Limited in Florenceville-Bristol, New Brunswick, Canada to this fact sheet is acknowledged.

For more information please contact:

Dr. Khalil I. Al-Mughrabi
Chair, National Late Blight Working Group

Potato Development Centre
New Brunswick Department of Agriculture and Aquaculture
39 Barker Lane, Wicklow, New Brunswick E7L 3S4, CANADA
Tel: (506) 392-5199; Fax: (506) 392-5102
E-mail: khalil.al-mughrabi@gnb.ca

