

DESIGN AND MANAGEMENT OF POSTHARVEST POTATO (*Solanum tuberosum* L.) STORAGE STRUCTURES

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Abstract

Potatoes must protect possibly their quality postharvest. The most important of main problems formed crop losses depend on storage in potato is insufficient storage structures. Reason of this is ignored structural and environmental properties depend on crop in the design of storage structures. To overcome of this problem determined temperature, relative humidity of crop for potatoes will subject to storage require. In addition, the design of storage structures should be done according to the standards. To be considered; are structural (wall, wind, snow, crop and floor loads), insulation (thermal requirement, fire retardant and moisture removal systems), mechanical (ventilation, heating and humidification systems), electrical and control systems. All a storage period can do is helping maintain quality. In this review were investigated environment conditions in storage, storage management, store systems and storage structures, to minimize the storage losses.

Key Words: Potato, environment conditions, store systems, storage structures

HASAT SONRASI PATATES (*Solanum tuberosum* L.) DEPOLAMA YAPILARININ TASARIMI VE YÖNETİMİ

Özet

Patatesler hasat sonra kalitelerini mümkün olduğunca korumalıdır. Patates depolamasına bağlı olarak ürün kayıplarının ana sorunlarının en önemlisi

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yetersiz depolama yapılarıdır. Bunun nedeni depolama yapılarının tasarımında ürüne bağlı yapısal ve çevresel özelliklerin göz ardı edilmesidir. Bu problemlerin üstesinden gelebilmek için patates ürününün depolamada gerekli olabilecek sıcaklık ve bağıl nemi belirlenmelidir. Ayrıca depolama yapılarının tasarımı belirtilen standartlara göre yapılmalıdır. Dikkat edilecek hususlar; yapısal (duvar, rüzgar, kar, ürün ve zemin yükleri), yalıtım (termal gereksinim, yangın geciktirme ve nem giderme sistemleri), mekaniksel (havalandırma, ısıtma ve nemlendirme sistemleri), elektrik ve kontrol sistemleridir. Depolama süresinin tamamı kalitenin sürdürülmesine yardımcı olmalıdır. Bu derlemede depolama kayıplarını en aza indirmek için depolamadaki çevresel koşullar, depolama yönetimi, depo sistemleri ve depolama yapıları araştırılmıştır.

Anahtar kelimeler: Patates, çevre koşulları, depo sistemleri, depolama yapıları

1. INTRODUCTION

The potato (*Solanum tuberosum* L.) is the most important food crop in the world after wheat, rice and maize. Over one billion people consume worldwide and potatoes are part of the diet of half a billion people in the developing countries. Potato is produced on about 310 million tons in the world every year. The largest potato producer of the world is the China. This country produces nearly 60 million tons of the total world production, followed by Russian, India and USA [1]. Hot spots and damage will occur if the bulk piles of potatoes are not ventilated. Losses during storage are dependent on many factors including length of storage time, potato temperature, ambient relative humidity and temperature, and the degree of mechanical and freezing injury [2,6].

Potato is a staple food in the colder regions of the world, while in other parts of the world it is generally used as a vegetable. In world potatoes are consumed in different forms such as cooked, roasted, French-fried, chipped etc. Cooking often reduces mineral and vitamin constituents.

In case of processed products it is possible to add missing or low ingredients in order to enhance overall nutritional value of the product.

An ideal storage environment must be provided if the tubers are to be stored up to 10 months. Tubers go through four different storage phases (curing, cooling, long-term storage and marketing), each requiring a different environment. To meet all of these requirements the potato storage must be designed to [7]:

- Maintain tubers at a desired temperature by exhausting the heat of respiration and circulating cool fresh air through the pile,
- Maintain a high relative humidity to promote wound healing at harvest and to prevent tuber desiccation (shrink),
- Provide oxygen for tuber respiration,
- Remove carbon dioxide, the by-product of respiration and other deleterious gasses, which affect tuber quality,
- Deal with adverse storage conditions where the tubers are wet, rotting, chilled, frozen or too warm.

There are four factors to consider when choosing a potato storage design:

- Style of structure,
- Insulation,
- Ventilation and humidification,
- Options such as auxiliary heating or refrigeration.

The main objectives of storage are future consumption, future processing, and maintenance of seed reserve. It allows a better use of processing capacity, better tuning of production and consumption, and better quality of seed potatoes. Arable products such as potatoes belong to the group of semiperishable goods, that is, product with a high natural moisture content. These products are more sensitive to quality loss than cereals because conservation using drying techniques cannot be applied. Loss of moisture leads to quality loss and finally to nonmarketable produce. The risk of unacceptable moisture loss, disease spread, mold infections, and insect pests is obvious. Low storage temperature, high relative humidity, and control of air composition are the main conservation factors for this group of products. To guarantee a top-quality product, storage conditions must be well controlled; however, the market value

does not allow full air conditioning. The storage should minimize physiological losses and losses due to mechanical damage [8,9].

2. ENVIROMENT CONDITIONS IN THE POTATO STORAGE

2.1. Temperature

Optimal holding temperatures for potatoes in storage depend on the potato variety and the intended end use of the product. Processing potatoes are generally stored between 6⁰C and 10⁰C to limit the concentration of reducing sugars in the tuber tissue. By comparison, potatoes intended for fresh market may be stored between 4 and 10⁰C, while those intended for seed are usually stored at 3 to 4⁰C. Although there is usually little consideration of table quality as it relates to storage temperature, the best quality is maintained at 4 to 8⁰C [10].

Storage temperatures are also used to minimize weight losses caused by respiration and shrinkage. Respiratory losses are usually minimal near 7⁰C. Tuber weight loss due to respiration alone can equal 1,5 percent of the total weight over an 8 to 10 months storage season. To remain viable and competitive, processors demand high quality potatoes from producers. Therefore, the producers must provide a storage atmosphere that can maintain high tuber quality throughout the storage period. A potato storage manager must minimize the loss of mass resulting from dehydration (moisture loss) and respiration (dry matter loss). At the same time, the storage manager must minimize accumulation of reducing sugars in potatoes that can lead to non-enzymatic browning (an undesirable browning of the chip colour) during frying [11,12].

An increase or decrease in potato storage temperatures can be used to minimize disease development. By reducing holding temperature, many storage disease problems can be minimized. Reconditioning refers to the use of elevated pile temperatures to help reduce the accumulation of reducing sugars in tubers. Higher temperatures increase the tuber respiration rate, thereby decreasing detrimentally high reducing sugar concentrations so that the processed potatoes meet the industry requirements.

Temperature changes in storage should be gradual and not exceed recommendations for various product uses. The rate of downward ramping of storage temperature for potatoes intended for processing should follow guidelines established by the processing industry. In general, temperature reductions should not exceed -17°C per day when cooling to specified holding temperatures. This gradual temperature reduction helps eliminate changes in the sugar content of tubers that can affect processed product quality. Guidelines for proper holding temperatures in storage may vary with the variety. For processing potatoes it is critical that minimal sugar accumulation occurs. Recommended storage temperature for potatoes for different usage is shown in Table 1 [7,13,14].

Table 1. Recommended storage temperature of potatoes for different usage

Usage	Temperature, ($^{\circ}\text{C}$)
Seed potatoes	2-4
Table consumption	4-5
French fry production	6-8
Crisps production	7-9
Flakes, granulates	7-10
Long-term chip storage (over 4 months)	10-13
Short-term chip storage	13

2.2. Relative Humidity

Most of the tuber shrinkage that occurs during the first month of storage results from water lost before the completion of the wound healing process. Maintaining high relative humidity (r.h.) in potato storage prevents some of the early season tuber dehydration and helps control the total shrinkage loss during the season. Shrinkage loss in storage is directly proportional to the length of the storage season and inversely proportional

to the relative humidity conditions maintained within that storage. The current recommendation is to maintain 95% r.h. or above for minimizing early storage tuber losses due to dehydration.

Free moisture is one of the most common problems traced to rot organism spread in storage. Condensation can become a problem when it occurs directly on the tubers or on any inside surface of the storage. Maintaining circulation air slightly cooler than the bottom of the pile will help prevent condensation directly onto the tubers. Likewise, condensation on building surfaces can be minimized by providing adequate insulation and making sure there is enough air movement to keep surfaces warm and to evaporate the moisture that collects before it drips onto the potatoes [13,15,16].

2.3. Carbon Dioxide

The quality of many fruit and vegetable crops is enhanced if stored under high levels of CO₂ combined with low oxygen. This is not the case with potatoes, increased levels of carbon dioxide can be detrimental, promoting sprouting and effectively shortening storage life. Even the small amount of CO₂ produced as the potatoes respire during the season can build to unacceptable levels up in a well sealed modern store, so it is always wise to ventilate periodically in stores with few natural leaks [17].

In a storage room equipment with a CO₂-control system, the desired CO₂ levels are maintained by controlling the airflow to the scrubber or by regulating the outflow into the storage area. There are four main reagents, which are commercially used for CO₂ absorption. They are: water, Hydrated lime, activated charcoal, and molecular sieve. In these systems, the O₂ levels are usually maintained by introducing outside air into the storage room [18,19].

Long-term storage atmospheres with reduced oxygen content are detrimental to potatoes. A level of 1,0% CO₂ should be considered the upper allowable threshold. A common level of CO₂ in ventilated bins is 0.2% to 0.3% [13].

2.4. Light

A potato tuber accumulates chlorophyll when exposed to light, which turns the tuber green. The longer the tuber is exposed to light, the more greening will occur. The process will not reverse- the green color will not go away- if you then store the potato in a dark place. The green color may be unappealing, but the color itself does not effect the taste of the potato. However, green potatoes can form compounds called glycoalkaloids that develop along with chlorophyll formation. Glycoalkaloids may make the potatoes taste bitter. In addition, glycoalkaloids are potentially toxic if you eat a lot of green potatoes at one time. If a potato has only small portions of green, you can safely remove these sections and eat the potato. Discard potatoes with a high proportion of green skin [20].

3. STORAGE MANAGEMENT

3.1. Preharvest Decisions

Before storing a potato crop, consider these factors:

- Potatoes affected during the growing season by temperature extremes, nutrient excesses or deficiencies, water stress, physical damage, or other unfavorable growing conditions may not respond to storage environments equally,
- Potatoes that are bruised or damaged during any part of the harvesting, hauling, piling, or storing operations may require additional considerations for proper storage management,
- Most modern storages can provide conditions that will allow the presence of some rot at the beginning of storage. As little as 1 to 3 percent rot can make potatoes difficult to store. In a modern storage facility, as a general rule, potatoes with up to 5 percent wet rot can be successfully stored if proper procedures are employed to eliminate excess moisture. The same is true for tubers damaged by frost,
- If potatoes are approaching an off-grade at harvest because of net necrosis, they should either not be stored or marketed within the first 2 months of storage,

- Potatoes with severe stress-related problems, such as sugar ends or jelly ends, or high overall sugar levels, should also be considered for immediate delivery.

3.2. Storage cleaning and maintenance

At the end of each winter storage period, significant quantities of soil and dust carried in with the crop during the previous harvest remain within the store, in lateral ducts, on floors, on ledges and walls, on boxes and machinery. Disinfection or cleaning of the storage facility is a good practice in all storages and is essential for seed producers (Figure 1). Cleaning of the store must be completed in time for the new harvest to begin. Off-season care of the potato storage facility is important in maintaining the functionality of the facility and to enable long-term storage of high quality potatoes [16].



Figure 1. Disinfection of the potato store

- Repair all insulation materials,
- Clean plenum and duct ports thoroughly,
- Replace worn humidity equipment and high pressure nozzles,
- Check for corrosion on all surfaces,

- Service the air system and check all fans for proper balance,
- Repair or replace worn components on air louvers,
- Calibrate all computerized sensors that are used for control functions,
- Service the relative humidity supply cell decks.

3.3. Filling the storage

Potatoes entering the storage should be free from dirt and rocks and should be handled in a manner that minimizes damage. This can be accomplished by observing the following practices [16]:

- Use well-maintained unloading, even-flow bins, and/or sorting equipment for delivery of potatoes from trucks to the storage,
- Keep all drops to 0.2 m or less and pad all sharp or hard surfaces on handling equipment,
- Keep all equipment running smoothly and full to capacity with potatoes,
- Use roll prevention belts on pilers and steep elevators (Figure 2),
- Pile the potatoes using a tier system,
- Use only well-trained personnel to operate piling equipment.

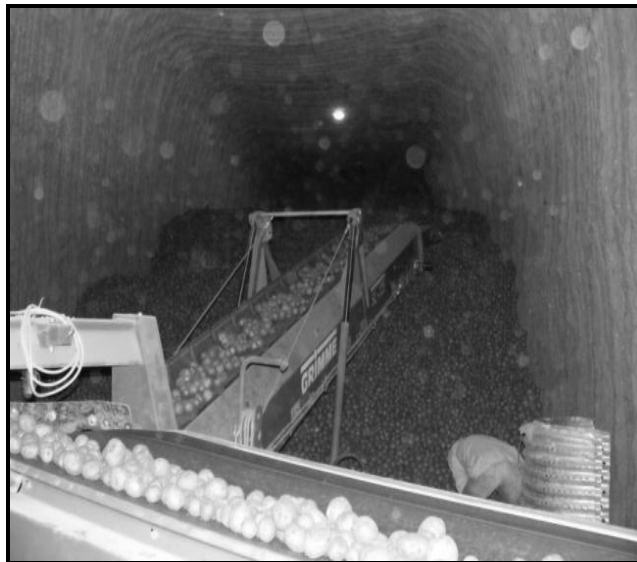


Figure 2. Filling of the potato store

4. THE POTATO STORAGE SYSTEMS

Topics discussed in this study:

- Low-cost storage structures,
- Natural ventilated storages,
- Cooled storages,
- Controlled atmosphere storage.

4.1. Low-cost storage structures

Since potatoes arrived in Europe in the 16th century [23], they have been stored in simple low-cost structures, some lasting the period of storage only and some permanent. The basic objectives were to prevent greening, frost damage, being eaten by rodents or birds, and theft. Storage involved either the use of cellars or caves, or protection from the weather using straw and soil. Caves or cellars were particularly good for storage as they reduced the extremes of temperature [21].

4.1.1. Clamps

Above-ground piles or clamps of potatoes were the traditional method of potato storage in Europe and are still used in various forms in many countries [22,23]. They comprise simply a pile of potatoes, which is covered with straw and soil to give some protection against the weather and rodents. They have a low capital cost but high labour requirement. Although there are a number of different types, they all require the potatoes to be heaped into a long narrow pile typically 1.0-2,5 m in width. Height is dictated by the angle of repose of the tubers, approximately 35⁰C, giving a corresponding height of 0,35-0,88 m (Figure 3). A covering of straw, 150-200 mm thick when compressed, is laid over the top of the tubers. This stops greening, insulates the crop from hot or freezing weather and minimizes subsurface condensation on the stored crop. Ditches are dug into the soil on either side of the pile to reduce the risk to the crop from flooding and wire mesh is inserted in the ground to deter rodents. After 2 weeks, once the initial high level of respiration following harvest has subsided, the straw is covered with two plastic sheets which overlap at the apex of the clamp to prevent rain penetration but have a gap between them

to allow for ventilation. The plastic sheet is then covered with friable soil 100 mm thick to prevent the plastic being blown away by strong winds and to prevent freezing winds from entering the clamp. In very cold climates a second layer of straw followed by more earth is applied.

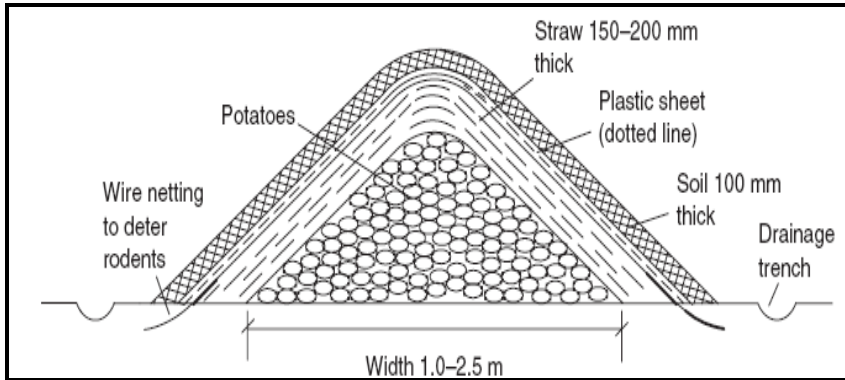


Figure 3. Potato clamp in-field storage [21]

A more sophisticated version of the clamp is the ‘Dickie Pie’ in which one or two ‘A’ ducts are placed parallel to the long sides (Figure 4) and bales of straw, placed around the perimeter, allow a greater bulk of potatoes to be stored. These ‘A’ ducts are open at each end and can provide some ventilation of the tubers, allowing the size of the clamp to be increased to between 4,0 and 5,0 m in width. Blocking the ducts with a bale of straw or equivalent can close the ‘A’ ducts. The cross-sectional area of the duct should be a minimum of $0,013 \text{ m}^2$ per every 10 t stored [21].

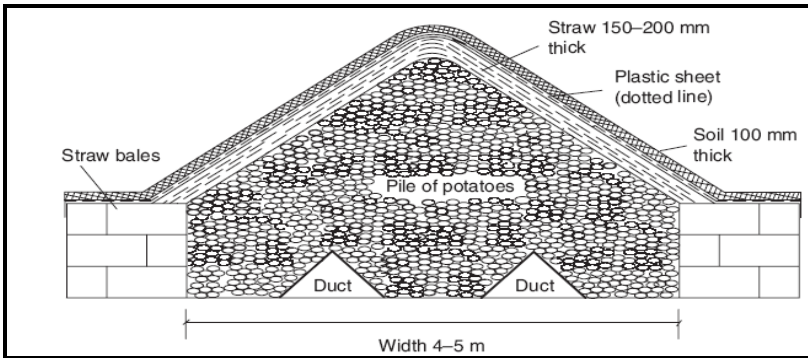


Figure 4. 'Dickie Pie' in-field storage [21]

4.1.2. Underground buildings

In continental climate areas of the world, like the mid-west USA, Turkey and Eastern Europe, low temperatures in winter and high temperatures in summer are the norm. By burying the building underground, the thermal mass of the soil above not only insulates the stored crop from extremes of hot and cold weather but also greatly reduces the effect of solar heat gain.

While the thermal concept of these buildings is sound, it does mean that the building structure has to carry the soil that covers the building. This adds to the initial capital cost. This, together with the increased availability of refrigeration and the relatively low cost of electricity, has meant that these types of buildings are no longer built. In some areas of the world, caves or old mine workings are used to achieve the same effect but without the high initial cost [21].

4.2. Natural ventilated storages

The basic principles that are used in a natural ventilated stores are:

- That the incoming heat in the store from solar irradiation is restricted to a minimum and is removed from the store by ventilation (Figure 5),
- The surplus of field heat of the potatoes is removed soonest,
- That the heat produced in the respiration process of the potato is removed by ventilation,

- Measures are taken to improve the stack ventilation (e.g. restricted piling height, pile not covered with airtide material, slatted floor, little adhering soil) [24].

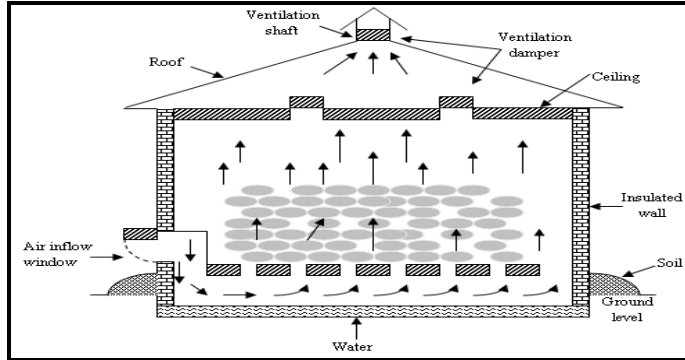


Figure 5. Natural ventilated stores for the potato storage

4.3. Cooled storages

There are 4 types of cooled stores;

- Non-refrigerated store,
- Refrigerated cooling store,
- Outside air cooling store,
- Evaporative cooling store

4.3.1. Non-refrigerated storage

For short-term storage involving 3-4 months, non-refrigerated on-farm storage methods such as clamps are cheap alternatives. They have been used by small growers in the Andes, by experienced farmers in Europe, and large growers in Argentina. In clamping, the potatoes are placed in a pile 1-3m wide at the base and as high as the natural angle of repose of the tubers permits. The pile is made as long as necessary and is made of straw. Clamps can be used in areas where the temperatures are low enough, e.g., in the mountains or on high plateaux in the tropics or in winter in the subtropics [25]. If the tubers are to be stored beyond the period of their natural dormancy, chemical sprout inhibitors will be required [26,27]. On-farm storage in heaps (unventilated clamps) and pits is common in some parts of India and Holland. Potatoes stored in this manner often contain low levels of reducing sugars and hence can be used for processing [27,29].

4.3.2. Refrigerated storages

In refrigerated storages almost all temperatures that are required can be kept is shown in Figure 6. The insulation and the needed cooling capacity depends on the temperatures occurring in the area where the storage is located. This type of storages is especially relevant for the storage of potatoes. They offer a good flexibility regarding the availability of potatoes in the desired physiological condition [24,30].

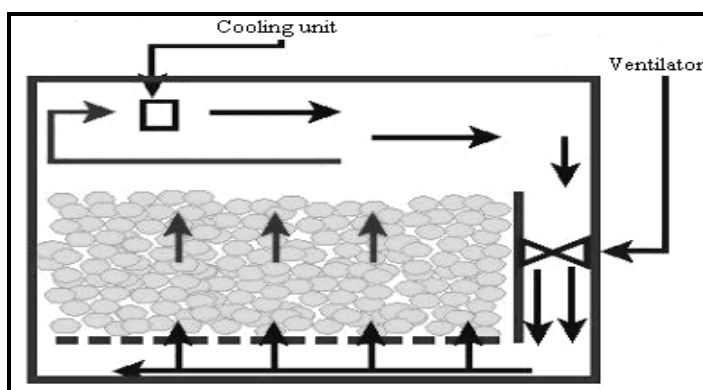


Figure 6. Refrigerated store for the potato storage

4.3.3. Outside air cooling

Stores with outside air cooling are insulated buildings, equipped with a ventilation system is shown in Figure 7. In cool periods potatoes are ventilated using outside air and when the temperature is high the outside air is prevented from entering. In this way it is possible to maintain temperatures in the storage equal to or higher than the minimum outside air temperature [24].

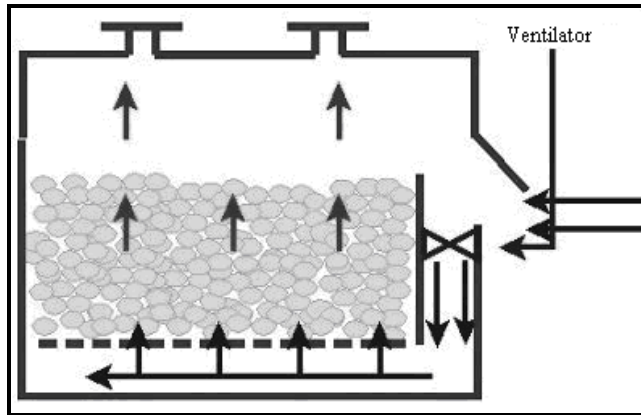


Figure 7. Outside air cooling store for the potato storage

4.3.4. Evaporative cooling storage

The principle of evaporative cooling is that the air that enters the store for cooling passes material which is moistened with water. Through evaporation of water the temperature of the air drops. The system only has an effect in periods when the relative humidity is low. A disadvantage is that in the store relative humidity is high, which accelerates the development of storage diseases [24,31].

The system is not well accepted for the following reasons:

- The cooling effect is limited during humid periods,
- The farmers are not willing to use their limited water resources for cooling,
- Evaporative cooling increases humidity in stores and accelerates the development of storage diseases.

4.4. Controlled atmosphere storage

Controlled atmosphere storage (CA) refers to the constant monitoring and adjustment of the CO_2 and O_2 levels within gas-tight storages or containers. CA is most effective when combined with temperature control. There has been great interest in using CA storage on potatoes for fresh, processing, and seed potatoes [32,34]. The amount of O_2 and CO_2 in the

atmosphere of the potato store can affect the sprouting of tubers, rotting, physiological disorders, respiration rate, sugar content, and processing quality (Table 2). The recommended a maximum of 10% CO₂ and a minimum of 10% O₂ as the optimum controlled atmosphere storage for potatoes [35]. Storing tubers in anaerobic conditions of total nitrogen can prevent accumulation of sugars at low temperatures but may result in undesirable side effects such as acid or bitter flavor [36]. Varying concentrations of CO₂ and O₂ in controlled atmosphere affected sprouting [37,38] with 3-6% CO₂-stimulated sprouting while 9% O₂ completely inhibited sprouting. From the results, it was concluded that controlled atmosphere storage at 6⁰C was not an alternative to chemical control of sprout growth. The showed that high CO₂ with low O₂ combinations during storage completely inhibited sprout growth and resulted in the darkest colored crisp (i.e., chips) which was reversed by reconditioning [33]. In a comparative study on the effects of normal and CA combinations at 9±1⁰C for 6 months using the tubers of Agria and Russet Burbank on tuber components responsible for acrylamide, it was found that there was only a limited increase in the concentrations of sugars under normal atmosphere conditions. Low-dose irradiation slightly decreased the rate of sweetening in tubers. The potential to form acrylamide remained almost the same in both storage conditions. CA storage, in which O₂ was decreased to levels below that required for respiration, increased sugars and thus the potential for acrylamide formation upon frying at 170⁰C for 10 min [25,39].

Table 2. Sugars (g per 100 g dry weight) in tubers of three potato cultivars stored for 25 weeks under different controlled atmospheres at 5 and 10⁰C and reconditioned for 2 weeks at 20⁰C [40]

Cultivars	Gas Combinations(%)		5 °C			10 °C		
	CO ₂	O ₂	Sucrose	RS ^a	TS ^b	Sucrose	RS	TS
Record	9.4	3.6	0.757	0.216	0.973	0.910	0.490	1.400
	6.4	3.6	0.761	0.348	1.109	1.385	1.138	2.523
	3.6	3.6	0.622	0.534	1.156	1.600	0.749	2.349
	0.4	3.6	0.789	0.510	1.299	0.652	0.523	1.175
	0.5	21.0	0.323	0.730	1.053	0.998	0.634	1.632
Saturna	9.4	3.6	0.897	0.324	1.221	0.685	0.233	0.918
	6.4	3.6	0.327	0.612	0.993	0.643	0.240	0.883
	3.6	3.6	0.440	0.382	0.822	0.725	0.358	1.083
	0.4	3.6	0.291	0.220	0.511	0.803	0.117	0.920
	0.5	21.0	0.216	0.615	0.831	0.789	0.405	1.194
Hermes	9.4	3.6	0.371	0.480	0.851	0.256	0.219	0.475
	6.4	3.6	0.215	0.332	0.547	1.364	0.472	1.836
	3.6	3.6	0.494	0.735	1.229	0.882	0.267	1.149
	0.4	3.6	0.287	0.428	0.715	0.585	0.303	0.888
	0.5	21.0	0.695	0.932	1.627	0.617	0.510	1.127

^a Reducing sugars, ^b Total sugars

5. STORAGE STRUCTURES

Almost any type of building can be adapted to store potatoes, however, commercial rigid frame steel buildings are not normally used because the exposed steel beams and columns are difficult to insulate. The most common storage buildings are concrete, wood stud and pole frame, and metal quonset. The factors that vary between various building types are capital cost, durability and longevity, and the type of insulation required for the exterior building envelope. Regardless of the type of building, the design should be undertaken by a Professional Engineer to ensure that the structure can withstand the forces exerted by the stored potatoes, wind and snow. Design and construction can typically require three to four months or more; therefore early planning is required to ensure the storage is ready at harvest time. The size of individual bins and storage systems vary widely with the needs of individual producers and the cost of construction. Potatoes from individual fields often behave differently in storage, requiring individual management. Ideally, the potatoes from each field should be stored in a separate bin, but since smaller bins cost more per hundredweight, storage management is compromised when storing potatoes from different fields in large bins. An enclosed loading area attached to the storage bin(s) is recommended. This will allow workers to comfortably load potatoes in severe weather and minimize potential problems associated with chilled tubers [7].

5.1. Loads on stores

There are three load factors to consider when designing a potato storage building.

- Wind and snow loads for the local geographic area. Most building contractors know the wind and snow load factors required for their area,
- Maximum floor load, primarily due to loaded field trucks,
- Loading of potatoes on the sidewalls of the building.

The values of lateral forces from potatoes can be calculated with the following expression Eq. 1 [19,41,42].

$$P = \frac{1}{2} \cdot \gamma \cdot h \cdot \tan^2 \left(45 - \frac{\phi}{2} \right) \cdot 0.01$$

where:

P : Lateral pressure, kPa

γ : Bulk density, kg.m⁻³

h : Store height, m

ϕ : Angle of internal friction of the potato, degree

5.2. Insulation

Storages must be properly insulated and sealed in order to maintain the environment required to keep stored potatoes healthy. Besides reducing heat loss and thus helping to maintain the desired storage temperature, insulation is also critical in preventing condensation. Condensation water, dripping onto the tubers, will encourage the development of soft rots and can significantly impact potato quality. It is recommended that enough insulation be installed to achieve a minimum thermal resistance (RSI) of 6.1. This is equivalent to 250 mm fibreglass or 150 mm of polyurethane insulation. Ceiling fans have also proved beneficial in reducing free moisture on ceiling surfaces and/or the top of the potato pile. The amount of insulation also impacts interior air quality. Insulation decreases heat loss through the walls and ceilings, resulting in more heat of respiration exhausted from the building via the ventilation system. In extremely cold weather, this allows the ventilation system to bring additional fresh air into the building, thus maintaining adequate levels of oxygen and reducing the level of deleterious gasses such as carbon dioxide [7].

5.3. Ventilation

The modern, fully automatic ventilation system controls temperature and circulates air through the potato pile. Air is forced down the main air plenum, outwards and up through the pile by lateral ducts. It is beneficial to have a bypass vent at the end of the main plenum to provide partial recirculation of air to help control condensation in coldest weather.

The ventilation system for this storage is designed to provide $8 \text{ L}\cdot\text{s}^{-1}$ per tonne. Some storage situations, such as processing potatoes and wet harvest conditions, may require greater air flow. Where this is desired, adjust fan size, controls and duct design as required and according to sound engineering principles. Other storage applications, such as seed potatoes, may require less air than specified in this plan.

Temperature of ventilating air is controlled by two sets of proportioning dampers which blend cold outside air with return air from inside the storage. Commercial control systems are available for this application. It is important to understand the operation of the particular system chosen.

Ventilation controls, with motorized dampers to blend ventilating air at the fan room, may have problems with freezing of the fresh air dampers in cold weather. This plan illustrates an effective method of minimizing this problem. Cold-air dampers are separated from the humid inside air by an insulated door which can be closed for cold weather. A smaller opening in this door, covered with a blanket or plywood, swings open for temperature control. This feature is not needed for locations where winter temperature is seldom colder than -20°C [43].

Ventilation controllers vary in complexity, depending on the number of control strategies. The simplest strategy involves running the fans continuously. The volume of air is manually adjusted through the number of fans operating or by adjusting the speed of the fan(s). In this situation, the minimum sensors required are: the temperature control sensor that modulates the mixing damper; a low limit in the supply air to prevent accidental chilling or freezing of the tubers; and an outdoor sensor to prevent outdoor air warmer than the pile from entering the storage [7].

5.4. Air requirements

The airflow required to keep potatoes in good condition will vary. Maximum airflow usually is not needed throughout the entire storage season. However, it should be available for rapid cooling and if "rots" begin to develop in the potato pile. Make provisions to reduce the total quantity of airflow for when the maximum is not needed. An interval timer

is frequently used to control the amount of total daily airflow. Also, reduced airflow can be accomplished using a two-speed fan or more than one fan per plenum chamber. Unused fans should be covered to prevent backflow, if more than one fan is installed in a plenum chamber [44].

5.5. Fan selection

Once the required ventilation air is determined, a fan must be selected. The fan selected must have the required air capacity at the static pressure or back pressure generated by the potatoes and the duct and damper system. Normally, choose fans which deliver the required air at about 3/4 inch of static pressure. So called "basket fans" will not work. They deliver large amounts of air at minimal pressures, but virtually no air at pressures caused by the potatoes. Either "centrifugal" or "axial flow" panel fans may be used for potato storages. Centrifugal fans are quieter but also more expensive [44].

5.6. Walls

Most modern potato stores are constructed with a framework, usually of reinforced concrete and steel frames. The supporting pillars are linked together by lower tie-bars, which are themselves secured to the floor slab, and by upper tie-bars, which hold the frame firmly together. It is essential that all joints are secure and accurate, and that the reinforcing rods are well covered with concrete.

The walls of the potato store are built between the supporting pillars. If the supporting posts are thicker than the walls, it is important that the extra thickness is on the outside of the building so that the internal surfaces of the walls are smooth and free from projections. This facilitates cleaning of the store, and avoids interference with other operations as well.

A vapour-proof barrier should be incorporated into the base of the walls, to prevent damp rising and causing damage to the store structure and its contents. Also, a concrete strip about 1 m wide should be laid around the outside of the warehouse, to prevent rain from eroding the base of the walls below the damp course [45].

5.7. Roof

Internal pillars supporting roof frames should be avoided because, as previously stated, they can interfere with pest control and other stock management procedures. Instead, roof frames should be designed so that they transfer the weight of the roof to the supporting columns (in framed buildings), or to the walls if the store is small.

Modern engineering techniques allow very wide 'free-span' roofs (i.e. roofs without internal supporting pillars) to be constructed. However, such roofs are very expensive and rarely used in store construction. A steel portal frame should be used if the span is to be greater than 15m. Stores less than this width may have reinforced concrete roof frames.

Roof frames made of wood or steel are only suitable for stores not more than 4 or 6 m wide. The wood used must be well dried and treated with a preservative. Roof cladding may be of galvanised steel or aluminium sheeting, or asbestos cement; the latter being more fragile but having better insulating properties. Tiles are not recommended, especially for large stores.

The roof should overhang the gables by 0,7 to 1,0m, and the eaves by at least 1m. This ensures that rainwater is shed well clear of the walls; and obviates the need for guttering and drainpipes, which may become blocked or assist rodents entering the store. The overhang also helps to keep walls cool and protects ventilation openings from rain [45].

5.8. Doors

Doors are commonly the major source of air leakage in potato stores. The best arrangement is for there to be only one crop loading door into the store, and it should open into a second building such as a grading area so that it acts as an airlock. The door should be well-sealed and easy to open and close. The number of doors will vary according to the size of the store. If possible there should be at least two doors, so as to be able to rotate stocks on a 'first in, first out' basis. However, this may not be possible or practical in a very small store.

Double sliding doors are recommended. Preferably made of steel, or at least reinforced along their lower edges with metal plate as protection against rodents, they should be sufficiently large (at least 2,5x2,5 m) and close fitting. If swing doors are fitted they should open outwards in order not to reduce the storage capacity of the store. It is recommended that the doors be protected from rain by an extension of the roof or a separate cover [45].

Sliding doors designed for food chillers also make good doors for potato stores. The track is so designed that when the door is nearly shut, it moves laterally, so that it seals against the frame of the doorway on all four sides [21].

6. CONCLUSION

The following conclusion can be drawn from this study:

1. Potato tubers are living, respiring, biologically active organisms that require optimal storage conditions to maintain the quality that is present at harvest. Successful storage requires that growers have an understanding of the factors that affect tuber health and quality.
2. The greatest weight loss from potatoes normally occurs during the first two to three weeks of storage. During this period high respiration rates high moisture loss and high heat production occurs. To minimize the amount of weight loss or shrink during early storage, proper suberization or wound healing must occur.
3. Basic structural requirements for potato storage include a) wall strength to resist the pressure of the potatoe, b) floor strength to support the load due to truck and equipment traffic c) insulation to reduce or prevent the insulation and structurel framework and reduce moisture loss from the storage. In addition to the loads imposed on the building by the potatoes, it must also support other loads such as wind and snow.
4. Ideal conditions are ventilated, cool temperatures, high humidity and no light.
5. Low-cost in-field storage is feasible but is labour-intensive and vulnerable to high crop loss through rotting and disease.
6. Carbon dioxide concentration in stores should be monitored routinely to ensure staff safety and to avoid blackheart in the crop.

7. Ventilation systems usually consist of an inlet, blending chamber, fan, distribution system and exit louvres.

8. Refrigeration systems are only operated when store louvres and doors are shut completely.

9. Physiological disorders in potatoes which remain in the store for a long time under such conditions is inevitable and thus causes storage failure. Therefore, temperature and moisture content of the potatoes and the resulting bulk density and angle of internal friction have to be taken into consideration in the design of stores.

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