# TUBER QUALITY

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Tuber size, shape, appearance, absence of diseases or defects, flavor, and cooked texture all contribute to potato quality. This section will provide suggestions for quality maintenance during production and storage.  Potato solids and sugars will be discussed, followed by tuber defect problems.  A more detailed discussion of potato tuber quality can be found in chapters 15 and 16 in the *Potato Production Systems* book.

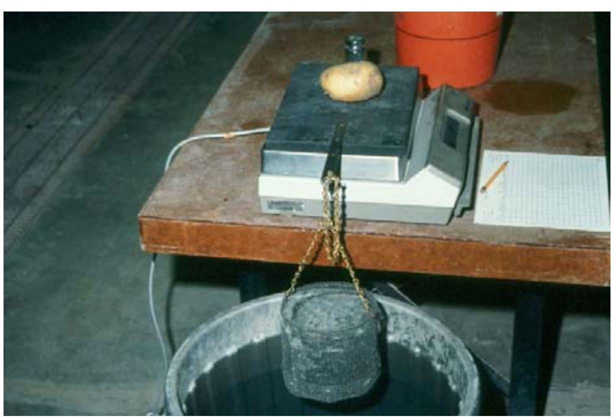
## PROCESSING QUALITY

Sugar and starch content are critical quality factors for processing potatoes.  Tuber solids make up about 20 percent of fresh tuber weight. Starch makes up about 70 percent of total tuber solids. Starch is heavier than water, and, therefore, is the primary determinant of tuber density, which is commonly referred to as tuber specific gravity. Starch, tuber dry matter content, tuber solids content, and tuber specific gravity are terms used interchangeably when related to tuber processing quality.

French fry color rating chart

Tuber sugar content is important because of its influence on fried product color. When tubers are fried, sugars combine with amino acids and other compounds to form the dark color and flavor we associate with “burned” food. The reducing sugars glucose and fructose create the most serious problems during frying because they are chemically reactive. Sucrose contributes little to dark color development but is still important because it is the substrate for creating more reducing sugars under the right environmental and physiological conditions.

## TUBER SPECIFIC GRAVITY


Apparatus for measuring specific gravity

### Environmental Factors That Influence Specific Gravity

Air and soil temperatures are the primary environmental factors affecting specific gravity of irrigated potatoes. Warm days (80° to 90°F) and cool nights (50° to 60°F) provide optimal conditions for producing high specific gravity tubers. High soil temperatures have a direct effect on tuber physiology and inhibit starch deposition. Other weather conditions can also affect tuber specific gravity. High evaporative demand caused by low relative humidity, high solar radiation, and/or high wind speed can also reduce photosynthesis. Prolonged periods with overcast skies can reduce light intensity to levels below that required for maximum dry matter production.  Any event or condition that destroys foliage or shortens the growing season can influence tuber specific gravity.

## Cultural Factors That Influence Specific Gravity

Unlike environmental factors, management factors are under the direct control of the producer. Management can impact tuber specific gravity as much or more than weather or climate. Factors a grower can control include the following:

### *Choice of Variety*

Potato varieties vary widely in their ability to accumulate starch in the tubers. The choice of variety is probably the most critical decision with respect to matching tuber quality with intended market.

### *Seed Management and Planting*

Producing a crop with high and consistent tuber specific gravity is dependent on having a uniform stand of vigorous plants. Growers need to design seed management programs that produce optimal plant populations and stem numbers. This will allow for efficient use of nutrients and water and help provide uniform growing conditions that will allow each plant to maximize productivity and tuber dry matter production.

### *Nutrient Management*

Optimum plant nutrient concentrations are essential for maintaining high vine and tuber growth rates over the entire growing season. However, applying excessive amounts of nitrogen and potassium can decrease specific gravity.

- **Nitrogen:** When other growing conditions are favorable, increasing nitrogen (N) availability up to the optimum level increases U.S. No. 1 yield and average tuber size without decreasing specific gravity. However, excessive N rates stimulate vine and root growth and delay tuber bulking and maturation.

- **Potash:** It is important to avoid excessive late-season applications of potash. Starch synthesis and specific gravity increase with increasing K concentration up to an optimum tuber concentration of 1.8 percent. However at higher K concentrations, specific gravity decreases as tubers begin to absorb more water due to the osmotic effects of increased tissue salt concentrations.

- **Phosphorus:** Phosphorus (P) tends to increase starch synthesis, but in contrast with N it hastens rather than delays maturity. Phosphorus deficient potato plants typically produce tubers with lower specific gravity compared to those with adequate P nutrition. The P/N balance is also important and, to a degree, adequate P can help counter low specific gravity associated with high N levels.

### *Irrigation*

Water stress (too much or too little) during tuber growth tends to decrease specific gravity, particularly when accompanied by high temperatures. To promote high specific gravity, available soil water content should be maintained above 65 percent throughout the tuber growth period until just before vine kill.

***Soil Conditions, Tillage, and Cultivation***

Medium textured soils, such as sandy loams, loams, and silt loams, generally produce potatoes with higher specific gravity than very sandy or heavy clay soils. Well-managed loam soils have good water-holding and nutrient supplying characteristics that allow for high rates of growth and tuber dry matter production.

Tillage, planting, or cultivation practices that increase soil compaction and hardpan development can increase plant water stress, restrict root and tuber growth, and decrease tuber dry matter accumulation. In addition, cultivation practices, such as late weed tillage that increase root pruning, can increase plant water stress and reduce tuber quality.

***Length of Tuber Growth Period***

Because specific gravity is related to maturity, tubers that have a longer time to accumulate carbohydrates will generally have higher specific gravity than those with shorter growth periods. Therefore, early planting can increase the number of days that can potentially contribute to tuber starch deposition.

***Disease Management***

Diseases, such as Verticillium wilt, early blight, and late blight that destroy foliage and shorten the length of the tuber growth period can also affect specific gravity. Disease suppression should involve season-long processes, rather than quick-fix strategies that can detrimentally affect crop growth.

***Vine Kill and Harvest Management***

Tubers that remain in the soil after vine death can actually lose dry matter as starch is converted back to sugars for use in respiration. This is especially evident when soil temperatures are high. Killing green vines while the root system is still actively absorbing water can cause significant amounts of water to move from the roots into the tubers and decrease specific gravity.

## TUBER SUGAR CONTENT

### Factors That Affect Tuber Sugars

As a general rule, any environmental or management factor that increases specific gravity also decreases sugars, and vice versa. For this reason there is no need to revisit all of the factors covered in the specific gravity section of this chapter as they relate to sugar content. Additional factors, including maturity, temperature, variety, storage stress, and handling that influence tuber sugars in a unique fashion will be discussed here.

***Tuber Maturity***
Potato tubers usually have high sugar content early in their development because the rate of transport from the leaves exceeds the rate of conversion to starch. As the tubers grow and mature, the sugar content decreases, reaching the lowest point when the vines are nearing complete senescence.

***Temperature***
Temperature both in the field and in storage has a large impact on tuber sugar content. High soil temperatures result in sugar ends or other sugar-related problems. Low temperatures result in cold-induced conversion of starch to sugars. The intended end use of potatoes dictates the appropriate storage conditions. Potatoes intended for chip processing are typically stored at 50 to 55 F, for french fry processing 47 to 50 F, for fresh use 42 to 45 F, and for seed 37 to 40 F.

***Variety***
It is critical to match varieties with intended use. In general, potatoes bred for the chipping industry are lowest in sugars. Potatoes bred for french fry processing typically have intermediate sugar contents, while those bred for the fresh market usually have the highest.

***Storage Stress***
In addition to cold induced stress, other conditions in storage can produce an increase in tuber sugars. The most important of these is insufficient air ventilation. If a pile of potatoes becomes oxygen starved because of infrequent operation of the storage air system or because of excess dirt or other air blockage, the normal physiology of the tuber can be disrupted and sugar levels increase. Other problems that increase sugars include sprouting due to inadequate inhibition and the development of “hot spots” due to the presence of rot.

***Handling***
Normal tuber handling as part of moving potatoes into or out of storage has been shown to cause a slight increase in tuber sugars. This increase is usually short-lived, and the tubers will decline to prehandling levels after a week or so if the tubers are not subjected to other stress factors.

## USING SUGAR MEASUREMENTS TO PREDICT AND MANAGE TUBER QUALITY

Growers and storage managers can use sugar measurements to assess current quality status and to predict possible changes in quality during storage. Sugar measurements can also be used to optimize harvest timing and make correct decisions on storage temperature protocols.

## Assessing Current Quality

Potatoes intended for chip production should have a reducing sugar level below 0.35 mg/g (or 0.035%) of fresh tuber weight (See Table below). Potatoes intended for processing as french fries should have less than 1.2 mg/g (or 0.12%) of tuber fresh weight. Potatoes with higher values than these will usually show color problems after cooking.

**Target maximum harvest and storage sucrose and glucose content in potatoes.**

| Intended market | Sucrose content (mg/g FW) | Glucose content (mg/g FW) |
|---|---|---|
| *Harvest time* | | |
| Chips | 1.5 (or 0.15%) | 0.35 (or 0.035%) |
| French fries | 1.5 (or 0.15%) | 1.20 (or 0.120%) |
| *During storage* | | |
| Chips | 1.0 (or 0.10%) | 0.35 (or 0.035%) |
| French fries | 1.5 (or 0.15%) | 1.20 (or 0.120%) |

## Chemical Maturity and Storage Monitoring

Probably the most valuable use of tuber sugar measurements is monitoring of sucrose for the purpose of evaluating the potential for color problems. This technique was originally described by Joe Sowokinos and Duane Preston (North Dakota State University and the University of Minnesota) and can be used to make proper harvest and storage management decisions.

*Maturity Monitoring*

Harvest timing decisions can be facilitated using sugar measurements.  During the last month of the growing season, fields should be sampled weekly and sugar content determined. Prior to harvest, during vine senescence, sugar levels should fall below the levels indicated in the table above.  This is indicative of chemical maturity and suggests harvest can occur with maximum likelihood that quality can be maintained in storage.  At this stage, the most critical factor is sucrose level. If it is below the indicated levels, harvest can occur and the tubers can be stored in a normal fashion with the final holding temperature dependent on the variety and intended market.

*Determination of Early Storage Condition*

If tubers come out of the field with sugar levels that are above the target values shown in the above Table, they are preconditioned to having cooking problems. However, storage managers can consider one of the following strategies that are based on manipulation of early storage temperatures. These economically critical decisions are based on levels of sucrose and glucose at harvest.

- **Scenario 1:** Sucrose levels are acceptable (<1.5), but glucose levels are too high (chips >0.35, fries >1.2). The immediate fry color may be too dark, but the potential for long-term storage can still be good.

- *Action*—During the wound-healing period at the beginning of storage, the temperature should be held at 60ºF for 2 weeks or until the glucose concentrations drop to acceptable levels. The temperature can then be ramped slowly downward to 45° to 48°F for fries or 50° to 52ºF for chips. Glucose levels should subsequently be determined at regular intervals to ensure they remain within the acceptable range.

- **Scenario 2:** Sucrose levels are too high (>1.5), but glucose levels are acceptable (chips <0.35, fries <0.12). The immediate fry color may be good, but long-term storage may be negatively impacted as sucrose is converted to reducing sugars.

- *Action*—The same wound-healing conditions should be use as given for Scenario 1. The sucrose levels should be determined at the end of the wound-healing period. If the sucrose levels are still too high, a higher than normal holding temperature (possibly 55ºF for chipping potatoes and 50ºF for frying potatoes) may be required. It may be necessary to sell these potatoes before others that have better sugar indicators.

- **Scenario 3:** Both the sucrose and glucose levels are too high. Both the immediate fry color and long-term frying potential may be poor.

- *Action*—The recommendations described for Scenario 2 should be followed. A wound healing temperature of 60ºF should be maintained until both the sucrose and glucose levels are acceptable. A more intensive monitoring program will be required, with sugars being measured at least every 5 days. The storage manager should consider moving these potatoes to market as early as feasible.

***Storage Maintenance***

As mentioned earlier, storage conditions can cause potatoes to accumulate unacceptable quantities of sugars, even when the levels are acceptable at harvest. Sugar analysis can be used to indicate when conditions need adjustment. Sugar accumulation in storage can generally be attributed to cold temperatures, inadequate supply of air to the pile, or senescent sweetening. These conditions can be detected by sugar monitoring, usually before any obvious decline in quality.

**Low Temperature Stress:** When storage temperatures are too cold, both sucrose and glucose levels will climb simultaneously into the unacceptable range. This can occur within a few days if the temperature is several degrees below optimum, or it can occur slowly when the temperature is only a few degrees too low. Problems with low temperature sweetening can usually be solved with a 2- to 4-week period of reconditioning at 55 to 60ºF, followed by a slow return to the desired holding temperature.

**Inadequate Air:** Oxygen deprivation caused by inadequate air movement in the storage, causes sucrose levels to slowly increase. Later, the glucose levels follow the same pattern and the fry color goes off-grade. Another typical symptom of ventilation stress is that individual tubers may fry darker in the middle than around the outside. Early detection of the rise in sucrose levels can help resolve this problem. Solving the problem may be as simple as increasing the frequency or length of ventilation to the pile.

If the problem is one of inability to move air through the pile due to obstructions or dirt, more drastic measures may be required, such as early marketing of the potatoes or movement to a different storage building. If ventilation stress is the culprit, an increase in air supply will result in an immediate response to corrective action, but the return to acceptable sugar levels may be slow.

**Senescent Sweetening:** The maintenance of acceptable sugar concentrations during the first 5 to 8 months of storage, followed by a slow increase in sucrose levels over the next several months, may be an indication of senescent sweetening. Senescent sweetening is a permanent condition and only gets worse with time. If no temperature stress or ventilation problems can be identified, and a sample of potatoes removed from the storage does not respond to reconditioning, then the potatoes should be marketed as quickly as possible.

If an entire pile of potatoes is suspected of age-related sweetening, it is critical that no attempt be made to recondition the potatoes. Warm temperatures will only speed up the aging process and make the problem worse.

## TUBER QUALITY FACTORS RELATED TO PHYSIOLOGICAL DEFECTS

Potato tubers can exhibit numerous defect problems or disorders that are not caused by diseases or insects. External tuber disorders can reduce marketability as well as cause reductions in processing quality and storability. Internal tuber disorders often go undetected until after tubers are cut and inspected. However, these disorders can also result in significant reductions in crop quality and marketability.

Understanding the primary causes of each physiological disorder and how they affect the storability and marketability of the crop will aid the grower in developing management systems that minimize their occurrence. Following is a discussion of common physiological problems, their causes, and management practices that will minimize their occurrence.

### External Physiological Disorders

**Malformed Shape:** Tuber growth rates often fluctuate in response to widely varying growing conditions causing malformations, such as bottlenecks, dumbbells, pointed ends, and knobs. *Symptoms and Causes*: Heat or water stress can cause constricted tuber growth

in the bud, middle, or stem end portion of the tuber, depending upon the extent of the stress and the stage of growth at which it occurs. For example, a tuber with a pointed bud end indicates that the stress-induced restriction in growth occurred during late tuber bulking, while pointed stem ends indicate early season stress. Growth interruptions during mid-bulking can cause dumbbell-shaped tubers. Knobby tubers are caused when secondary growth occurs at lateral eyes on the tuber due to loss of apical dominance. These symptoms can cause potatoes to be graded as U.S. No. 2's and can also cause sugar accumulation and specific gravity reduction in the affected area of the tuber.
_Management_: Management approaches for preventing malformed tubers include promoting uniform growth by establishing uniform stands, avoiding large fluctuations in nitrogen availability, maintaining available soil water content above 70 percent, and general avoidance of cultural practices, such as late cultivation, that may alter tuber growth patterns.

***Heat Sprouts/Tuber Chaining:*** During periods of hot weather (85ºF and above), plants may respond by increasing top growth rather than tuber production. One consequence of this growth pattern is the tendency for stolons to remain vegetative. The result can be the development of heat sprouts and chain tubers or heat runners.
_Symptoms and Causes_: Heat sprouts develop when stolons continue to elongate, emerge through the soil surface, and develop into a leafy stem. This may occur before any tubers set on the stolon, or as a result of stolons reforming from the bud end of tubers at any stage of development. Tuber chaining symptoms occur when multiple tubers develop on a single stolon. In severe cases, tubers develop from the eye or stolon of another tuber. Heat sprouts and chain tubers are caused by renewed growth after periods of interrupted development during extended exposure to warm soil temperatures (greater than 75°F).
_Management_: Prevention of these disorders includes avoidance of environmental stress and encouraging uniform vine and tuber growth by using proper planting, hilling, fertility, and irrigation practices.

***Tuber Cracking:*** Potato tuber cracking can take the form of growth cracks, elephant or alligator hide, skin checking, or any other symptom showing a cracked appearance of the skin. Symptoms can be either superficial or affect a major portion of the tuber.
_Symptoms and Causes_: Growth cracks appear as large, open fissure in the tuber skin and flesh and are caused by irregularities in tuber growth, especially in response to widely fluctuating water supplies.

Other factors, including virus infection and herbicide injury, can also cause tuber growth cracks. Elephant or alligator hide develops during the growing season and appears as shallow, corky cracks on the tuber skin. The primary cause of this condition is unknown, but contributing factors may include high temperature, high soil organic matter, and excessive soil moisture and fertilization.
*Management*: Prevention of growth cracks is accomplished primarily by maintaining uniform, adequate soil moisture and nutrient levels throughout tuber bulking. Minimizing elephant hide is largely a matter of growing resistant varieties.

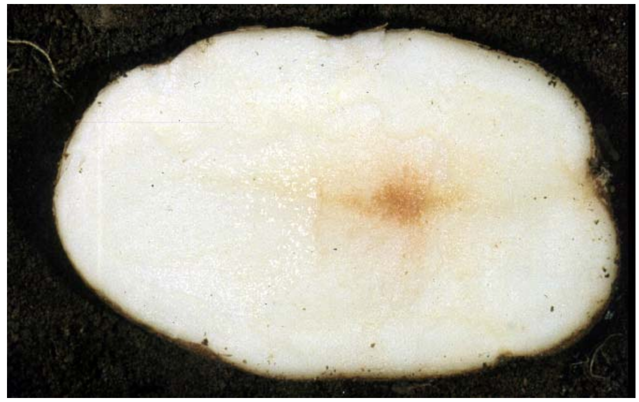
***Feathering/Skinning:*** Feathering or skinning is commonly observed after handling immature potatoes and is a result of incomplete development of the skin layer (periderm). The potential for weight loss and disease in storage is considerably greater with feathered potatoes.
*Symptoms and Causes*: Feathering or skinning occurs only upon handling. The skin of the potato is partially or completely removed, exposing the underlying tuber flesh. If the skin is partially removed, it remains attached to the tuber but dries out and has an "onion-skin" texture.
*Management*: Approaches for preventing this disorder include managing irrigation, fertilizer, and vine kill practices to achieve proper maturity and skin set at harvest. High late-season nitrogen availability and excessively wet soils will delay maturity and increase susceptibility to skinning and feathering. Achieving complete vine kill 14 to 21 days before harvest will usually provide sufficient time to "set" the skin.

***Enlarged Lenticels:*** Lenticels are openings on the potato that allow for air exchange and can become enlarged when exposed to waterlogged soils or prolonged wet conditions.
*Symptoms and Causes*: Reductions in oxygen availability resulting from saturated soils or maintaining wet tuber surfaces for extended periods of time in storage will cause lenticels to open and become enlarged. Enlarged lenticels look like small, white bumps on the surface of the tuber. This disorder not only makes a tuber less attractive, but makes it more susceptible to the entry of disease organisms, especially soft rot.
*Management*: To avoid enlarged lenticels, proper irrigation practices should be followed, especially late in the season. Allowing soil moisture to drop to 65 to 70 percent between irrigations is usually adequate to prevent swollen lenticels.

***Greening:*** Light-induced formation of a green surface color, resulting from chlorophyll accumulation, is known as greening.
*Symptoms and Causes*: Tubers growing at or close to the soil surface may become green from direct exposure to sunlight or from light penetrating through cracks in the soil surface. This is usually an intense

green color on a limited part of the tuber surface. Greening also occurs from extended exposure to low light levels in storage or on store shelves. This situation usually produces a lighter and more diffuse coloration of the entire tuber.
*Management*: Several cultural practices can be used to minimize greening, including proper seed planting depth and hilling, and rolling during vine kill to close soil cracks. In storage, potatoes should not receive prolonged exposure to light.

**Internal Physiological Disorders**



***Brown Center/Hollow Heart:*** Brown center and hollow heart can cause serious losses in crop quality and economic return to the grower. The causes of these related disorders can be complex, and development can occur throughout tuber growth.
*Symptoms and Causes*: A brown discoloration, without a visible flesh separation in the center of the tuber (pith region), is known as brown center. Although this disorder does not always result in hollow heart, it is considered to be a milder form of the same defect. Soil temperatures below 55 F for 5 to 7 days during early tuber development can initiate brown center. Available soil moisture >80 percent and high level of available nitrogen fertilizer can increase the incidence of brown center. Hollow heart is characterized by the formation of an irregular cavity in the flesh of the tuber, often surrounded with brown, discolored tissue. The cavities can vary in size and can form in the center of the pith or near the stem or bud ends of the tubers, depending on when the disorder develops. Two distinct types of hollow heart can exist in potatoes, namely early- and late-initiation hollow heart. Early-initiation hollow heart appears shortly after tuber set and is caused by the same factors that cause brown center. Late-initiation hollow heart occurs during the latter part of the tuber-bulking period and is not usually associated with brown center. It is most commonly caused by conditions that slow tuber growth, cool soils, and/or water or nutrient stress, followed by a return of favorable conditions and rapid tuber growth.

*Management*: The potential for developing brown center and hollow heart can be reduced by establishing uniform plant spacing and planting depth to encourage uniform emergence, and using cultural practices that promote steady, uniform growth rates. Applications of N fertilizer should be small during early tuber development to maintain adequate tuber growth rates while minimizing the potential for brown center and hollow heart development. In addition, maintaining available soil moisture between 65 and 80 percent should minimize the development of these disorders while allowing for acceptable tuber yield and quality.

***Internal Necrosis:*** Internal necrosis is also referred to as internal brown spot (IBS) or heat necrosis. It is generally a problem only in areas with high air and soil temperatures during late tuber bulking.

*__Symptoms and Causes__*: This disorder is typified by small, brown, necrotic lesions or spots primarily inside the vascular ring of the tuber. Internal necrosis differs from brown center in that it does not concentrate in the center (pith) of the tuber, but rather appears as diffuse spots distributed elsewhere in the tuber flesh. Symptoms may begin to develop shortly after tuber initiation but, more commonly, this problem becomes more severe during late tuber bulking and senescence. Symptoms also tend to intensify during storage, particularly under warm conditions.

*__Management__*: Prevention of internal necrosis requires maintaining adequate soil moisture, especially during hot periods, applying adequate calcium in the tuber-forming zone in the soil (particularly in sandy or low calcium soils), and managing fertilization, irrigation, and other cultural practices to promote uniform vine and tuber growth.

***Stem-end Discoloration:*** Several diseases, including Verticillium wilt and potato leafroll virus, can cause vascular and/or stem-end discoloration. However, there is also an abiotic disorder that causes symptoms that are similar to the disease-induced vascular discoloration, called stem-end discoloration (SED).

*__Symptoms and Causes__*: This physiological disorder is typified by a shallow, brown discoloration in the vascular system (phloem and xylem) near the stolon attachment. Intensity can vary with season and cultivar but typically does not extend greater than 0.5 to 1.0 inch into the tuber. SED may or may not be visible at harvest but may develop during storage. SED can easily be confused with net necrosis and laboratory analysis for potato leaf roll virus (PLRV) will determine whether the visible symptoms are due to SED or to net necrosis caused by PLRV.

*__Management__*: Practices for reducing SED are difficult to elucidate because causal factors have not been clearly identified. However, cultural practices should include avoiding vine killing when the plants are subject to moisture or high temperature stress, or if the vines have not begun to senesce. Irrigation before vine kill may often reduce the potential for SED development.

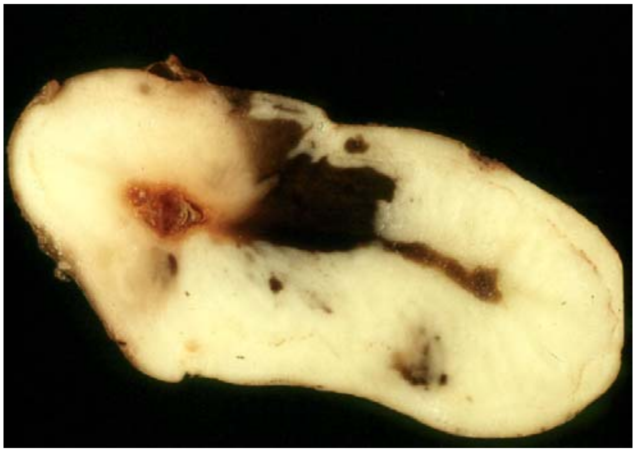
***Sugar Ends/Translucent Ends:*** The physiological disorder commonly referred to as sugar ends is also known as translucent ends, glassy ends, or jelly ends. It is a serious concern for processing potatoes and mostly affects varieties with long tuber type such as Russet Burbank.

*Symptoms and Causes*: This disorder usually shows up as a post-fry darkening of one end of a french fry, usually on the stem end of the tuber. This darkening is primarily caused by the accumulation of reducing sugars at the one end, which when fried, produces the undesirable dark color. Often the end of the tuber that fries dark also exhibits a restriction in growth or pointed end. This affected end will typically have lower specific gravity and a visible “glassy” or translucent appearance of the flesh. In severe cases, this disorder predisposes the tuber to subsequent tissue breakdown and the development of jelly end rot. Sugar ends are typically associated with periods of high air and soil temperatures and water deficits during tuber initiation and early bulking.

*Management*: Minimizing sugar end development requires avoiding moisture stress during tuber initiation and bulking, especially during early tuber development. Heat stress during this time can substantially increase the development of sugar ends. The following management checklist outlines some of the key cultural practices that can be used to minimize sugar end development:

1. Choose fields that have the potential to grow a high quality potato crop. Avoid fields with highly variable texture or topography, especially those with shallow or high bulk density soils.
2. Plant potatoes after wheat, barley, corn, or other crops that leave significant amounts of crop residue after harvest and minimize soil compaction. Shallow incorporation of crop residues can improve water infiltration and aeration and can reduce soil bulk density. Avoid planting potatoes after sugar beets or onions because of the reduced amounts of crop residue and a greater potential for soil compaction.
3. Bed soil in the fall when weather and soil conditions permit to facilitate early planting.
4. Manage irrigation to provide uniform water application and optimal water infiltration and soil water distribution throughout the field. Sprinkler irrigation is preferred over gravity irrigation because of greater water application uniformity and flexibility in irrigation scheduling.
5. Apply straw mulch or PAM in irrigated furrows, which can improve water infiltration and distribution within the hill. On sloping, variable ground use a properly designed sprinkler system with flow control nozzles and use basin tillage where appreciable runoff is expected.
6. Monitor evapotranspiration and soil water status on a regular basis to determine crop water requirements and maintain available soil water content in the crop root zone within the optimal range.
7. Use a good soil sampling and testing program and fertilize according to established guidelines for your area. Avoid excessive nitrogen applications since high N can delay tuber bulking, thereby increasing potential exposure to heat stress.

***Blackheart:*** Blackheart occurs in the field or in storage when the oxygen supply to tubers is insufficient to support adequate respiration rates.



*Symptoms and Causes*: This disorder causes distinctive symptoms typified by a dark, black, or black-blue discoloration in the center of the tuber. In the field, this disorder is most prevalent in waterlogged soils in low-lying areas. Blackheart that develops in the field is not always observed because the tubers tend to break down before harvest. Blackheart can also occur in storage if proper ventilation is not supplied to the tubers.

*Management*: In-field management for blackheart prevention includes proper irrigation scheduling and using basin tillage to minimize the accumulation of run-off water into the low spots of the field. Maintenance of adequate ventilation and proper temperatures helps minimize blackheart development during potato storage and transport. Maintaining proper airflow through the potato pile will also minimize the potential for blackheart.

***Freezing/Chilling Injury:*** Potato tubers are susceptible to frost or chilling injury. Pulp temperatures below 30°F for extended periods or colder temperatures for short periods can severely damage tubers. Widespread injury can result in total loss.

*Symptoms and Causes*: Damage may occur while the potatoes are still in the ground before harvest, in transit, or in storage. Potatoes that are exposed to freezing (below 28°F) or chilling (28 to 34°F) temperatures can show multiple symptoms. Freezing damage is difficult to diagnose while the tubers are frozen because they show no obvious symptoms other than the surface being hard. As the tubers begin to thaw, the first obvious sign of frost damage is free moisture (weeping) on the outside of the tuber. The next phase is cellular breakdown causing the tissue to turn brown, gray, or black. Typically, a distinct line is visible between healthy and frozen tissue. In the case of chilling injury, cells are not frozen and tissues do not rapidly break down. Chilling injury is not visible on the tuber surface, but internal tissues exhibit a variety of symptoms, including mahogany browning, reducing sugar accumulation and fry darkening, tissue graying upon boiling, and necrotic phloem injury.

*Management*: To minimize frost or freezing damage, proper hilling procedures should be used to minimize tuber exposure to cold air temperatures. If possible, potatoes should be harvested before potential frost exposure. In addition, potatoes should be transported in favorable conditions and storage temperatures maintained above 37ºF.

***Internal Sprouting:*** Internal sprouting is a disorder that occurs in storage. As the tubers break dormancy, sprouts typically will grow away from the tuber, but because of an external growth restriction, the sprouts grow into the tuber rather than outward.
*Symptoms and Causes*: Internal sprouting can be caused by chemical or physical sprout inhibition. Symptoms include the growth of sprouts from eyes that penetrate back into the tuber flesh. One physical cause of this disorder is thought to be pressure or contact by other tubers, debris, or storage walls against a sprouting eye, thus restricting outward growth and forcing the sprout to grow inward. Internal sprouts can also occur when residue levels of the sprout inhibitor CIPC are insufficient to completely inhibit growth, or when sprout inhibitors are applied after significant sprouting has begun.
*Management*: To prevent internal sprouting, adequate turgidity of the stored tubers should be maintained, dirt and debris should be eliminated from the stored potato pile, and the proper rate and timing of sprout inhibitor applications should be used.

**Bruise Damage**
Impact damage during harvest and handling or pressure damage during storage can cause blackspot, shatter, or pressure bruise. The type of tuber damage that can occur is dependent upon several factors: (1) the variety; (2) the physiological condition, temperature, and hydration level of the tubers; (3) the size and shape of tubers; and (4) the type and force of impact.

***Blackspot Bruise:*** Significant impact to tubers during harvest or transport causes the cell membranes within the affected tissue to rupture. As a result, cell contents intermix and react, causing the formation of a black pigment, melanin, which is responsible for the discoloration.
*Symptoms and Causes*: Blackspot bruises appear beneath the skin, and there are generally no external symptoms. Blackspot symptoms will typically not be apparent for 12 to 24 hours after the damage has occurred, which makes early detection of the damage difficult. The damaged area first turns pink to reddish-brown, then darkens to grayish-black as the melanin begins to form. Factors that favor blackspot bruise include large tuber size, poor tuber hydration or turgidity, high specific gravity, potassium deficiency, tubers with significant curvature, and physiologically old or very mature tubers. Cultivars differ greatly in susceptibility to blackspot bruising primarily because of differences in chemical composition and tuber shape.
*Management*: Practices for reducing blackspot bruise include selection of less susceptible varieties; maintenance of proper tuber hydration levels before harvest; proper fertilizer applications, especially with nitrogen and potassium; avoidance of early dying and advanced tuber maturity; and good harvest and handling procedures with proper tuber maturity and pulp temperatures and correct harvester adjustment and operation.

***Shatter Bruise:*** Shatter bruise differs from blackspot bruise in that the cell walls of the tuber tissue separate due to impact. The result is development of a visible crack in the tuber surface.
*Symptoms and Causes*: Shatter bruise produces a cracked or shattered appearance at the point of impact due to a rupture in the tuber skin and the tissue directly underneath. Symptoms become readily apparent when the tissue dries out and separates. Factors that favor shatter bruise development include high tuber hydration or turgidity, cool (<45°F) pulp temperatures, and improper handling. Thumbnail cracks, also called air checks, are a mild form of shatter bruise with shallow, curved cracks on the tuber surface. They are caused by handling injury on cold, turgid tubers, followed by exposure to low humidity conditions. On occasion, simply lifting tubers from the soil, with an associated release of pressure, is enough to cause thumbnail cracks.
*Management*: Management practices for reducing shatter bruise include proper fertilization, irrigation, and pest control to allow tubers to reach proper maturity at harvest; allowing tubers adequate time to mature after vine kill; avoiding excessive soil moisture during tuber maturation; harvesting only when tuber pulp temperatures are above 45°F; and using harvesting and handling practices that minimize tuber damage.

***Pressure Bruise:*** Pressure bruise is a disorder resulting from tissue damage due to the weight of an overlying potato pile. It is strictly a storage problem and affects otherwise healthy tubers, especially after exposure to low humidity conditions.
*Symptoms and Causes*: Externally, pressure bruises appear as flattened areas or indentations on the tuber surface. If there are not internal symptoms, this is termed “pressure flattening.” Internal symptoms include a gray to black discoloration in the flesh, usually darker in the vascular region. In severe cases, pressure bruise can affect one entire side of a tuber and be accompanied by tissue cavitation. Conditions that favor pressure bruise development include dehydration of tubers coming into storage, low storage humidity (<90 percent), warm storage temperatures, excessive potato pile height, and long storage duration.
*Management*: Practices to reduce pressure bruise include pre-wetting the storage floor, maintaining storage humidity above 90 percent RH, keeping storage temperatures in the optimal range, gradually cooling the storage to the final holding temperature, and not piling potatoes higher than 18 feet.