Chapter 15
Tuber Quality

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Contents

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Introduction

Tuber size, shape, appearance, absence of diseases or defects, as well as the flavor, color, and texture of cooked or processed products all contribute to potato tuber quality. Quality may be related to visual appeal, consumer culinary preferences, or the ability to meet market specifications.

Two of the most important quality characteristics of potatoes are starch content, which impacts cooked product texture, and sugar content, which has a direct bearing on fried product color. This chapter will provide basic information on tuber sugar and starch physiology and how they respond to environmental and cultural factors. The impact of diseases and physiological disorders on quality are discussed in Chap. 9 and Chap. 14.

Processing Quality

More than half of all potatoes grown in North America are used for processing, mostly for making chips and french fries. Potatoes produced for processing must meet closely monitored specifications for starch and sugar content.

High starch content is favored by processors to ensure products have acceptable texture and keep processing costs down by limiting the amount of raw product needed, the cooking time required, and the amount of oil absorbed. Baked potato products also need high levels of starch to produce the fluffy, relatively dry texture that is preferred by most consumers.

Table 15.1 Values for converting potato specific gravity to percent dry matter and/or starch content

Tuber specific gravity	% dry matter[a]	% starch[b]
1.050	14.2	7.9
1.055	15.3	8.9
1.060	16.4	9.8
1.065	17.4	10.8
1.070	18.5	11.8
1.075	19.6	12.8
1.080	20.7	13.8
1.085	21.8	14.8
1.090	22.9	15.8
1.095	24.0	16.8
1.100	25.1	17.8
1.105	26.2	18.8
1.110	27.3	19.8

[a]Calculated from Kleinkopf et al. (1987) where % dry matter = −214.9206 + 218.1852 (specific gravity)

[b]From Hassel et al. (1997), Ohio State University Horticulture Series 666. Calculated from the Von Scheele equations where % starch = 17.565 + 199.07 (specific gravity – 1.0988)

Tuber solids make up about 20% of tuber fresh weight, comprised mainly of starch, sugars, amino acids, proteins, and minerals. Starch makes up about 70% of total tuber solids, while the other compounds are present in much smaller amounts. 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 describing tuber baking and processing quality.

For most processed products, a starch content of 13% or higher, a solids or dry matter content of 20% or higher, and/or a specific gravity of 1.080 or higher is preferred (see Table 15.1 for interconversions). Tuber specific gravity is the measure of choice for estimating starch content and characterizing the processing potential of tubers. Consequently, it is a commonly used measurement when calculating quality incentives in processing contracts.

Although high solids and low sugars are essential for the processing industry, potatoes produced for other uses may have very different requirements. When boiled, potatoes with high solids content often fall apart, an undesirable characteristic known as sloughing.

Low specific gravity potatoes, typical of red varieties, for example, tend to be best for boiling and canning. Obtaining good boiling potatoes is largely a matter of choosing the proper variety, while producing good processing potatoes involves many aspects of management.

Tuber sugar content also has an important effect on the quality of processed products because of its large influence on fried product color. When exposed to high levels of heat, which is typical of the frying process, sugars (glucose and fructose) combine with amino acids (esp. asparagine) and other compounds to form the dark color and flavor we associate with "burned" food. This process is a non-enzymatic reaction known as the Maillard reaction (Fig. 15.1).

Even a low content of the reducing sugars glucose and fructose has unwanted effects on the quality of processed tuber products, such as chips and french fries. Sucrose, however, contributes little to dark color development in fried products but is still important because it is the substrate for creating more reducing sugars under the right environmental and physiological conditions. Reducing sugar accumulation in tubers varies with variety, storage temperature, physiological maturity, plant stresses, and tuber age.

Carbohydrate Production and Storage

As with all plants, potatoes use chlorophyll in leaves to trap energy from light and convert it to sugar through the process of photosynthesis. A portion of the sugars produced in the leaves is retained in the leaves and vines and utilized in respiration

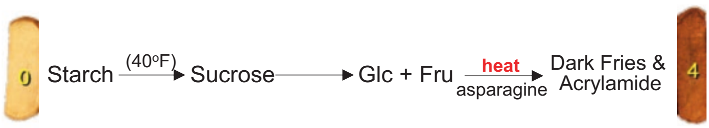

Fig. 15.1 The Maillard reaction

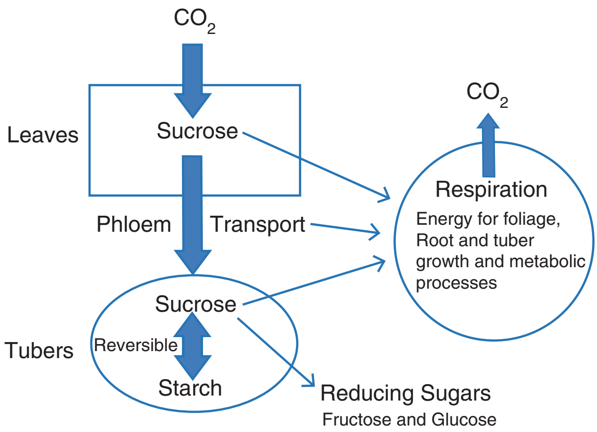

Fig. 15.2 Carbohydrate production and metabolism in potato plants

to provide energy for the plant, maintain growth, and drive critical metabolic processes (Fig. 15.2). Surplus sugars are transported to the tubers where they are either deposited in the cytoplasm for use by the tuber cells or converted into starch in the amyloplasts. Because sugars are the substrate for the production of starch in tubers, their respective biochemical pathways are closely linked.

During maturation, potato tubers accumulate nearly all of their carbohydrate reserves as starch and only a small amount as soluble sugars such as sucrose, glucose, and fructose. During storage, sugar concentrations increase at the expense of starch in response to low storage temperatures. This “cold-induced sweetening” response is observed in potatoes and other plants, with the soluble sugars functioning as cryoprotectants in the cells. The temperature-dependent conversion of starch into sugars is reversible in relatively young, healthy, non-stressed tubers, which provides an opportunity to “recondition” tubers that have undergone cold-induced sweetening. Reconditioning involves raising the storage temperature to 50 °F or above. However, as tubers age during prolonged storage, they gradually lose the ability to recondition, resulting in irreversible “senescent sweetening.” As a result of starch-sugar interconversion in tubers, their starch and sugar contents are inversely correlated.

Starch and sugar content of tubers is controlled by a number of genetic factors, which can differ significantly among varieties. Since there is an optimal range for tuber starch content for fresh and processing potatoes, tuber specific gravity is an important trait to select for in potato breeding programs.

Numerous environmental and management factors also affect the concentration and proportion of sugars and starch in tubers (Fig. 15.3). For example, the processes of sugar production and transport to the tubers can be disrupted by water or heat stress, disease, or early senescence. This will usually limit starch deposition in the tubers, resulting in lower specific gravity.

Other conditions, such as high soil temperatures, may not hinder production or transport of the sugars, but may disrupt conversion to starch in the tubers. Either way, the result is nearly always a loss of quality.

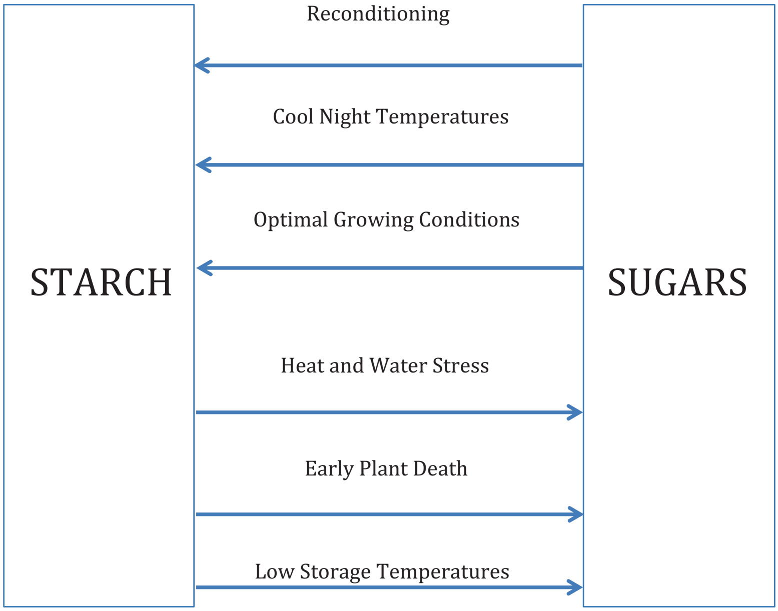

Fig. 15.3 Environmental and management factors influencing the relative proportion of sugars and starch in potato tubers

During early development, tubers are low in starch and high in sugars (Fig. 15.4). Near the end of vine growth, the tubers reach the point—known as physiological maturity—when they achieve maximum dry matter content and minimum sugar content. Specific gravity in overly mature tubers typically decreases while reducing sugar concentrations, particularly in the stem ends of tubers, increase following physiological maturity. Delaying harvest well beyond physiological maturity can result in sugar ends at harvest or continued sugar increase in the tubers during storage, resulting in loss of process quality (darker and/or non-uniform process fry color) developing early in storage, as shown in Fig. 15.4.

The general management strategy for maximizing tuber quality is to maintain good plant health through the tuber bulking period, time vine kill and harvest to correspond with physiological maturity, and employ appropriate storage temperatures and techniques with respect to the intended market.

Factors Affecting Specific Gravity

Greater consumer preference for potato products made from high specific gravity tubers is reflected in the quality incentives contained in potato processing contracts, which typically are based on tuber grade, size distribution, specific gravity, and percent defects. Consequently, a primary management goal of potato growers is to

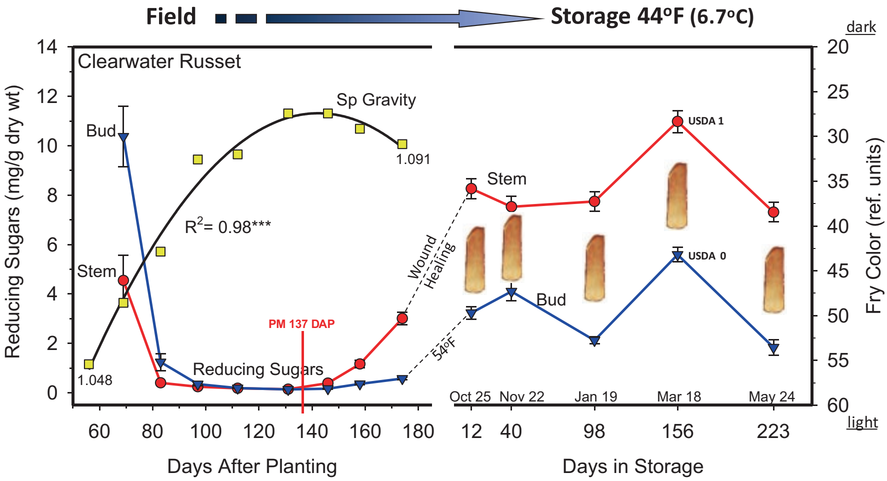

Fig. 15.4 Changes in tuber specific gravity and reducing sugar concentrations in the bud and stem ends of Clearwater Russet tubers versus days after planting (Othello, WA 2010). Tubers reached physiological maturity approximately 137 days after planting (DAP). Following harvest (174 DAP), the tubers were wound-healed at 54 °F for 12 days and then stored at 44 °F through a 224-day storage season. Fry colors were measured on the indicated dates with a Photovolt reflectance meter. (NR Knowles, Washington State University, unpublished)

produce a high-yielding crop with few external and internal defects and high specific gravity.

Given the large proportion of potatoes used for processing and the difficulty in producing a crop with good processing quality, it is important for producers to consider the environmental and cultural factors that maximize tuber specific gravity and minimize tuber sugar content. Any condition, natural or imposed, that affects crop growth can affect tuber specific gravity. Some of these factors are environmental in nature, such as climate, weather, and soil type, and are difficult to control. Others are management related, and the grower can manipulate these factors to improve tuber specific gravity and produce a higher-value crop.

Environmental Factors

Air and soil temperatures are the primary environmental factors affecting specific gravity of irrigated potatoes. Warm days (80–90 °F) and cool nights (50–60 °F) provide optimal conditions for producing high specific gravity tubers. Air temperatures greater than 90 °F can reduce net photosynthesis, thereby reducing the amount of carbohydrate that can be transported to the tubers and converted into starch.

High soil temperatures have a direct effect on tuber physiology and inhibit starch deposition. For that reason, high soil temperatures are even more detrimental to tuber quality than high air temperatures. Extended periods with soil temperatures above 70 °F can have a marked negative effect on tuber specific gravity.

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 by causing stomata to close with an accompanying restriction in CO_2 uptake. Conversely, 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. This includes serious disease or insect infestations. Hail injury during mid to late tuber bulking can cause a severe loss of tuber quality if damage to foliage is extensive. Late summer frosts can also reduce specific gravity by destroying leaves and shortening the time period available for transporting sugars to the tubers.

Obviously, weather and climate are not under the control of the potato grower. Stress resulting from natural factors cannot be eliminated. However, through proper management, the damage to tuber quality caused by environmental factors can be minimized.

Cultural Factors

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. Ideally, the grower's management system should produce a growing environment that allows for high photosynthetic rates over the entire season. Management decisions that can influence specific gravity involve a wide range of agronomic and pest management practices.

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. There are distinct expectations on the part of consumers for certain types of potatoes to have specific cooking qualities.

- Red-skinned varieties generally have lower specific gravity and are primarily for boiling or microwaving.
- Russet-type varieties with moderate to high specific gravity generally are best for baking and frying.
- Long-white and round-white varieties are divided into those suitable for general home use where potatoes are often boiled, and those that have high specific gravity and are intended only for making potato chips or french fries.

Before selecting a variety for processing, growers should consider market potential and quality characteristics, as well as the ability for producing potatoes with high specific gravity.

Seed Management and Planting

Producing a crop with high, 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.

Irregular stands and low plant populations, which result from planting skips, poor seed quality, or disease, can cause excessive nutrient uptake in the affected parts of a field. Excessive nitrogen uptake can delay tuber bulking and maturation and reduce specific gravity. Irregular stands can also increase variability in specific gravity, which can make processing more difficult.

Planting density and uniformity also affect tuber size distribution, which, in turn, influences specific gravity. Fields with closely spaced plants and doubles usually produce a higher proportion of small tubers compared to fields with normal or optimal spacing. In general, large tubers tend to have higher specific gravity than small tubers. This is especially true in growing areas with long seasons. Therefore, seed spacing and uniformity are important factors in maximizing both tuber size and specific gravity.

Physiological age of seed can affect the developmental rate of the crop, as well as yield and specific gravity. Potato plants grown from physiologically young seed typically begin to bulk later in the growing season than those produced from physiologically old seed. With respect to tuber specific gravity, this delayed response can be either positive or negative, depending on the production area and climate.

In areas with relatively short growing seasons, specific gravity of late-developing tubers produced from physiologically young plants may be reduced due to inadequate time for sugars to be transported to the tubers and converted to starch. By comparison, plants produced from physiologically old seed may die too early to reach maximum tuber solids content. Physiologically old plants also bulk and mature sooner and utilize soil nutrients earlier in the growing season. Therefore, appropriate adjustments in the nutrient management program need to be made to maximize quality.

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 (N)

When other growing conditions are favorable, increasing nitrogen availability up to the optimum level increases U.S. No. 1 yield and average tuber size with minimal reductions in specific gravity. However, excessive N rates stimulate vine and root growth and delay tuber bulking and maturation. In areas with short growing seasons, delayed tuber growth and dry matter accumulation can reduce specific gravity. High N rates also increase the concentration of soluble organic N compounds, further reducing specific gravity.

Potassium (K)

Potassium nutrition is also an important factor in determining tuber specific gravity as a result of its influence on starch synthesis and water content. Starch synthesis and specific gravity increase with increasing K concentration up to an optimum tuber concentration of about 1.8%. 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.

The effects of high tuber K concentrations on water absorption and reduced specific gravity are generally greatest at the bud end. This response is also more pronounced when fertilizing at high rates with KCl than with K_2SO_4 due to the greater salt effect of KCl.

Large amounts of K fertilizer applied during tuber bulking are more detrimental with respect to effects on specific gravity than the same amounts applied preplant. The negative effects of in-season K applications on specific gravity are greatest when applications of more than 50 lbs. K_2O/ac are made late in the season. Growers, therefore, should avoid late-season K applications when specific gravity is a concern if petiole K concentrations are at adequate levels.

Phosphorus (P)

Phosphorus tends to increase starch synthesis when applied at increasing rates up to the optimum, 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. As a result, adequate P nutrition is an essential factor in obtaining high specific gravity.

To a certain extent, phosphorus can counteract the negative effects of high N rates on specific gravity (Fig. 15.5). However, applying optimal rates of all required nutrients is the best approach for obtaining both high yield and high specific gravity.

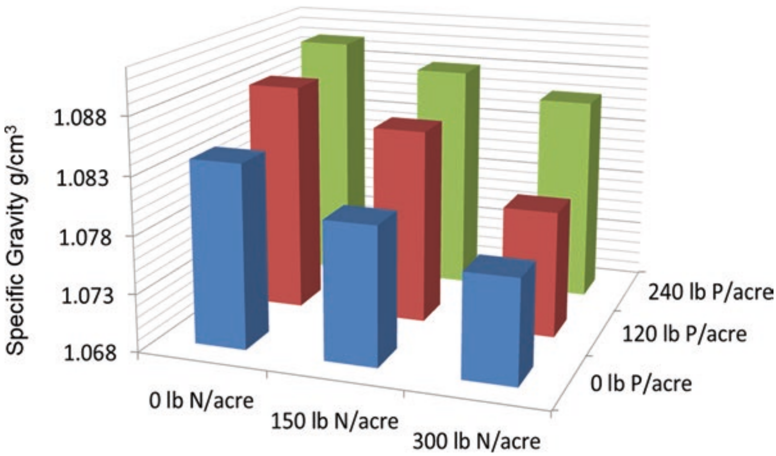

Fig. 15.5 Specific gravity of Russet Burbank potato tubers as influenced by N and P fertilization rates. (Stark 1985)

Irrigation

Water stress during early- to mid-season tuber development tends to decrease specific gravity due to reduced photosynthesis, particularly when accompanied by high temperatures. Late season water deficits, on the other hand, partially dehydrate tubers creating what might be viewed as an artificial increase in specific gravity that is due to lower tuber water content. However, late season water stress increases both the level of reducing sugars in tubers and susceptibility to blackspot bruise.

To promote high specific gravity, available soil water content should be maintained above 65% throughout the tuber growth period until just before vine kill. Soil moisture after vine kill should remain above 60% to minimize tuber dehydration.

Soil Conditions, Tillage, and Cultivation

Potato root system development can be greatly affected by soil physical conditions. 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 are harvested early often have lower specific gravities than those allowed to develop for the entire growing season. Early planting can increase the number of days that can potentially contribute to tuber starch deposition if environmental conditions are conducive to early season growth and development.

Disease Management

Diseases, such as Verticillium wilt, early blight, and late blight, which shorten the length of the tuber growth period and damage foliage can also affect specific gravity. Crop rotations and cultural and pest management practices that help suppress diseases can extend the period of tuber dry matter accumulation and increase specific gravity. However, disease suppression should involve season-long processes, rather than quick-fix strategies that can detrimentally affect crop growth. For example, growers should avoid late season N applications for the purpose of slowing disease progression because of the negative effects of N on specific gravity.

Vine Kill and Harvest Management

Several factors associated with vine kill and harvest can influence the specific gravity of harvested tubers. 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. This problem can be minimized by timely harvest and placing the tubers in storage where conditions can be controlled.

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. For potatoes going directly into processing, it may be preferable to dig the vines green without vine killing to prevent excessive tuber hydration.

Even if the crop is still actively growing, harvest date can influence specific gravity as the result of changes in the relative amounts of water and dry matter accumulation in tubers.

In areas with relatively long growing seasons, specific gravity can actually decrease during the latter stages of growth if tuber water uptake exceeds dry matter accumulation. Although this late season growth period can increase total yields, the decrease in specific gravity can significantly decrease processing quality if it drops too low.

Tuber Sugar Content

Allowable sugar levels in potatoes—standards set by processors—continue to decline. This is directly related to consumer preference for light-colored, attractive fried products. Given this trend, it is critical that potato growers and storage managers understand the principles and techniques for controlling the sugar content of potato tubers.

The predominant sugars found in potato tubers are sucrose, glucose, and fructose. Sucrose formed during photosynthesis is translocated to the tubers during bulking. In very general terms, non-stressed healthy tubers convert the sucrose into starch during development. Stresses (e.g., heat, disease, water) can interfere with this process, resulting in breakdown of sucrose to its component sugars—fructose and glucose. The involvement of sugar as a substrate in the synthesis of starch means that anything affecting one of these compounds will also have some influence on the other.

Measuring Tuber Sugars

Tuber sugars can be measured directly using one of many methods. The invention of the Yellow Springs Instrument (YSI) by the Yellow Springs Instrument Company in Yellow Springs, OH, has simplified sugar measurements to the point where YSI is now the method of choice (Fig. 15.6). Most processing companies now use the YSI to test for sugars in raw product.

A sample of tubers is ground in a buffer solution, filtered, and injected into the YSI, and a sugar value is obtained that can be expressed as either percent or mg/g. Values for both sucrose and glucose (the main reducing sugar in potatoes) can be obtained.

An indirect measure of sugar content can be obtained by frying tuber slices at 350–375 °F for 3–4 min and comparing the cooked color with publicly available USDA color charts or reflectance readings made with a Photovolt reflectance meter that are calibrated with reducing sugar concentrations (Fig. 15.7). Although this will only give an estimated sugar content value, it will provide good information about potential processing quality.

Fig. 15.6 Yellow Springs Instruments glucose analyzer. (Photo credit: Jeffrey Stark)

Fig. 15.7 Photovolt reflectance meter used to determine fry color (Photo credit: NR Knowles, Washington State University)

Factors That Affect Tuber Sugars

Because of the close relationship between sugars and starch, any environmental factor that affects tuber specific gravity also creates changes in sugar concentration. As a general rule, any environmental or management factor that increases specific gravity reduces sugars, and vice versa.

Consequently, a review of management factors for optimizing tuber specific gravity in the preceding section will provide an understanding of how these same factors affect sugar content. For this reason there is no need to revisit all of the factors covered in the specific gravity section as they relate to sugar content. Maturity, temperature, variety, storage stress, and handling influence tuber sugars in a unique fashion and 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. For the tubers, this point is known as physiological maturity. Tubers left in the field after reaching physiological maturity generally begin to increase in sugars.

Temperature

Temperature both in the field and in storage has a large impact on tuber sugar content. High soil temperatures shortly after tuber set can lead to higher tuber sugar concentrations. In extreme cases, the physiology of the stem end of the tuber is changed sufficiently to permanently disrupt starch synthesis. This leads to high levels of sugar accumulation in the stem end of the tuber and the development of a condition known as sugar ends (also known as translucent ends and when severe enough to cause tissue death, jelly ends). Sugar ends are considered a severe defect in the processing industry and can lead to rejection of the crop.

The other temperature response that is important to understand is cold-induced conversion of starch back to reducing sugars. This can occur in the field or in storage. At temperatures from 50–55 °F, the balance between starch and sugars remains relatively static. As temperatures drop below this range, starch conversion to sugar becomes evident in most varieties. As temperatures decrease, the conversion of starch to sugars increases resulting in a higher final concentration.

The intended market and end use of the potatoes dictates the appropriate storage temperature. See Chap. 17 for detailed information on appropriate storage temperatures.

Potatoes that have accumulated excess sugars after exposure to low temperatures in the field or storage experience a partial recovery toward lower sugar concentrations when exposed to temperatures above 55 °F (60–65 °F is considered optimal). This process is termed reconditioning and is occasionally used to restore acceptable sugar levels in a lot of potatoes that has become unacceptable for processing during extended storage.

Reconditioning has limitations and cannot restore tubers to their pre-harvest low sugar levels. It is also more effective within the first 6 months of storage when the tubers are young and physiologically responsive.

After 6–10 months of storage, sugar accumulation may occur that is not temperature induced; it is due simply to age. This is called senescent sweetening and is a result of the tuber's inability to control its sugar metabolism. Reconditioning will not reverse senescent sweetening and, in fact, may make it worse.

Variety

Potato varieties exhibit large differences in sugar content, especially after storage. For that reason, 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.

Potato breeders are currently making a concerted effort to develop varieties for chip or french fry processing that can be stored at temperatures as low as 42 °F and still maintain sufficiently low sugar levels. Several such varieties are now available. As they become recognized and accepted, temperature requirements for stored potatoes will need to be adjusted accordingly.

Storage Stress

In addition to cold-induced sweetening, a few other conditions in storage can produce an increase in tuber sugars. The most important of these is insufficient air movement.

Tubers require oxygen for respiration and low-level physiological activity. 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 tubers 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 tuber sugars will decline to pre-handling levels after a week or so if they are not subjected to other stress factors.

Using Sugar Measurements to Predict and Manage Tuber Quality

Because sugar content is directly related to fried product quality, monitoring sugars is a valuable tool for predicting and maintaining 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

Using the YSI, a measure of reducing sugars (dextrose) can be obtained for any lot of potatoes. This can give a measure of current fry potential. Potatoes intended for chip production should have a reducing sugar level below 0.35 mg/g (or 0.035%) of fresh tuber weight. Potatoes intended for processing as french fries should have less than 1.0 mg/g (or 0.10%) of tuber fresh weight. Potatoes with higher values than these will usually show color problems after cooking.

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, which can be used to make proper harvest and storage management decisions.

During tuber growth, the enzyme that converts sucrose to reducing sugars, acid invertase, is inhibited. Therefore, even if tuber sucrose concentrations are high during this time, there are usually no color problems evident in cooked products.

In storage, however, acid invertase becomes active and, if there is a sufficiently large pool of sucrose available, sucrose conversion results in a high level of reducing sugars. In simpler terms, high levels of sucrose at harvest can potentially result in high levels of reducing sugars in storage in varieties with high acid invertase activities, which results in poor frying quality.

Any stress on tubers in storage, such as low temperatures or insufficient air supply, can also cause an increase in the sucrose pool with associated reducing sugar and color problems. By knowing the relationship between sucrose concentrations and the future potential for quality problems, management tactics can be designed that will minimize the problems before they become detrimental to quality.

Maturity Monitoring

Growers and storage managers can measure tuber sugars to assess maturity and optimize the timing of harvest. If weather allows, harvest should be delayed until sugar levels cease to decline. If the potatoes have not been stressed during the growing season, sugar levels should fall below the levels indicated in Table 15.2.

Again, the most critical factor is the 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

Tubers that come out of the field with sugar levels that are above the target values shown in Table 15.2 are preconditioned to having color 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 (<0.15%), but glucose levels are too high (chips >0.035%, fries >0.1%). 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 60 °F for 2 weeks or until the glucose concentrations drop to acceptable levels. The temperature can then be ramped slowly downward to 45–48 °F for frying potatoes or 50–52 °F for chipping potatoes. Glucose levels should subsequently be determined at regular intervals to ensure they remain within the acceptable range.

Scenario 2 Sucrose levels are too high (>0.15%), but glucose levels are acceptable (chips <0.035%, fries <0.1%). The immediate fry color may be good, but long-term storage may be negatively impacted as sucrose is converted to reducing sugars.

Table 15.2 Target maximum sucrose and glucose concentrations at harvest and in storage for potatoes intended for chip and french fry processing based on fresh weight values

Intended market	Sucrose (mg/g fresh weight)	Glucose (mg/g fresh weight)
At harvest		
Chips	1.5 (0.15%)	0.35 (0.035%)
French fries	1.5 (0.15%)	1.0 (0.10%)
During storage		
Chips	1.0 (0.10%)	0.35 (0.035%)
French fries	1.5 (0.15%)	1.0 (0.10%)

Adapted from Sowokinos and Preston (1988)

Action: The same wound-healing conditions should be used 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 55 °F for chipping potatoes and 50 °F 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 60 °F 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 low 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 low, 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 60 °F, 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, 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 5–8 months of storage, followed by a slow increase in sucrose levels over the next several months, may be an indication of senescent sweetening. If no temperature stress or ventilation problems can be identified, and a sample of potatoes removed from storage does not respond to reconditioning, then the potatoes should be marketed as quickly as possible.

Senescent sweetening is a permanent condition and only gets worse with time. If an entire pile of potatoes is suspected of being affected by 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.

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