Chapter 14
Physiological Disorders

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Contents

Introduction

Potatoes are subject to a wide range of physiological disorders that are not directly caused by an infectious pest; instead they result from unfavorable environmental conditions or management practices that cause stress. The following is a discussion of common physiological problems, their causes, and management practices that will minimize their occurrence.

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Types of Disorders

Physiological disorders are also commonly referred to as abiotic (i.e., non-living), nonpathogenic, nonparasitic, or noninfectious diseases. Often a disorder is caused by the combined effects of both environmental conditions and management practices. A common characteristic of many physiological disorders is a delay from the time the stress or injury is initiated until symptoms are visible, which makes diagnosis and identification of causal factors very difficult. These disorders also often weaken the plant and allow pests to attack as a secondary consequence, which may mask the underlying causes.

Symptoms of physiological disorders are expressed in both the foliage and tubers. Tuber symptoms reduce crop value, while foliar symptoms affect productivity. Tuber disorders can be expressed in the field but can also occur in storage and can be either external or internal. External tuber disorders can reduce marketability, as well as cause reductions in processing quality and storability. Internal tuber disorders often go undetected until tubers are cut and inspected. However, these disorders can also result in significant reductions in crop quality and marketability.

Foliar Physiological Disorders

Physiological disorders of potato foliage can be caused by frost, chemicals, nutritional imbalances, hail, wind, lightning, air pollution, and waterlogged soils. These disorders are usually typified by symptom uniformity across the field or symptoms occurring in a regular pattern or topographic position within the field. In comparison, plant pathogen and insect damage can often show random distribution patterns ("hot spots") or can be associated with field edges. If visible symptoms or patterns do not provide a unique diagnosis, a plant or tuber sample should be submitted to a local extension specialist or qualified diagnostic laboratory for clinical evaluation for the presence or absence of a pest.

Frost Damage

Frost damage can occur when temperatures drop below 30 °F for any significant length of time. When injury occurs during a calm period, symptoms are usually more visible in low-lying areas.

Diagnosis

The first sign of injury is a darkening (very dark green to almost black) of the leaves. If damage is minor, the dark color will fade, leaving characteristics of leaf yellowing (chlorosis), leaf distortion, or brown, necrotic (dead) areas on the tips of the leaves

Fig. 14.1 It is common for early-season frost to injure one plant severely (right) while leaving adjoining plants untouched

on the upper part of the plant. If damage is more severe, leaves and/or stems will become water-soaked and turn dark brown to black in color, and within a few days the tissues will become desiccated and brittle (Fig. 14.1). In some cases, all foliage above ground will be killed. Any frost damage will slow plant growth, but severe frost injury will seriously delay development because plants must regrow from below-ground buds. This is especially true if freezing temperatures penetrate below the soil surface.

Management

A primary approach for prevention of frost damage is to plant potatoes late enough in the spring to minimize exposure of young plants to frost. For early planting, the use of vigorous, large seed pieces will allow the plants to recover more readily from frost injury if it does occur.

Little can be done to prevent frost damage to an emerged crop. Initiating irrigation before the frost and continuing until the temperature is above freezing can minimize damage, but this is often not practical on a large scale. If done improperly, irrigation may actually increase injury. Irrigation immediately before, but not during, the freezing temperatures will often increase symptoms.

Chemical Damage

Chemical damage or "burning" of the foliage can occur when: (1) pesticides, fertilizers, or other agricultural chemicals are applied improperly, (2) when chemicals drift onto a non-target field (Fig. 14.2), or (3) when chemical residues carry over in the soil from an application to a previous crop. Some chemical herbicides, such as glyphosate and dicamba, can carry over in seed potatoes, causing symptoms in the subsequent crop.

Fig. 14.2 Malformed leaves are symptoms of phenoxy-type herbicide drift or carryover

Diagnosis

A wide range of foliar symptoms can occur as a result of chemical damage. Growers need to systematically evaluate these symptoms in relation to crop history, chemicals applied, and environmental conditions. Some characteristics of chemical damage include leaf distortion or curling, yellowing of the leaves and stems, necrotic or brown spots on leaf margins, stunted growth, or plant death. Often the distribution of chemical damage symptoms in the field will follow a pattern consistent with the equipment or method used to apply the chemicals. Chemical carryover in seed potatoes results in a random distribution pattern in the field, usually at low levels. Some specific classes of herbicides also cause characteristic disorders in the tubers, such as multiple growth cracks, that can be used in diagnosis.

Chemical damage symptoms may often be confused with those caused by virus infections or other diseases or pests. Consequently, all pertinent chemical application information should be evaluated and related to current and previous crops in and around the affected field along with information on previous pest problems in the field and prevailing weather conditions.

Management

Effective management practices may not be available to alleviate chemical damage symptoms. In a few cases, appropriate remedial actions may be apparent when the causal factor is diagnosed. See Chaps. 9,11, and 12, for more detailed information on foliar damage symptoms related to pest problems and pesticide applications.

Nutrient Imbalances

Proper fertilization is an important part of producing a high-yielding, high-quality potato crop, but nutrient imbalances can result in foliar and tuber abnormalities. Foliar symptoms associated with improper fertilizer management are often difficult to distinguish from those caused by environmental stresses.

Diagnosis

Nutrient excesses usually cause symptoms similar to those of salt burn, such as leaf necrosis, and can best be prevented by using a proper nutrient management program. Nutrient deficiencies typically produce a wider range of symptoms, which are fairly specific for each nutrient. Information on fertilizer sources and rates, soil type, pH, salinity, soil and plant nutrient concentrations, and application rates of other chemicals can help determine if the damage is nutrient related. Petiole and/or soil samples can provide further insight into any nutrient imbalances. See Chap. 8.

Management

A proper nutrition program involving soil and plant tissue analysis will prevent most nutrient imbalance problems.

Hail Damage

On occasion, hail can cause severe crop injury, which can result in large yield and quality losses. Yield losses occur when hail damages foliage during the early part of the season while potato plants are still in the vegetative stage. Yield loss will be proportional to the timing and degree of defoliation. During early tuber bulking, minor hail damage has little effect on yield, but substantial defoliation at this stage of growth can decrease U.S. No. 1 yields, primarily as a result of the increased production of malformed tubers. Specific gravity can also be decreased by early-season defoliation. However, severe hail damage during mid tuber bulking will usually cause substantial yield and quality losses. Damage caused by hail when plants are near maturity will generally result in only minor losses in yield or quality. The impact of hail injury is generally greater for early-maturing varieties.

Diagnosis

Potato leaves will look torn and perforated after a damaging hailstorm (Fig. 14.3). In severe cases, a complete loss of foliage will occur. Damage on stems is usually superficial, producing gray lesions or pockets.

Management

Prevention measures are not available for hail damage, and subsequent management will depend on the extent of injury, developmental stage of the plants, and variety. Minor hail damage usually does not require a change in management plans. Major damage may require an adjustment in irrigation and fertility programs, usually typified by a delay in added inputs.

Fig. 14.3 Plants will be torn and perforated after a severe hailstorm; this damage will greatly reduce yield and tuber size if it occurs during tuber bulking

Fig. 14.4 Leaf tip burn is a symptom of foliar damage caused by wind, low humidity, and/or high air temperatures

Hail-damaged plants usually will not require additional foliar nutrient applications if petiole nutrient concentrations were sufficient before injury. Applications of excessive amounts of nitrogen (N) directly after severe hail damage may actually slow tuber bulking by stimulating excessive vegetative growth.

Windburn/Leaf Tip Burn

Leaf tip burns are physiological disorders that commonly occur in potato fields in arid regions. This disorder is especially prevalent when conditions are dry, warm, and windy.

Diagnosis

Symptoms are often mistaken for disease, chemical damage, fertilizer burn, or water deficits. As a result, a grower or crop adviser should carefully consider the pattern of symptom distribution in the field, as well as associated weather conditions. Foliar symptoms will typically appear in the upper canopy as brown, necrotic, irregular spots on leaves, especially on the tips and margins, but can occur on any part of the leaf (Fig. 14.4). Stems can also show wind damage as light brown lesions or pockets in the tissue.

Management

No effective management practices exist to avoid tip burn, other than making sure adequate soil moisture levels are maintained to minimize the potential for leaf dehydration.

Lightning Damage

Lightning damage produces symptoms that are similar in many respects to a “hot spot” or outbreak of a disease, such as blackleg, Rhizoctonia, or late blight.

Diagnosis

Symptoms of lightning damage will appear as circular or oval areas in the field within a few days of a thunderstorm. Affected plants initially have stems that collapse at the top and become water-soaked and black to brown in color. Characteristically, the stem pith tissues collapse and form crosshatched horizontal plates that can be seen by slicing the stem longitudinally. The damaged stems soon turn brown to a light tan as they dry. Sometimes the leaves may remain green with only the stems affected, but often the whole plant will subsequently die. Look for distribution patterns showing perfectly healthy plants next to a few dead or severely injured plants. Lightning damage often occurs in wet areas in the lowest parts of the field, where the intensity of the electrical discharge tends to be greatest.

Management

No control or management strategies exist for damage caused by lightning.

Air Pollution Damage

Air pollution injury is not a common problem in most production regions, but occasionally will cause damage to leaves. Air pollution damage is difficult to identify due to its similarity to symptoms caused by pests and other environmental stresses. Damage may be the result of high levels of chemicals in the air, such as ozone, nitrous oxide, and sulfur dioxide. Foliar injury symptoms can occur adjacent to industrial areas and major roadways.

Diagnosis

Injury will vary with pollutant type, concentration, and length of exposure, as well as with plant growth stage at the time of exposure. Symptoms vary, but generally appear as a necrotic speckled or pinpoint spotting on the leaf. This advanced injury can be confused with spider mite damage.

In diagnosing potential air pollution damage, possible sources of pollutants (factories, exhaust emissions from vehicles using a nearby highway, etc.) should be investigated near the damaged areas of the field. Prevailing wind direction and environmental conditions are other considerations in relation to the location and pattern of damage in the field. Other causes of damage that lead to similar symptoms are agricultural chemicals, weather, disease, and insects. Some varieties are more sensitive to air pollution than others.

Management

No effective field management practices are available for control of air pollution injury, other than to avoid planting potatoes in potentially polluted areas or choosing less sensitive varieties.

Waterlogged Soils

Excessively wet or flooded soil conditions that last for several days or more can damage potato foliage and tubers. The damage is primarily the result of anaerobic (oxygen deprived) conditions in the root zone that interfere with plant water and nutrient uptake.

Diagnosis

Foliage of affected plants initially becomes light green to yellow and will eventually wilt and turn brown if waterlogged conditions persist. Tubers and roots become susceptible to rot organisms under excessively wet soil conditions.

Management

It is important to ensure proper irrigation system design and management that will prevent waterlogged areas from developing in the field. Basin tillage or installing drain tiles are possible management strategies where runoff is a potential problem.

Tuber Physiological Disorders

Tuber disorders may consist of external quality damage and/or internal problems. Bruises are physiological disorders that have both internal and external symptoms. With some disorders, pathogen invasion can result, which causes additional loss of quality.

External Physiological Disorders

Malformed Shape

Malformed tubers are a result of environmental or cultural stresses, such as wide fluctuations in air and soil temperatures; water deficits; abrupt changes in nutrient availability; and defoliation due to insects, diseases, or hail. 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

Any stress that causes a reduction or stoppage in plant growth 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 (Fig. 14.5). 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 (Fig. 14.6).

These symptoms can cause potatoes to be graded as U.S. No. 2 and can also cause sugar accumulation and specific gravity reduction in the affected area of the tuber. This sugar accumulation may make the tuber unacceptable for processing due to non-uniformity in the fry color (sugar ends).

Fig. 14.5 Malformed and misshapen tubers result from environmental or cultural stresses during critical periods of tuber growth

Fig. 14.6 Knobs are caused when secondary growth occurs at lateral eyes on the tuber

Management

Potatoes are particularly sensitive to stress during tuber initiation. Studies with Russet Burbank have shown that moderate to severe soil water deficits during tuber initiation can reduce U.S. No. 1 yields by 10–40%. Management approaches for preventing malformed tubers include promoting uniform growth by establishing uniform stands; avoiding large fluctuations in N availability; maintaining available soil water content above 70% and avoiding cultural practices, such as late cultivation, that may alter tuber growth patterns.

Heat Sprouts/Tuber Chaining

During periods of hot weather (85 °F 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 (Fig. 14.7). 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 (Fig. 14.8). 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.

Fig. 14.7 Heat sprouts develop when stolons elongate rapidly and emerge from the soil as a leafy stem. Symptoms depend on the timing of stress. Sprouts may develop from the apical buds on a tuber (**a**) or may result from an elongating stolon that never terminates in a tuber (**b**)

Fig. 14.8 Another symptom of heat injury during growth—tuber chaining—takes two forms. Slight to moderate stress causes long stolons with multiple tubers set on side branches, while severe injury causes eyes to sprout and develop into stolons and, subsequently, new tubers

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 are the most common type of cracking and are often caused by irregularities in tuber growth, especially in response to widely fluctuating water supplies (Fig. 14.9). Other factors, including virus infection and herbicide injury, can also cause tuber growth cracks and abnormal-looking tubers. Clinical diagnosis may help to identify non-management factors that cause cracking. Thumbnail cracking is caused by shallow breaks in the skin of well-hydrated tubers that have been exposed to drying conditions (see the section on shatter bruise later in this chapter). Potato varieties vary widely in their susceptibility to tuber cracking.

Fig. 14.9 Rapid tuber growth, or periods of drought stress followed by rain or irrigation, may result in growth cracks

Fig. 14.10 Elephant or alligator hide is a skin-cracking defect that can show mild (**a**) or severe (**b**) symptoms

Elephant or alligator hide appears as shallow, corky cracks on the tuber skin (Fig. 14.10). 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. Improper timing of maleic hydrazide applications has also been reported to cause an elephant-hide type of appearance on some varieties.

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 in immature potatoes and is a result of incomplete development of the skin layer (periderm). When tubers are immature, the skin is easily rubbed off during handling. This disorder is particularly important

Fig. 14.11 Feathering or skinning occurs during harvesting or handling of immature tubers

for fresh market potatoes because of its effect on consumer appeal. Also, the potential for weight loss and disease is considerably greater with feathered potatoes.

Symptoms and Causes

Feathering or skinning occur only upon handling. The skin of the potato is partially or completely removed, exposing the underlying tuber flesh (Fig. 14.11). 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. Careful handling of the potatoes and proper wound healing conditions in storage are also important. High late-season N availability and excessively wet soils will delay maturity and increase susceptibility to skinning and feathering. Achieving complete vine kill 14–21 days before harvest will usually provide sufficient time to "set" the skin.

Enlarged Lenticels

Lenticels are openings on the tuber surface 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 or after packaging will cause lenticels to open and become enlarged. Enlarged lenticels look like small, white bumps on the surface of the tuber (Fig. 14.12). This disorder makes the tuber more susceptible to the entry of disease organisms, especially soft rot.

Fig. 14.12 Enlarged lenticels appear as small, white dots on the tuber skin

Fig. 14.13 Greening occurs when the tuber is exposed to light, resulting in the development of chlorophyll

Management

To avoid enlarged lenticels, potatoes should not be allowed to sit in saturated soils for extended periods (1–2 days), especially late in the season. Allowing soil moisture to drop to 65–70% between each irrigation is usually adequate to prevent swollen lenticels. During storage, avoid wet spots resulting from condensation, excess humidity, and temperature differences.

Greening

Light-induced formation of a green color on tuber surfaces 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 (Fig. 14.13).

Fig. 14.14 Pink eye appears as raised pink or brown water-soaked areas around the eyes

Greening also occurs from extended exposure to light in storage or on store shelves. This situation usually produces a lighter and more diffuse coloration of the entire tuber. The rate of greening is slower at lower temperatures. Thin-skinned potatoes, particularly those with white skins, are more affected because the greening is more visible.

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. Placing daylight blockers on outside vents helps to decrease light exposure in storage.

Pink Eye

Pink eye is a physiological disorder characterized by raised pink or brown water-soaked areas around the eyes, although the disorder may affect areas other than just the eyes. It is often accompanied with a cracking of the periderm producing a "corky patch" and providing an entry point for other pathogens, such as Pythium, soft rot, and Fusarium.

Symptoms and Causes

Small patches of disrupted periderm can be peeled to expose a brown or pink-colored tissue (Fig. 14.14). Under blue ultra-violet fluorescent light the exposed tissue will autofluorescence blue, whereas healthy tissue will not. This autofluorescence is due to higher accumulation of phenolic compounds in that area.

The pink eye disorder results from compromised skin tissue that lacks suberin, resulting in cell death. Although the cause of pink eye is unknown, higher incidence of the disorder has been associated with high soil temperatures and moisture late in the growing season during senescence or after vine death. It is also associated with compacted soils that lead to low oxygen conditions and eventual cell death within and beneath the periderm of the tuber.

Fig. 14.15 Brown center appears as brown tissue in the pith area of a tuber

Management

Maintain a healthy crop and manage to avoid "uneven" premature plant or stem death due to Verticillium or early die. Avoid excessive soil moisture when the plant does not require it, especially late in the growing season with premature vine death. Use proper tillage and crop rotation to avoid field compaction.

Internal Physiological Disorders

Brown Center/Hollow Heart

Brown center and hollow heart defects can cause serious losses in crop quality and economic return to the grower. The causes of these related disorders can be complex, and their development can occur throughout tuber bulking.

Symptoms and Causes

A brown discoloration without a visible flesh separation in the center of the tuber (pith region) is known as brown center (Fig. 14.15). The brown coloration results from the rupture of cell membranes and death of the affected cells.

This cell damage is apparently caused by inadequate nutrient and carbohydrate concentrations in the affected tuber tissue that reduce cell membrane integrity. The inadequate nutrient and carbohydrate concentrations are either the result of competition with the vines or the inability of the plant to absorb and transport sufficient quantities of nutrients to the pith area of the tubers. This disorder is also associated with periods of slow growth, followed by rapid tuber growth.

Tubers are most susceptible to brown center during the period from tuber initiation through early tuber bulking. Although this disorder does not always result in hollow heart, it is considered to be a milder form of the same defect and can even be a precursor to hollow heart.

Brown center symptoms can dissipate if subsequent tuber growth is moderate and uniform, and healthy cells grow between the damaged cells, diluting the brown

Fig. 14.16 Hollow heart is an irregular or lens-shaped cavity, of variable size, often accompanied by a brown discoloration in the tuber flesh

coloration. Research has shown that soil temperatures below 55 °F for 5–7 days during early tuber development can initiate brown center. Available soil moisture levels above 80–85% during early tuber development can also increase the incidence of brown center, possibly due to the slower warming of wet soils.

Hollow heart is characterized by the formation of an irregular cavity in the flesh of the tuber, typically surrounded with brown, discolored tissue (Fig. 14.16). The cavities can vary widely in size and form in the center of the pith or near the stem or bud ends of the tuber, depending on when the disorder develops.

Two distinct forms of hollow heart exist in potatoes; namely, early- and late-initiation types. Early-initiation hollow heart appears shortly after tuber set and is caused by the same factors that cause brown center. Rapid tuber enlargement results in the cavitation of the damaged tissue. This cavitation is often associated with a period of restricted tuber growth caused by cool soil temperatures, followed by accelerated growth rates that occur as temperatures warm up. High N availability during tuber initiation may increase the incidence of early-initiation hollow heart by producing a large canopy, which competes with tubers for nutrients and cools the soil by shading the soil surface.

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 a growth stoppage due to 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. Excessive soil moisture and N availability during tuber initiation and early development can increase the potential for brown center/hollow heart development, particularly under cool growing conditions.

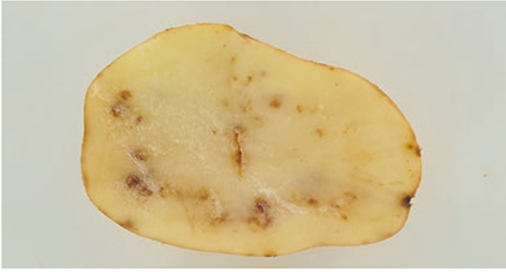

Fig. 14.17 Internal brown spot or heat necrosis symptoms can be mild or severe, and occur throughout the flesh

Surveys of growers' Russet Burbank fields during high hollow heart years have shown that N fertilization rates above 200 lb. N/acre and available soil water contents above 80–85% before row closure can significantly increase the incidence of brown center and hollow heart. Consequently, applications of N fertilizer should be moderate during early tuber development to maintain adequate tuber growth rates, while minimizing the potential for brown center and hollow heart development. Optimal rates of other nutrients should also be applied to avoid additional stresses. In addition, maintaining available soil moisture between 65 and 80% 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.

Symptoms and Causes

This disorder can be described as small, brown, necrotic lesions or spots primarily inside the vascular ring of the tuber (Fig. 14.17). Internal necrosis differs from brown center in that it does not concentrate in the center (pith) of the tuber; rather it 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 increasingly severe during late tuber bulking and senescence. Symptoms also tend to intensify during storage, particularly under warm conditions.

Although the factors that result in internal necrosis are not completely understood, researchers have established a relationship between the development of this disorder and lack of adequate calcium in the tuber. This may be the result of inadequate soil calcium availability, or the inability of the plant to absorb soil calcium and transport it to the tubers. Hot, dry weather, as well as high soil temperatures and fluctuating soil moisture conditions during tuber bulking, are also associated with the incidence and severity of the defect. This disorder can be more prevalent in sandier soils that have low cation exchange capacities and greater conductance of heat.

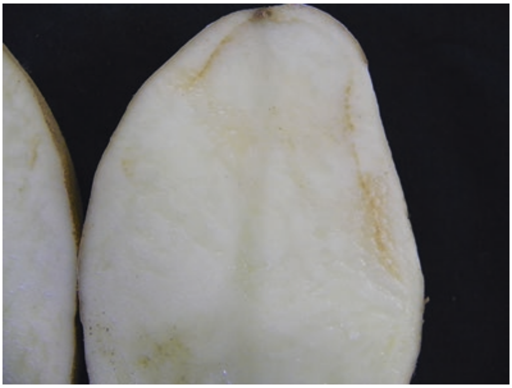

Fig. 14.18 Stem-end discoloration is a physiological problem that can be similar in appearance to net necrosis caused by the potato leafroll virus

In very susceptible varieties, such as Atlantic, there is an association between days from planting to harvest and incidence of heat necrosis. As tubers bulk and become larger, combined with warm soil and air temperatures, heat necrosis can greatly increase.

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. Harvesting the crop when mature, but before tuber size becomes excessive, can also reduce the incidence of this disorder.

Stem-End Discoloration

Several diseases, including Verticillium wilt and potato leafroll virus (PLRV), can cause vascular and/or stem-end discoloration. See Chap. 9. There is also an abiotic disorder that causes symptoms that are similar to the disease-induced vascular discoloration. This disorder is called stem-end discoloration (SED).

Symptoms and Causes

SED is typified by a shallow, brown discoloration in the vascular system (phloem and xylem) on the stem end of the tuber (Fig. 14.18). Intensity can vary with season and variety, but typically does not extend greater than 0.5–1.0 in into the tuber.

SED may or may not be visible at harvest, and may develop during storage. Laboratory analysis for PLRV will determine whether the visible symptoms are due to SED or to net necrosis caused by PLRV. Symptoms of SED will increase with time in storage but not to the extent of net necrosis.

Fig. 14.19 Sugar ends are the result of stress-induced accumulation of sugar, usually in the stem end of the tuber, and are associated with translucent appearance in the raw potato and dark ends in the fried product

The causal factors of SED are not known, but several influential factors have been evaluated. Among factors previously implicated in causing SED is the rate of vine kill. Earlier research showed an increase in SED with rapid vine kill, particularly when the vines were still green and vigorously growing. However, recent research has not been able to confirm a relationship between the rate of vine kill and SED. Other studies have shown that killing water-stressed potato plants under high-temperature conditions, or a severe frost prior to plant senescence, can increase SED. But none of these factors have consistently caused SED. Many other unknown factors may be involved in the development of this physiological disorder.

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 temperature stress, or if the vines have not begun to senesce. Irrigation before vine kill may 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 primarily a concern for processing potatoes and mostly affects varieties that are susceptible to a wide range of stresses, 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 (Fig. 14.19). Often the end of the tuber that fries dark also exhibits

Fig. 14.20 Jelly end rot is an extreme expression of the sugar end disorder that often affects the stem end of heat-stressed tubers

a restriction in growth or pointed end. This darkened end will typically also have lower specific gravity and a visible "glassy" or translucent appearance. In severe cases, this disorder predisposes the tuber to subsequent tissue breakdown and the development of jelly end rot (Fig. 14.20).

Sugar ends are typically associated with periods of high air and soil temperatures and water deficits during tuber initiation and early bulking. Research has shown that high soil temperatures inhibit the conversion of sugars to starch in the tubers, thereby increasing the proportion of reducing sugars in the affected tissue. Water deficits may also interfere with the transport of sugars within the plant causing unequal distribution of reducing sugars after alleviation of the stress.

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:

- 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.
- 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.
- Bed soil in the fall, when weather and soil conditions permit, to facilitate early planting.
- Manage irrigation to provide uniform water application and optimal water infiltration and soil water distribution throughout the field.

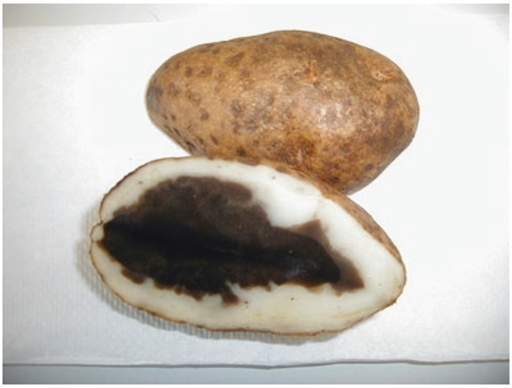

Fig. 14.21 Blackheart symptoms are a result of oxygen deprivation in the field or storage

- On ground of variable slope, use a properly designed sprinkler system with flow control nozzles and use basin tillage where appreciable runoff is expected.
- 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. See Chap. 13.
- Use a good soil sampling and testing program and fertilize according to established guidelines for your area. Avoid excessive N 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 (Fig. 14.21). In the field, this disorder is most prevalent in waterlogged soils in low-lying areas. In these areas, soil remains saturated for extended periods, thereby promoting anaerobic conditions and reducing gas exchange with the tubers. 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. Warmer storage temperatures increase tuber respiration rates and oxygen demands, which can accelerate blackheart development if ventilation is inadequate.

Management

In-field management for blackheart prevention includes proper irrigation scheduling and using basin tillage to minimize the accumulation of runoff water into the low spots of the field. Maintaining adequate ventilation and proper temperatures helps minimize blackheart development during potato storage and transport. Further, maintaining proper airflow through the potato pile will also minimize the potential for blackheart. In part, good airflow is the result of proper installation and operation of equipment, minimizing the amount of dirt and debris in storage, and proper distribution of air ducts.

Sidebar 14.1: Purple Pigmentation in the Tuber Flesh

Some potato varieties occasionally exhibit streaks or blotches of purple or pink coloration in the flesh. Although rare, this disorder can be a concern to the potato grower because of negative consumer response. The pigmentation is harmless, but is definitely out of the ordinary for the average potato buyer.

The pink or purple color in tuber flesh is due to anthocyanins (Fig. 14.22). This group of plant pigments is the most common source of red or purple color in nature. Red color in fall leaves, red or purple color in flowers, and the intense purple color in plants, such as table beets, are usually due to the presence of anthocyanins.

The skin color of red potatoes and red and purple flesh in novelty potatoes is also due to these same anthocyanins, demonstrating that their presence is natural and normal. Many of these pigments are used as natural food colorants, and new research has shown they have a positive impact on human nutrition as a result of antioxidant characteristics.

Upon cooking, anthocyanins in tuber flesh may fade or entirely disappear, especially if the color is initially faint. Anthocyanins can break down during baking or frying or can be leached out during boiling.

All evidence points to the fact that flesh purpling should not concern the consumer. However, even when something is understood, it is not necessarily accepted. For this reason, most growers prefer to minimize this disorder.

The causes of flesh purpling are not well understood. Variety choice is the only usable management tool. Some varieties are prone to the problem, while others are rarely affected. Flesh purpling is commonly seen in HiLite Russet, Frontier Russet, and occasionally Russet Norkotah. Pigmentation is also more common in potatoes that are subjected to certain stresses. Tubers that are close to the soil surface, especially if they show field greening, are more likely to show purple streaking in the flesh. Also, the condition has been correlated with exposure to cold temperatures, either in the field or storage.

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. See Sidebar 14.1.

Fig. 14.22 Anthocyanin in tuber flesh of the cultivar Frontier Russet

Symptoms and Causes

Potatoes that are exposed to freezing or chilling temperatures can show multiple symptoms depending upon whether they are observed frozen or thawed. Damage may occur before harvest, in transit, or in storage. Exposure to soil temperatures below 28 °F for several hours can kill the exposed tuber tissue by causing ice crystals to form in the cells. Freezing injury usually occurs on the part of the tuber closest to the soil surface, which is usually the bud end. The severity of damage will also depend upon the duration of the frost period and rate of thaw. Freezing damage is difficult to diagnose while the tubers are frozen because they show no obvious symptoms other than the surface being hard and difficult to damage. As the tubers begin to thaw, the symptoms become visible.

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. Affected tissues often break down completely and become liquid, having the appearance of a water-soaked rot. Tissues in the vascular ring are particularly sensitive to low-temperature injury.

Chilling injury can occur by exposure to temperatures between 32 and 37 °F, typically resulting in a discoloration of the internal tuber tissue (Fig. 14.23). However, cells are not frozen and tissues do not break down rapidly.

Chilling injury is not visible on the tuber surface, but internal tissues exposed to temperatures in this range can exhibit a variety of symptoms, including mahogany browning, reducing sugar accumulation and fry darkening, tissue graying upon boiling, and necrotic phloem injury. Mahogany browning is a symptom in which chilled tuber tissue turns a pinkish-red to reddish-brown or gray color.

Management

To minimize frost or freezing damage, proper hilling procedures should be used to minimize tuber exposure to freezing temperatures. If possible, potatoes should be harvested early, before potential frost exposure. In addition, potatoes should be transported only in favorable conditions or in insulated containers and storage temperatures maintained above 37 °F, accompanied by adequate ventilation.

Fig. 14.23 Chilling injury showing an internal discoloration of the tuber tissue

Fig. 14.24 Internal sprouting symptoms showing inward growth of sprouts of a red-skinned variety

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 (Fig. 14.24). 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.

Another potential contributor to this problem is chemical in nature and associated with sub-optimal application of a sprout inhibitor. Internal sprouts can occur when residue levels of the sprout inhibitor 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) variety; (2) physiological condition, temperature, and hydration level of the tubers; (3) size and shape of tubers; and (4) type and force of impact.

Minimizing bruising is important in the control of tuber decay, since bruises allow *Fusarium* and other organisms to enter the potato. Bruise damage can also increase weight loss in storage and diminish overall tuber quality, product recovery, contract incentives, and consumer acceptability.

Blackspot Bruise

Many physiological and physical factors affect the susceptibility of tubers to blackspot bruise. Exposure of tubers to impact forces during harvest or transport causes the cell membranes within the affected tissue to rupture and begin to leak. This damage to the cellular membranes allows the enzyme polyphenoloxidase (PPO) to come into contact with phenols (primarily tyrosine) in the intercellular space. As a result, phenols are oxidized and form the 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 fully apparent for 12–24 hours after the damage has occurred, which makes early detection of damage difficult. The damaged area first turns pink to reddish-brown, then darkens to grayish-black as the melanin begins to form (Fig. 14.25).

Factors that favor blackspot bruise include large tuber size, low tuber hydration or turgidity, high specific gravity, potassium (K) deficiency, tubers with significant curvature, and very mature tubers. Varieties differ greatly in susceptibility to blackspot bruising, primarily because of differences in cell structure, chemical composition and tuber shape.

Management

Practices for reducing blackspot bruise include selection of less-susceptible varieties; maintenance of proper tuber hydration levels between vine kill and harvest; proper fertilizer applications, especially with N and K; avoidance of early

Fig. 14.25 Blackspot bruise symptoms in a Ranger Russet tuber

Fig. 14.26 Shatter bruises, shatter cracks, and/or thumbnail cracks are external symptoms of tuber handling injury. Thumbnail cracks can occur when handling cold, turgid tubers, even with minimal impact

dying and advanced tuber maturity; and good harvest and handling procedures. See Chap. 16.

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 (Fig. 14.26). Often, the margins of the damaged areas exhibit discoloration, similar to the color of blackspot-bruised tissue. Internally, the damaged tissues can have a light gray appearance that extends into the tuber. Factors that favor shatter bruise development include high tuber hydration or turgidity, cool (<45 °F) pulp temperatures, and improper handling.

Fig. 14.27 Pressure bruise forms during storage and results in depressed areas that may or may not be discolored in the flesh underneath

Thumbnail cracks, also called air checks, are shallow, curved cracks on the tuber surface. They are caused by handling injury to cold, turgid tubers, followed by exposure to low humidity conditions. They are similar to shatter cracks in that they are due to cell wall separation. Thumbnail cracks are unique in that they are generally superficial and require minimal impact to occur. 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. Varieties differ greatly in susceptibility to shatter bruising; therefore, selecting a less susceptible variety can reduce incidence of this disorder.

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 (Fig. 14.27). If there are no 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%), warm storage temperatures, large differentials in pile temperature, 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%, keeping storage temperatures in the optimal range, gradually cooling the storage to the final holding temperature, and not piling potatoes higher than the specifications for the storage and ventilation system.

Summary of Physiological Disorder Management

The first step in management of physiological disorders is proper diagnosis. As pointed out above, many of these disorders are easily confused with injury due to pests and diseases. Using a systematic approach that employs the following methods will help in identification of many specific disorders:

- Collect information on field history.
- Evaluate symptom distribution patterns in the field.
- Review recent and past chemical and fertilizer applications.
- Review recent weather conditions.
- Perform a clinical diagnosis to rule out possible disease pathogens.

Tuber physiological disorders can usually be diagnosed by evaluating symptoms, although some similarities exist with symptoms of a limited number of pathogens. Because tuber disorders are usually detected after harvest, a pattern in the field is more difficult to establish, and primary causes of tuber damage may be difficult to confirm.

Once a diagnosis is made, the second step is to understand the causes of the physiological disorder and how it may affect the yield, storability, and marketability of the crop. Knowledge of USDA inspection rules and individual contract specifications for external and internal tuber defects will help identify which disorders have the greatest effect on marketability and economic return.

The third step is to understand the environmental and management factors that influence the development of the disorder. Many of the foliar and tuber disorders discussed in this chapter are stress-related problems. Stress is defined as any factor (moisture, temperature, nutrient availability, etc.) above or below the optimum for plant growth and tuber production. The impacts of stress tend to be cumulative in that a longer period of stress is more damaging than a short period, and two simultaneous stresses (e.g., drought and heat) cause more damage than a single stress.

Sudden changes in conditions from one extreme to another also tend to be more damaging than a gradual change.

Since many physiological disorders in potatoes are associated with stress caused by heat and drought, knowledge of how these two factors impact vine and tuber growth is useful in management. See Chap. 2. The optimum temperatures for potato growth and development have been defined as 77 °F during the day and 54 °F at night. No growing region has those conditions every day; therefore, potatoes are subjected to some stress every growing season. At temperatures above 77 °F photosynthesis (energy production) decreases, while respiration (energy consumption) increases rapidly, doubling with every 10 °F increase. The net result is less energy in the form of carbohydrates available for transfer to tubers, and eventually tuber growth slows or even stops. Compounding this situation is the fact that high temperatures promote vine growth and also hasten the senescence rate of individual leaves. If high-temperature conditions last long enough, the plant suffers from a lack of energy production, and most of the energy that is produced is partitioned to the vines instead of the tubers. The net result is a reduced, irregular tuber growth pattern that leads to a high incidence of both external and internal disorders.

Water use by the crop is directly impacted by temperature, so it is difficult to separate heat stress from drought stress. As temperature increases, daily water use by the crop increases, and it becomes more difficult to keep soil moisture levels above the 65% threshold at which the plant begins to experience stress. See Chap. 13. The earliest observed response to drought stress is reduced stomatal conductance, which controls the exchange of water and CO_2 at the leaf surface that is necessary for regulating temperature and photosynthesis. Drought stress also reduces leaf expansion (even prior to wilting) and delays canopy development. All of these responses further reduce energy available for tuber production.

There is little growers can do to directly impact environmental conditions that cause stress. Therefore, the key to reducing stress-related disorders is not contributing to the problem by making mistakes in managing the crop. This approach starts with selecting varieties that are known to have resistance to heat and drought stress. Many of the more recently released varieties for both the fresh pack and processing markets have much better resistance to stress-related disorders compared to Russet Burbank, and as a consequence, exhibit much lower levels of defects even when the crop experiences stress during the growing season.

Another important concept is maximizing development of the root system. Potato plants are relatively susceptible to drought and heat stress due to limited ability of their roots to transport water efficiently to stems and leaves. Practices that lead to a reduction in rooting volume or depth, such as compaction and late cultivation, further increase the susceptibility to stress. Likewise, practices that lead to excessive vine development, such as over application of N fertilizer, increase water demand while having little impact on the plant's ability to take up water through the root system. The result can be an imbalance in vine and root growth that makes the crop susceptible to stress.

While excessive vine growth can increase susceptibility to stress, inadequate vine development also has negative consequences in managing stress. This is

Sidebar 14.2: Sugar-End Potatoes

One of the most severe problems resulting from sugar accumulation in potatoes takes the form of a defect called sugar ends. The name is indicative of the accumulation of high levels of sugars in one end of the tubers, usually the stem end. When fried, sugar-end potatoes produce french fries that are brown on one end, a processing defect known as dark ends (Fig. 14.28).

Generally, sugar ends are more common in years with hot temperatures or in fields that experience drought stress during the growing season. The common assumption is that the resulting stress on the foliage causes a disruption in the growth of the plant that results in interruption of sugar transport and metabolism.

Research at the University of Idaho's Kimberly Research & Extension Center, however, provides evidence that the damaging aspect of heat and drought stress is high soil temperatures, especially during tuber initiation and early bulking. Apparently, high soil temperatures have a direct disruptive effect on the biochemistry of the developing potato tuber.

In the Idaho study, four treatments were included:

- A control with ambient temperatures under natural conditions.
- Low soil moisture, allowed to fall to 50% available between irrigations.
- High soil temperature—heat cables were used to raise soil temperature 10 °F above the control.
- A combination of the low moisture and soil heating treatments.

The results of the Idaho study indicate that low moisture, by itself, impacts neither tuber specific gravity nor the percentage of sugar-end potatoes (Table 14.1). In contrast, the addition of heat to the hill had a definite negative impact on all quality parameters measured. The combination of heat and drought stress produced a slightly lower percentage of U.S. No. 1 tubers and a higher percentage of sugar ends than heat alone.

because shading from the vines is one of the few ways to reduce soil temperatures when air temperatures are high. High soil temperatures have been shown to be one of the most important factors in the incidence of external tuber defects and sugar ends. See Sidebar 14.2. Therefore, establishing a uniform stand; promoting early season growth by eliminating compaction; drought; nutrient deficiency; herbicide injury; and damage from diseases, such as Rhizoctonia stem canker, are keys to promoting adequate early-season vine development. Likewise, maintaining a healthy canopy by controlling both foliar and soilborne diseases that can lead to early plant death before vine kill will reduce exposure of tubers to large fluctuations in soil temperatures late in the season, which leads to quality defects associated with overmaturity. See Chap. 15.

Fig. 14.28 Sugar ends are a serious disorder that impacts processing quality. A major cause of sugar ends is warm soil temperatures during early tuber bulking.

Table 14.1 Effect of soil moisture and temperature at tuberization on tuber quality and sugar ends

Treatment	Percent U.S. No. 1 tubers	Specific gravity	Percent sugar ends
Control: High moisture, ambient soil	69	1.081	4
Low moisture, ambient soil	53	1.082	0
High moisture, hot soil	39	1.068	23
Low moisture, hot soil	37	1.071	33

Source: Kleinkopf et al. (1988)

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