# INTERNAL QUALITY

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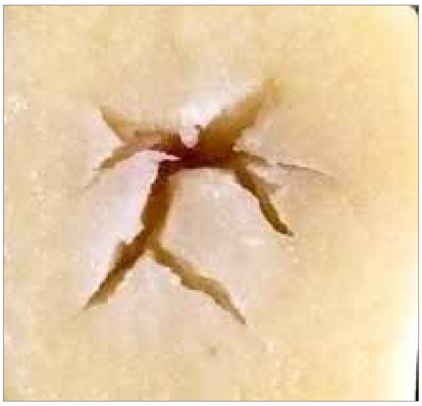
# INTERNAL QUALITY

The *internal quality of potatoes* is a broad concept, the exact meaning of which can vary depending on the intended use of the potato. The factors defining a good seed potato are therefore not necessarily the same as for fresh market potatoes or processing potatoes. There are, however, factors of overall interest when referring to the internal quality of potatoes, including the presence of physiological disorders, the specific weight, as well as the susceptibility to pathogenic infection. These factors form the basis of the discussion to follow. Factors not included here, and which may be of more interest to processing quality, are not in fact being disregarded in terms of their importance in determining internal quality, but shall rather form part of a another factsheet.

The purpose of this factsheet, and in particular the diagram on the back page, is to outline the complexity of the numerous factors affecting internal quality, and not to provide a detailed description of each. More information is available in the list of references on page 7.

*Brown core*



*Hollow heart*

## Physiological disorders

This refers to non-pathogenic disorders that usually results from environmental conditions that negatively affect the normal functioning of the plant.

**Brown core and hollow heart** are well-known physiological disorders that cause a reduction in quality and result in loss. There are no visible external symptoms, and cultivars differ in their susceptibility to such physiological disorders. Under certain conditions, brown core and hollow heart can be regarded as two different stages of the same disorder, and are most likely both caused by the same conditions.

Hollow heart can, however, occur without being preceded by brown core, and tends to affect large tubers rather than smaller ones. Cavities can form along the length or width of the tuber and can also be irregular in shape. The tissue lining the cavities can be white or brown, and skin tissue sometimes forms. Cavities can occur in different places in the tuber, depending on the time of the season at which they originate. Where small tubers with internal brown spot are left to grow slowly and consistently, the dead brown cells are distributed amongst the normal living cells.

The causes of brown core and hollow heart are numerous and often confusing. Brown core develops when tubers are very small and the temperature is low (<15°C) for a few consecutive days, especially during tuber initiation, until the tuber reaches approximately 50 g. Cells die off, turn brown, and easily tear apart from one another. Where small tubers with brown core grow quickly and/or inconsistently, cells in the brown core tend to tear apart from one another and, as the tuber grows, hollow heart then develops. This condition is aggravated by over-irrigation and the application of large quantities of nitrogen, especially during tuber initiation.

Hollow heart that is not preceded by brown core is associated with a rapid growth rate in tubers, varying soil moisture levels, and in some cases also the application of large quantities of nitrogen.

**Internal brown spot/fleck** often occurs in large tubers, and not all the tubers on a plant are necessarily affected. Cultivars also differ in terms of their susceptibility to internal brown spot, and the disorder can also develop during the storage of tubers. The tubers do not usually show any external symptoms of brown spot, but irregular brown spots, found mainly inside the vascular ring, are characteristic. Conditions leading to irregular tuber growth or moisture stress, including extreme or varying air and soil temperatures and soil moisture levels, are the primary causes of brown spot. It is more common in sandy soils, while improper fertilisation, which can induce an internal calcium deficiency, can also encourage the development of brown spot. High soil temperatures, especially during the later stages of the tuber bulking period, are often associated with

*Internal brown spot*

brown spot. Where soil temperature is extremely high, the roots are unable to function optimally, with the result that insufficient water and Ca are absorbed. Internal brown spot can also occur when the air temperature is high and the soil temperature low. Under these conditions transpiration occurs normally through the leaves, but the absorption of water and nutrients through the roots is delayed. As a result, the bulk of the water and nutrients, especially Ca, that is actually absorbed, will be transported to the leaves and not to the tubers, which in turn places the tuber cells under stress. Under conditions of low soil moisture, Ca intake is low, because assimilable Ca is dissolved in the groundwater.

Plants cultivated in sandy soil are susceptible to brown spot, since the water retention capacity of sandy soil is low and the soil temperature tends to rise rapidly. On the other hand, an oxygen shortage under waterlogged conditions could prevent the absorption of water and Ca. Heavy soil tends to become waterlogged during the rainy season and with excess irrigation.

**Black heart** mainly affects large tubers. The affected tubers are grey-black to black inside, and the affected tissue is well defined. A cavity can form in the black heart, and the affected tissue becomes hard and leathery. Black heart occurs as a result of an oxygen shortage in the affected tissue, causing the tissue to die off, especially where a shortage of oxygen is accompanied by high temperatures. High temperatures lead to increased respiration, which in turn increases the need for oxygen.

**Cold damage** is a result of exposure to temperatures around 0°C - 2°C**.** Symptoms of cold damage are mainly internal in the vascular tissue and on the stem end of the tuber can cause the tissue to appear grey in colour. Tissue can appear dark grey or black, or grey or reddish in colour. With sufficient exposure to

*Cold damage*

sub-zero temperatures, ice crystals can form in the tissue. Upon defrosting, cells die and turn into a watery mass.

Cold-damaged seed tubers' ability to sprout is often negatively affected. Fried chips made from cold-damaged potatoes are dark in colour. Boiling such tubers leads to the tissue becoming grey or black in colour.

**Physiological age and sprouting of seed potatoes.** Environmental and fertilisation factors are not only responsible for the development of physiological disorders that reduce internal quality, but can also affect the characteristics

*Black heart*

*Sprouts (left) showing apical dominance and sprouts (right) forming lateral branches* associated with physiological age and sprouting ability of seed potatoes. The physiological age of seed potatoes, or the stage of development, changes over time, but can also be affected by the growth and storage conditions. External stressors can cause seed potatoes to age more rapidly, which can hamper sprouting after planting. Normal apical dominance of sprouts is more common in seed potatoes with a high Ca content (sprouts left in photo). Sprouts of seed potatoes with a low calcium content tend to form lateral branches, similar to physiologically old seed potatoes (sprouts right in photo), such branches tend to form haulms with poor vigour.

**The keeping quality** of tubers determines whether they can be transported by road over long distances and is a function of various internal tuber properties, including moisture loss and resistance to mechanical damage during handling and transportation. The keeping quality also depends on the cultivar, meaning that certain cultivars are more suited to long-distance transportation.

**Specific gravity** (SG) is a characteristic of potatoes that is often used as a measure of internal quality. Processing companies, for example, demand potatoes with a specific gravity of at least 1.075. SG is an indication of the density (percentage of solid matter), including starch. In the case of potatoes with a low specific gravity, more oil is required for frying, which raises the cost of processing. Low specific gravity also has a detrimental effect on the texture of processed chips, as required by a large sector of the processing industry. High temperatures during the growing season are particularly detrimental to SG. At temperatures of >28°C, photosynthesis is reduced, meaning that less starch and other solids can be formed.

**Reducing sugars.** High concentrations of reducing sugars, specifically glucose and fructose, result in undesirable browning of the tissue during frying. This is known as the Maillard reaction and is caused by a chemical interaction between the sugars and amino acids at high temperatures. Cultivars differ

*Crisps made from tubers containing a high concentration of reducing sugar*

significantly in terms of the percentage of reducing sugars in the tuber tissue, but conditions during cultivation, as well as during storage, are of the utmost importance.

Both low- and high temperatures during cultivation, can lead to an increase in the concentration of reducing sugars. In order to limit the formation of reducing sugars, the optimal temperature during tuber growth is between 15°C and 25°C. High levels of nitrogen during tuber growth are also associated with a high concentration of reducing sugars. Increasing the level of fertilisation with potassium, however, can reverse this effect, with sufficient potassium being deemed essential in optimising the percentage of dry material as well as the reducing sugar concentration, in processing cultivars.

### Tuber diseases

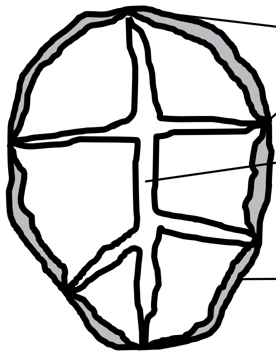
Pathogenic infections have a significant effect on both the yield and quality of potatoes. The resistance of plant tissue to infection by pathogens is influenced by the Ca content of the tissue, amongst other things. Ca in the cell wall helps to prevent the pathogen from digesting the cell wall. More information on tuber diseases is available in other relevant fact sheets.

## THE ROLE OF CALCIUM (Ca) IN INTERNAL TUBER QUALITY

Of all the nutrients, calcium appears to play the most important role in determining a tuber's susceptibility to cell damage. Physiological disorders in potatoes can be associated with a localised shortage of Ca in the tuber tissue.

Calcium is important in the cell to maintain the integrity of the membrane and cell wall and thus improve resistance to damage from biotic or abiotic stress. A shortage of Ca causes the cell membranes and cell walls to lose integrity under conditions of stress, with the result that the contents of the cytoplasm and the vacuole mix together and the cells die off.

**Calcium content in potato plants.** The highest percentage of Ca in the plant occurs in the foliage (up to 1.5%), while a very low percentage is found in the tuber (0.01 to 0.15%). Ca is also not uniformly distributed throughout the tuber. There are higher concentrations of Ca in the periderm or skin (0.05 to 0.25% dry mass) than in the medulla or inner cells (0.01 to 0.06% dry mass).




The Ca concentration in the medulla correlates with the tubers' susceptibility to physiological disorders, while the Ca content of the periderm helps to strengthen the cells' resistance to pathogens. In terms of resistance to pathogens such as soft rot bacteria, the Ca content of the medulla and periderm is important. Such bacteria penetrate the host cells when the enzymes that they release break down the pectin between cells. This leads to a loss in cell structure, which destroys the cells. The more calcium present in the cells, or more specifically in the pectin layer, the better the resistance to infiltration by the enzymes and the spread of the bacteria in the tissue.

**Calcium uptake and transport in the plant.** Unlike most other elements, calcium is not mobile within the plant. It cannot be translocated from the leaves to the tubers and the Ca concentration is always higher in older leaves. The reason for this is that Ca uptake is driven mainly by transpiration and therefore occurs only through the xylem. The Ca present in the tubers is mainly absorbed through the stolon roots of the tuber in question. Although the tubers also transpire, most of the water and thus Ca is translocated to the leaves *via* transpiration. This is aggravated by conditions that accelerate transpiration, such as high temperature, high light intensity, low relative humidity, and combinations of these factors. Calcium uptake is also affected by conditions in the root zone; waterlogged soil, high salt content and high soil temperatures. This is why the application of higher levels of Ca does not necessarily lead to higher calcium content in the tubers.

**Calcium application.** To ensure the sufficient absorption of Ca by the tubers, it is important to look at the environmental factors as well as the time, place and type of Ca application. Sufficient Ca in the soil solution where and when tubers are formed is thus essential. The application of calcium during tuber initiation and early tuber bulking stages can increase the Ca content of the periderm and medulla. Cultivars differ in respect of the Ca concentration in the tuber. Tuber initiation in many cultivars take place over a period of time, or even throughout the season.

Although there is a link between the Ca content of tubers and their internal quality, the uptake and distribution of Ca in the plant depends on a variety of internal and climatic factors.

# FACTORS AFFECTING INTERNAL QUALITY

## Choice of cultivar

Cultivars differ in respect of their propensity to poor internal quality. This is related to a cultivar's tendency towards lush foliage growth, the development of only a few tubers per haulm, its susceptibility to soil-borne pathogens, leaf diseases and insect damage, its level of heat and drought tolerance, or the number of root hairs on the root tips. It is because of all these factors that certain cultivars tend to exhibit one or more characteristics of either poor or good internal quality.

## Plant factors

1. *The age and internal quality* of seed potatoes determine the number of haulms that form, as well as the vigour of those haulms. Seed potatoes that are physiologically old, or which have a low Ca content, form branched sprouts with reduced vigour.

2. *A low number of haulms per seed potato* can result in only a few tubers forming per plant, which, under conditions of high N and high temperature in particular, can bulk too quickly and lead to hollow heart. A low number of haulms per plant usually results when physiologically young seed potatoes are planted – a condition influenced by the conditions and period of storage.

3. *Rapid tuber growth.* When tubers bulk rapidly, cells under certain conditions can tear apart from one another, leaving cavities in the tuber (hollow heart).

4. *Leaf surface.* Sufficient assimilates must be produced through photosynthesis before tubers will initiate. Foliage damage during tuber formation leads to fewer tubers forming per plant than normal. This can increase the growth rate of these few tubers at a later stage, when the foliage recovers. Given that transpiration and the associated absorption of water and Ca are limited during tuber formation (the critical stage for Ca absorption), it is evident that calcium-related internal defects are possible. Foliage can be damaged by wind, hail, frost, leaf diseases and chewing insects.

Overly lush foliage, on the other hand, will lead to significant moisture loss, while the transpiration stream will channel Ca to the leaves instead of the tubers. Lush foliage could be the result of over-fertilisation, high levels of organic material in the soil, or a nutrient imbalance in the soil.

5. *Number of root hairs.* Ca is absorbed through the unthickened cell walls of the root hairs. Root hairs are delicate extensions of the epidermal cells on the tips of the roots. When the soil dries out, so too do the root hairs and they subsequently die. Once moisture conditions have been restored, it takes approximately four days before new root hairs are formed. Relative to other crops, potatoes form few root hairs and this is a cultivar related characteristic. It is therefore important that soil moisture does not drop too low, especially during tuber formation.

*Delicate root hairs on root tips*

## Interaction with climate

6. *Excess transport of water to the foliage* can result from a high rate of transpiration due to high temperature (>25°C), low air moisture (<60% RH), and/or windy conditions. The rate of transpiration is especially high when the latter factors prevail simultaneously. This condition is aggravated when a low K content in leaves hinders the stomata from closing properly and thus preventing moisture loss.

7. *Low transpiration rate.* Where there are high levels of moisture in the air (>90% RH) and low temperatures (<15°C), transpiration from the leaves occurs slowly, particularly where these two conditions occur simultaneously. The transpiration stream is consequently weak, with poor absorption of water and nutrients, including Ca. Under these conditions, the absorption of Ca through the stolon roots is too slow to ensure sufficient Ca in the tuber tissue.

## Interaction with soil conditions

8. *Conditions in the soil environment,* such as high (>25°C) or low (<10°C) soil temperature, availability of oxygen, soil moisture and salt quality of the soil, have an effect on the growth rate of tubers, the absorption of Ca, the functioning of the roots, and the withdrawal of water and nutrients from the tubers.

9. *Soil conditions,* such as waterlogging and crust formation, lower the $O_2$ concentration in the soil, leading to poor root function. Every effort must therefore be made to prevent ploughsole formation, soil compaction, over-irrigation and poor drainage. Poor root function inhibits the absorption of nutrients, especially calcium, which is absorbed only through the young root tips.

10. *Soil-borne diseases and pests* are responsible for causing physical damage to roots, which has an impact on root function. The presence and functioning of pathogens and pests, such as nematodes, can also be affected by soil health. In general, it can be said that conditions that negatively affect root function can lead to stress in the roots, which lowers their resistance to infection. Healthy and balanced populations of soil microbes surrounding the roots, on the other hand, not only create an unfavourable environment for such pathogens, but are also responsible for providing the nutrients to be absorbed by the roots.

## Interaction with fertiliser

11. *Plant nutrients* (shortage, excess and imbalance, as well as plant availability) have an effect on root function, calcium intake and vigour. An excess of plant nutrients can lead to overly lush foliage and subsequent excess transpiration, leading to a shortage of calcium in the tubers since Ca is transported towards the foliage instead.

12. *Poor absorption of Ca* through the roots can also result from a low [Ca] concentration in the soil solution, which in turn is affected by the Ca source, as well as a high $NH_4$ concentration and low Ca:Mg ratio in the soil solution.

13. *Time and placement of calcium application.* Research done locally at Stellenbosch University, found that Ca must be available for absorption through the stolon roots at the stage of tuber initiation and for approximately four weeks thereafter. Calcium that is applied too late has no effect on tuber quality.

14. *Reduced allocation of nutrients and water to tubers.* Under conditions of wind, high temperature and low air moisture, water and nutrients (especially Ca) are primarily transported to the foliage and not the tubers. This causes water gradient pressure or stress, which can ultimately result in tissue damage. Where very young tubers are subjected to such conditions, it could result in brown spot, internal brown spot and hollow heart.

## References

Bussan, A.J., 2007. The Canon of Potato Science: 45. Brown Centre and Hollow Heart. Potato Research, 50(3), pp.395-398.

Busse, J.S. and Palta, J.P. 2006. Investigating the in vivo calcium transport path to developing potato tuber using $^{45}Ca$: a new concept in potato tuber calcium nutrition. Physiologia Plantarum 128:313-323

Crumbly, I.J. 1970. Some physical and physiological aspects of hollow heart in potato, Solanum tuberosum L. Ph.D. Thesis. North Dakota State Univ.77 pp.

Gunter, C., Ozgen, S., Karlsson, B. and Palta, J., 2000. 589 Calcium Application at Pre-emergence and during Bulking May Improve Tuber Quality and Grade. HortScience, 35(3), pp.498-498.

Hiller, L.K., Koller, D.C. and Thornton, R.E., 1985. Physiological disorders of potato tubers. Potato physiology, pp.389-455.

Hiller, L.K. and D.C. Koller. 1982. Brown center and hollow heart as a quality factor. Proc Washington State Potato Conference 21: 101–108.

Iritani, W.M., Weller, L.D. and Knowles, N.R., 1984. Factors influencing incidence of internal brown spot in Russet Burbank potatoes. American potato journal, 61(6), pp.335-343.

Karlsson, B.H. and Palta, J.P., 2002, August. Enhancing tuber calcium by in-season calcium application can reduce tuber bruising during mechanical harvest. In XXVI International Horticultural Congress: Potatoes, Healthy Food for Humanity: International Developments in B reeding, 619 (pp. 285-291).

Kleinhenz, M.D., Palta, J.P., Gunter, C.C. and Kelling, K.A., 1999. Impact of Source and Timing of Calcium and Nitrogen Applications onAtlantic'Potato Tuber Calcium Concentrations and Internal Quality. Journal of the American Society for Horticultural Science, 124(5), pp.498-506.

Krantz, F.A. and E.P. Lana. 1942. Incidence of hollow heart in potatoes as influenced by removal of foliage and shading. American Potato Journal 19: 144–149.

Li, P. ed., 2012. Potato physiology. Elsevier.

Łojkowska, E. and Hołubowska, M., 1989. Changes of the lipid catabolism in potato tubers from cultivars differing in susceptibility to autolysis during the storage. Potato research, 32(4), pp.463-470.

McCann, I.R. and Stark, J.C., 1989. Irrigation and nitrogen management effects on potato brown center and hollow heart. HortScience, 24(6), pp.950-952.

Miller, D.E. and M.W. Martin. 1985. Effect of water stress during tuber formation on subsequent growth and internal defects in Russet Burbank potatoes. American Potato Journal 62: 83–89.

Ozgen, S., Karlsson, B.H. and Palta, J.P., 2006. Response of potatoes (cv Russet Burbank) to supplemental calcium applications under field conditions: Tuber calcium, yield, and incidence of internal brown spot. American Journal of Potato Research, 83(2), pp.195-204.

Palta, J.P., 2010. Improving potato tuber quality and production by targeted calcium nutrition: the discovery of tuber roots leading to a new concept in potato nutrition. Potato research, 53(4), pp.267-275.

Reyes-Cabrera, J., Zotarelli, L., Rowland, D.L., Dukes, M.D. and Sargent, S.A., 2014. Drip as alternative irrigation method for potato in Florida sandy soils. American Journal of Potato Research, 91(5), pp.504-516.

Rex, B.L., Mazza, G. 1988 Cause, control and detection of hollow heart in potatoes. American Potato Journal, 66: 165 – 183.

Silva, G.H., Chase, R.W., Hammerschmidt, R., Vitosh, M.L. and Kitchen, R.B., 1991. Irrigation, nitrogen and gypsum effects on specific gravity and internal defects of Atlantic potatoes. American Potato Journal, 68(11), pp.751-765.

Van Denburgh, R.W., Hiller, L.K. and Koller, D.C., 1986. Ultrastructural changes in potato tuber pith cells during brown center development. Plant physiology, 81(1), pp.167-170.

Vaughan, K., 2014. Preventing Hollow Heart.

Vreugdenhil, D., Bradshaw, J., Gebhardt, C., Govers, F., Taylor, M.A., MacKerron, D.K. and Ross, H.A. eds., 2011. Potato Biology and Biotechnology: Advances and Perspectives: Advances and Perspectives. Elsevier.

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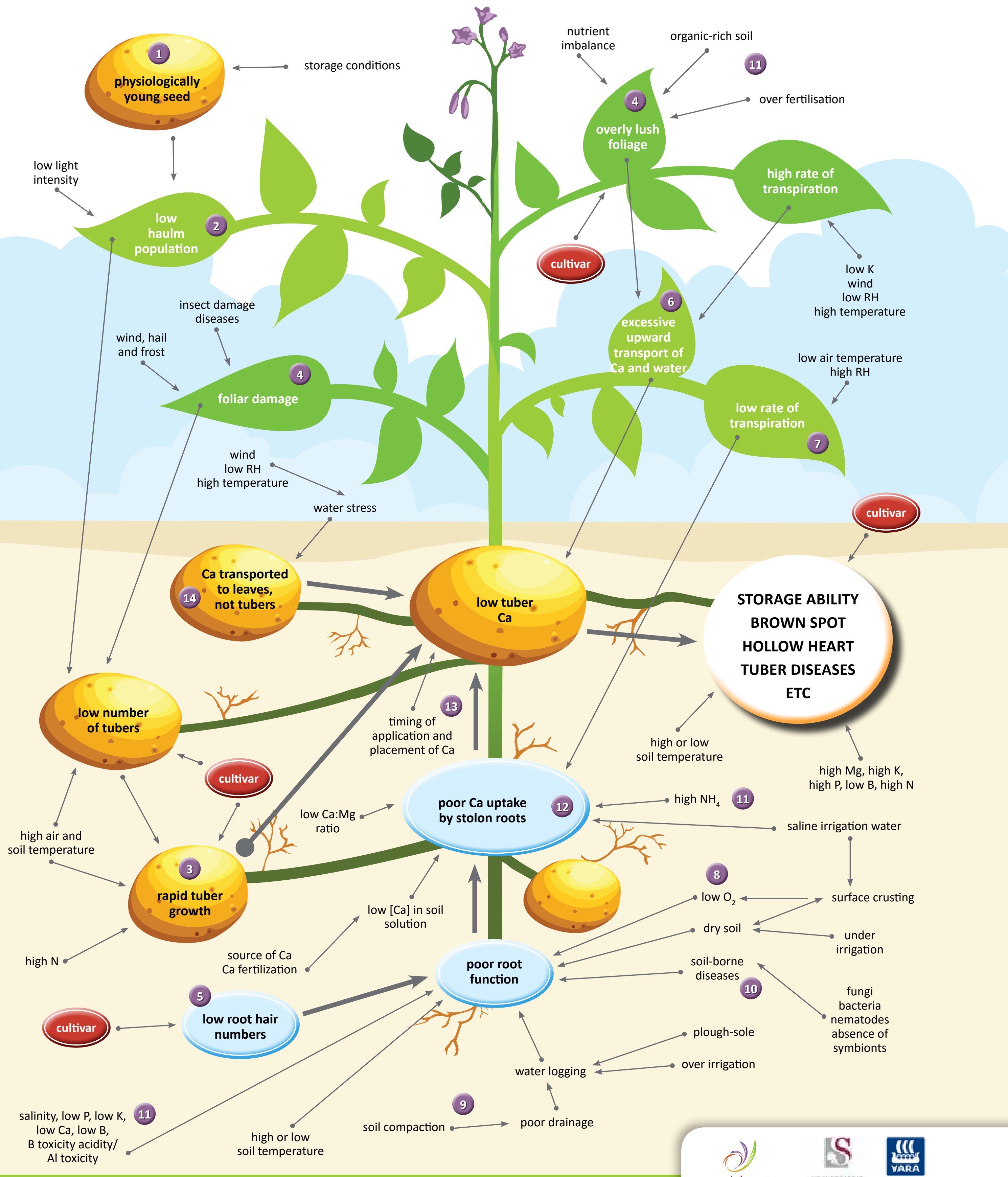


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