Potato Nutrition – IBS

By; Peter Aleman
Bio-Gro, Inc.

Introduction

Internal brown spot (IBS), also known as internal browning, internal rust spot and/or internal brow fleck is a serious internal defect in potato tubers.

It is characterized by small, brown necrotic lesions visible primarily inside the vascular ring in the medullary tissue of the tuber.

"Hollow Heart"

Internal Brown Spot

Furthermore, there are also different ways that IBS may manifest itself; therefore the different descriptions such as "brown fleck", "blotch", "internal physiological necrosis", "hollow heart", "brown center" and others mentioned above. Different varieties of potatoes will also likely develop different patterns of IBS dependent on the potato growth pattern and also the timing of the condition that causes IBS.

IBS is localized cell senescence (collapsed cells) most likely associated with a calcium deficiency.

IBS and Storage

In is also important to note that in a published study, the average percentage of tubers with IBS was 30.4% at harvest and increased to 45.0% after 5 months in storage at 41-45 ^{o}F and then 3 weeks at room temperature (72 ^{o}F).

Is Low Calcium the Cause of IBS?

Although IBS has been studied for 50 years, many diverse opinions still exist as to what factors actually cause IBS. Weather definitely plays a role and so does soil moisture, especially during early periods of tuber formation when potatoes are most susceptible to IBS. However, the question remains, are the temperature and moisture fluctuations a "direct cause", or do the temperature and moisture fluctuations further suppress calcium uptake?

The first reference to the relationship between IBS and calcium was concluded from greenhouse studies in 1934, in Holland [9]. In 1978, Collier, et al made the first direct connection between calcium and IBS in a pot experiment where 0, 1, 3, 9 and 27 mM of calcium chloride were applied together with essential plant nutrients.

	Calcium Concentration (mM)				
	0	1	3	9	27
Total Yield / pot (grams)	249.9	279.5	338.1	349.3	312.4
Average % of tubers showing IBS per pot	35.5%	25.4%	4.5%	0%	0%
Calcium content of tubers dry matter (g/100 g)	0.012	0.010	0.009	0.039	0.066

In much of the recent literature, there is a growing agreement that there is a direct relationship between low tuber calcium and IBS.

Many studies have shown that tubers with IBS symptoms have lower Ca concentration than unaffected tubers. (1, 2, 3, 4)

Tubers are Naturally low in Calcium…

Compared with other potato plant vegetative parts, tubers have very low levels of calcium, ranging from 0.009 to 0.066 g/100 g dry matter, depending on the variety. (1) Therefore tubers are naturally susceptible. In our own nutrient tracking system, we have calculated that in a 25 ton/acre crop (500 sacks) tubers will accumulate only about **5 lbs/acre** calcium in the tuber, whereas the leaves and stems (mostly leaves) will accumulate from **60-75 lbs/acre**. Tuber calcium is usually 1/10 of plant calcium.

25 tons/acre	Pounds/acre Calcium	Pounds/acre Magnesium
Leaves & Stems	60-75	15-25
Tubers	4-6	10-13

This is due to the fact that tubers are a “low transpiring organ” and therefore do not have a high “pull” for calcium.

The physiological reasons for this low tuber calcium condition are now much better understood. Low calcium content in the tissue by growth is necessary in fruits and storage tissues for rapid cell expansion and high membrane permeability. (12). High growth rates of low-transpiring organs, however, increase the risk that the tissue content of calcium falls below the critical level required for cell wall stabilization and membrane integrity, and perhaps also for functioning as second messenger. In fast-growing tissues and organs so-called calcium deficiency-related disorders are wide-spread, such as tipburn in lettuce, blackheart in celery, blossom end rot in tomato or watermelon, and bitter pit in apple and IBS in potatoes!

IBS is Related to the Level of Peel Calcium

Many studies indicate that the amount of calcium in the peel of the tuber is related to the amount of potential IBS. [3] The level would be variety specific, reported here are russet burbank, but there is still a correlation between peel calcium and incidence of IBS.

Peel Calcium	0.226%	0.130%
Number of tubers with IBS	5%	42.5%

In these studies, side dressed calcium nitrate significantly reduced IBS, although only increasing peel calcium slightly.

Rate of Calcium Nitrate	220 lbs/ac	75 lbs/ac	0 lbs/ac
Peel Calcium Content	0.145%	0.134%	0.124%
Number of tubers with IBS	15.0%	36.3%	60.0%

These and other authors specify that the lack of calcium is especially in the periderm. (See also 5, 6, 7)

Calcium uptake & Transpiration

Transpiration is the main driving force for calcium transport in plants. Calcium moves along with water in the xylem. Potato tubers being surrounded mostly by moist soil have much less transpiration as compared to above ground parts.

The worst possible condition for the development of IBS is a period of cool weather and water logged soils, followed by a period of high heat. First, water logged soils result in poor root development and poor calcium uptake. Then a quick shift to high temperatures increases the transpiration rate of the plant, resulting in more calcium being translocated to the vegetative part and less to the tubers; along with reduced uptake due to poorly developed roots.

Effect of Transpiration Rates of the Shoots of Red Pepper during Fruit Growth on the Mineral Element Content of the Fruits [13]

Transpiration rate (relative)	Mineral element content (mg g^{-1} dry wt)			Fruit dry wt (g per fruit)
	K	Mg	Ca	
100	91.0	3.0	2.75	0.62
35	88.0	2.4	1.45	0.69

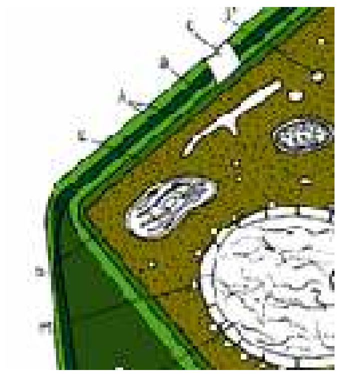
The issue of rapid transpiration of aboveground vines due to hot weather, can be proven by an experiment that demonstrated the effect of an “anti-transpirant”, a compound which allows the plant to get oxygen, but slows down moisture loss. These compounds are used in frost prevention. In potato plants subjected to soil drying, calcium deficiency-related tuber necrosis could be significantly reduced by foliar spray with anti-transpirants and a corresponding alteration of the leaf-tuber water potential gradients [16]. Timing would be the critical factor, furthermore, it is likely that most of the symptoms of IBS are formed during the time when the vine is in a rapid growth stage.

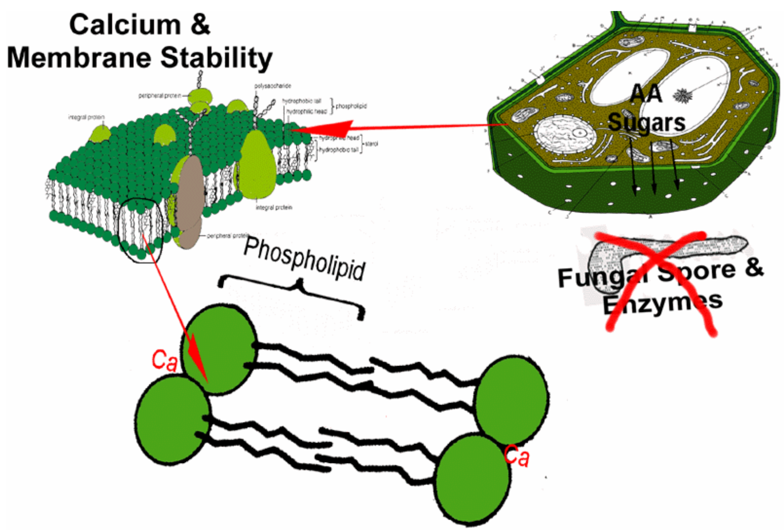
Calcium & Membranes

It is now well established that cell structure and integrity cannot be maintained without adequate levels of calcium around the membranes. If the level of membrane bound calcium is reduced the membranes become leaky, resulting in a lost of cellular salts and organic compounds. This loss, if not reversed, leads to eventual cell death (brown spot).

In order to illustrate "membrane calcium", following are diagrams of a cell and cell wall make up. In the 1st diagram "A" is the cell wall(s), joined together by "B" the middle lamella. "D" is the membrane as illustrated in the 2nd diagram.

A. The cell wall
B. Middle lamella
C. Plasmodesmata
D. Plasma membrane





It is important to visualize the "membrane" of the cell. Simply put it is a layer of compounds that forms a sort of a filter on the very inside of the cell wall.

These compounds are called "phospholipids" indicating the phosphate molecule, which binds with calcium.

Calcium has 2 charges (arms) and it binds the phospholipids together, allowing for a "filter" with no "holes". In low calcium conditions, these sites are not adequately filled, allowing the membrane to come a part and leak. Complete breakdown of the cell wall results in IBS.

The membrane-protecting effect of calcium is most prominent under stress conditions such as low temperature [14] and anaerobiosis [15] as illustrated in the table on the next page.

Influence of Calcium on Carbohydrate Loss from Cotton Roots'

Treatment			
Aeration	Temperature (°C)	Solution	Carbohydrate loss (,ug per seedling (4 h)$^{-1}$)
O_2	31	Distilled water	18
O_2	5	Distilled water	57
O_2	5	10^{-5} M Ca^{2+}	7
N_2	31	Distilled water	89
N_2	31	10^{-5} M Ca^{2+}	7

Although this data is from an experiment down on cotton, do not discount the negative effect of excess rain (distilled water) and resulting low soil oxygen levels and calcium levels. Again, this would be especially aggravated when followed by a hot spell and rapid growth.

Soil Calcium Availability & pH

The concentration of other cations in the external solution is another important factor to consider. Because of its replacement by other cations from its binding sites at the exterior surface of the plasma membrane, the calcium requirement increases with increasing external concentrations of heavy metals, aluminum, sodium, or protons (low pH). At low compared to high pH the Ca^{2+} concentration in the external solution has to be several times higher in order to counteract the adverse effect of high H^+ concentrations (low pH) on root elongation.

In order to protect roots against the adverse effects of high concentrations of various other cations in the soil solutions the Ca^{2+} concentrations required for optimal growth has to be much higher in soil solutions than in balanced flowing nutrient solutions [17]. The way to measure this is to take periodical saturated paste tests during tuber iniation.

Calcium Flow & Auxin

Prior to discussing solutions and mechanisms of improving calcium uptake and availability, there is one more important topic to cover. Bio-Gro, Inc. is a leader on complete systems approaches to plant nutrition, so we evaluate compounds that effect nutrient uptake. In certain products that we manufacture (NUE Cal-8) you will find specific compounds designed to trigger the uptake of nutrients, especially calcium, into the plant. We also make products that specifically stimulate photosynthesis, thereby providing more “energy” for plant growth.

There is another, very interesting concept, which must be discussed and further evaluated and that is the effect of certain agricultural chemicals (fungicides that may act as auxin transport inhibitors) on plant growth, physiology and nutrient movement. It is not the scope of this document to cover this, but due to the fact that we are covering calcium mobility in the plant, one must discuss the relationship between calcium and auxin.

It is best to here directly quote from “Mineral Nutrition and Higher Plants” by Dr. Horst Marschner, Institute of Plant Nutrition, University of Hohenheim in Germany. Dr. Marschner was a world leader in plant nutrition and although he has passed away, this book is still the foremost and most complete source of information. I quote;

"In the fine regulation of the import rate of calcium into growth sinks, a nonvascular component, presumably cell-to-cell transport linked with a countertransport of auxin (IAA), plays an important role (De Guzman and De la Puente, 1984). The basipetal (downward) polar transport of IAA in young tissue takes place most likely by H+-IAA symport at one end of the cell and a Ca^{2+}-regulated IAA efflux at the other (Allan and Rubery, 1991). Accordingly, Ca^{2+} is required for the polar basipetal IAA transport. Simultaneously, the polar IAA transport is linked with an acropetal (upward) polar transport of calcium. Table 3.14 shows that in hypocotyl segments of sunflower calcium transport is higher towards the apical (younger) relative to the basal end of the segments, and distinctly enhanced by IAA application. This enhancing effect can be diminished by TIBA, an inhibitor of polar IAA transport (De Guzman and De la Fuente, 1986)

This causal relationship between IAA and calcium transport in a tissue can also be demonstrated in young leaves of lettuce (Banuelos et al., 1988), in different shoot organs of mango trees (Cutting and Bower, 1989) and in young tomato fruits (Table 3.15). Pretreatment with TIBA inhibited polar basipetal IAA transport from the young fruit and simultaneously depressed the polar acropetal calcium transport into the fruit. In contrast, the acropetal transport rates of 86Rb(K) and water were not affected by the TIBA treatment."

Table 3.15
Effect of TIBA Pretreatment (24 h) on Basipetal IAA Transport and Acropetal Transport of ^{45}Ca; $^{86}Rb(K)$ and $^{3}H_2O$ in 10-Day Old Tomato Fruits"

		Acropetal transport (B. per fruit)		
Treatment	IAA (pmol per fruit)	^{45}Ca	^{86}Rb	$^{3}H_2O$
Control	18	33	17	39
TIBA	12	18	15	38

"Based on Banuelos *et al.* (1987).

All above quoted references can be found in his book, if you have read this far and are still interested, you should really acquire a copy, as a matter of fact, Bio-Gro, Inc. will purchase a copy for anyone of our loyal or distributors.

How Does Calcium Move in Plants/Tubers?

Because of its low concentrations in the phloem sap the import of calcium into growth sinks such as shoot apices, young leaves or fruits takes place nearly exclusively in the xylem, whereas the import in the phloem is negligible. Basically, calcium moves up the plant, not down.

Developing potato tubers (10) are exceptions as they can cover part of their calcium demand by direct uptake from the soil solution. Functional tiny root hairs on the tuber and also at the stolen/tuber junction, allow for the direct uptake of calcium into the tuber.

Calcium import rate into growth sinks is also dependent on the formation of new cation exchange sites in the apoplasm (cell walls) acting as sinks for calcium and thereby removing it from the exchange sites at the end of the xylem vessels [11]. This may contribute to the well-documented sharp decrease in the calcium import rate per unit of transpired water after termination of the extension growth of leaves [11] and fruits [12].

Cell wall formation and "CEC" of cell walls is also related to the availability of boron, which plays in important role in the formation of cell walls and is also known to play a role in the suppression of IBS symptoms.

How does the tuber get more calcium?

In studies [8] the addition of calcium to the main root system does not increase the calcium content of the tuber tissue. However, applications of soluble calcium to the tuber and stolon area, result in a 3-fold increase in calcium concentration of the tuber peel and even medullary tissue.

The most critical form of calcium is soluble calcium found in the soil and it is important to maintain a high level of soluble calcium during initiation and tuber bulking.

This late season tuber calcium is likely more important to implement in the seed growing program, as Dr. Palta also demonstrates that the calcium content of the daughter tubers is directly related to the calcium content of the mother tuber (seed).

This is not to say that in season applications of calcium are not recommended, increasing early soil calcium is an important tool in minimizing the effect of weather patterns on tuber growth and potential development of IBS. However, timing and placement would be most critical.

Relationship to Balanced Fertilizer Program

In a particular study to determine the effect of various applications of calcium, magnesium and potassium were evaluated. In the applications of the individual nutrients alone, it was interesting to note that magnesium by itself and also potassium did not have a significant effect on IBS, rather magnesium sulfate increased IBS. This is likely due to the suppression of calcium uptake.

Treatment	% IBS	Treatment	% IBS
Broadcast Calcium		Side Dress Magnesium	
0 lbs/acre gypsum	28.0%	0 lbs/acre $MgSO_4$	18.9%
780 lbs/acre gypsum	13.2%	235 lbs/acre $MgSO_4$	22.4%
Side Dress Calcium		Side Dress Potassium	
0 lbs/acre gypsum	33.8%	0 lbs/acre K_2SO_4	24.4%
390 lbs/acre gypsum	7.5%	380 lbs/acre K_2SO_4	16.9%

The key word in this subject is "Balanced", notice the effect of a complete fertilizer program in the same study.

Incidence of Internal Brown Spot (%)

Broadcasted Gypsum	Side Dressed With: 0 lbs/ac K_2SO_4, 0 $MgSO_4$	0 lbs/ac K_2SO_4, 235 $MgSO_4$	380 lbs/ac K_2SO_4, 0 $MgSO_4$	380 lbs/ac K_2SO_4, 235 $MgSO_4$
	Side Dressed 0 lbs/acre Gypsum			
0 lbs/ac	37.5%	70.0%	35.0%	40.0%
780 lbs/ac	30.0%	17.5%	12.5%	27.5%
	Side Dressed 390 lbs/acre Gypsum			
0 lbs/ac	15.0%	10.0%	10.0%	6.6%
780 lbs/ac	7.5%	7.5%	3.3%	0.0%

Conclusion – Final Check List

By the supporting evidence listed above, we recommend that growers implement the following measures to lessen the potential effect of weather and low calcium on tuber quality, especially the formation of IBS.

Seed – Track seed piece calcium by measuring both periderm and medullar calcium levels. This is directly related to the calcium level of the crop you grow. Call your Bio-Gro fertility expert for more information on how to implement these tests.

Soil Testing – If VERIS soil mapping and lime/dolomite is not an option, we recommend adjusting the planter band MAP – Dolomite ratio to pH and % of calcium, magnesium and potassium on CEC. Call your Bio-Gro fertility expert for more information on how to implement these tests.

Saturated Paste – It is highly recommended to take 2-3 fields with different soil types and implement a weekly soil testing program (complete test) and included a saturated paste extract to measure the amount of soluble calcium. These tests should start when the plant is 4”-6” high and continue for 4-5 weeks. Call your Bio-Gro fertility expert for more information on how to implement these tests.

Hilling – It is highly recommended to apply a large amount of soluble calcium and magnesium during a hilling operation, especially during springs of high rainfall. We highly recommend testing applications of CHB Premium 6 at 2-5 gallons per acre with your calcium solution. Field demonstrations indicate that this may affect calcium uptake.

Foliar – Although foliar applications of calcium have no direct effect on tuber calcium (does not translocate down), applying foliar applications during fungicide sprays may help supply calcium for rapidly growing plant tissue.

Those who have done a lot of field research on potatoes in regards to IBS, have found that although there is a correlation between calcium and IBS, this is not always the case. Therefore, there are other factors involved.

References

1 – Collier, et al, 1978, J Ag Sci, v91, pg 240-243
2 – Silva, et al., 1991, Am Potato Journal, v68, pg 751-765
3 – Tzeng et al., 1986, Am Potato Journal, v63, pg 87-97
4 – Clough, 1994, J Am So Hort Sci, v119, pg 175-179
5 – Win et al., 1991, Plant Physiology, v96, pg 116-120
6 – Sterrett et al., 1991, Am Potato Journal v68, pg 467-477
7 – Bamberg et al., 1993, Am Potato Journal v70, pg 219-226
8 – Palta, Jiwan, U of Wisconsin – Numerous Papers
9 – Van Schreven, D.A., 1934, Tijdschr Plantenz, v40, pg 226-255
10- Krauss and Marschner, 1975, Z. Pflanzenernahr. Bodenk, v138, pg 317-326
11- Marschner and Ossenberg-Neuhaus, 1977, Z. Pflanzenphysiol. V85 pg 29-44
12- Mix and Marschner, 1976a, Z. Pflanzenernahr. Bodenk, v139, pg 537-549
13- Mix and Marschner 1976b, Z. Pflanzenernahr. Bodenk, v139, pg 551-563
14- Zsoldos and Karvaly, 1978, Physiol. Plant. V43, pg 326-330
15- Christiansen *et al.* (1970), Plant Physiol. V46, pg 53-56
16- Win *et al.,* 1991, Physiol. Plant. V96, pg 116-120
17- Asher and Edwards, 1983, Ency. Of Plant Physiol. V 15A, pg 94-119