PROSPECTIVE POTATOES

New technology identifies CIS traits in varieties

By Sanjay K. Gupta

Accumulation of high levels of reducing sugars during cold storage, known as cold-induced sweetening (CIS), is one of the more significant concerns for potato processing. This physiological change in tuber sugar concentration detrimentally impacts processing quality with unacceptably dark products and the production of acrylamide, a possible human carcinogen, following frying.

Processing potatoes are commonly stored at 46˚ F to 54˚ F to mitigate the accumulation of reducing sugars. However, storage at colder temperatures (38-40˚ F) is more conducive for maintaining tuber dormancy, reducing tuber shrinkage and limiting storage diseases. A wide range of genetic and biochemical factors have been identified that contribute to CIS.

My research of a large number of genetically diverse potato clones revealed that for best CIS resistance and long-term cold storage, a potato clone should have high expression of A-II isozymes of UGPase, which is responsible for sucrose formation in the cell, and low levels of acid invertase enzyme activity, as well as low levels of inhibitor protein. It is important to note that high levels of acid invertase enzyme activity mask the effect of A-II isozymes of UGPase.

Based on the CIS resistance, a quantifiable scale of 1 to 3 units has been developed, and potato clones were categorized as Class A (best CIS resistance), Class B (intermediate CIS resistance) and Class C (low or no CIS resistance). For the best CIS resistance and long-term cold storage, a potato

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variety should have high levels of A-II protein and a low level of acid invertase enzyme activity (preferably below 1 unit). My research demonstrates that acid invertase activity increases during cold storage, and the level of increase depends on the genotype and storage temperature

These biochemical markers I have developed are very different

from DNA markers. These markers are basically active proteins that are associated with reducing sugar accumulation. These marker classes have been studied for several years, and found to be stable over many years. Thus, if a potato variety is categorized as class A, it will maintain processing quality in cold storage. These markers can be used for potato breeding programs, national trials for new variety development and storage management for long-term cold storage.

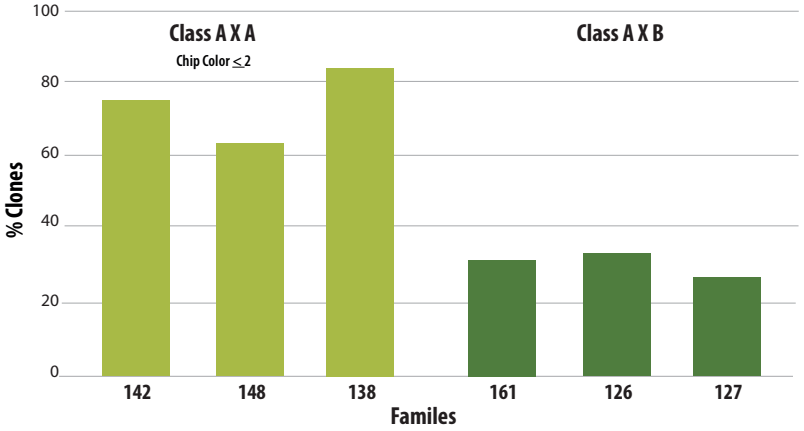
Use of biochemical markers

In a breeding program, more than 99 percent of breeding populations are discarded within the first two years of the selection process. Increasing selection efficiency at early generations is pivotal for potato breeding. To save resources and improve efficiency, it would be advantageous to select the parents and progenies by using biochemical and genomic information through marker-trait associations.

The biochemical markers for CIS resistance have been used to characterize a diverse set of breeding clones from various U.S. programs.

I have established six families with both or only one parent from class A. Results showed wide variation in acid invertase activity in the population. Similar patterns were observed in terms of reducing sugar accumulation, chip color and other parameters.

Parents and progenies were analyzed for chip color and sugar levels at harvest and after three months storage at 42˚ F. In the segregating populations, the percentage of clones with desirable reducing sugar level varied based on the class of parents. Progenies in the family with both parents from class A demonstrated more than 90 percent desirable clones, whereas progenies with one parent from class A and another from class B demonstrated 50 percent reduction in desirable clones. Chip color and reducing sugar levels were significantly lower in families with both parents from class A than in families with only one parent from class A. All three families demonstrated a significantly higher number of clones, with acceptable chip color of 2 or less.



The preliminary data clearly suggest that by identifying appropriate parents based on the biochemical markers, progeny can be obtained with a much higher

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frequency of desirable sugar levels and chip color. With the help of these biochemical markers, breeders can be more precise in their choice of parents, resulting in progenies with a much higher frequency of clones with higher CIS resistance and acceptable processing quality. Breeders can select new, advanced varieties as parents, and in addition to the wild germplasm for the source of CIS resistance. The advantage of using the new varieties as parents is that the variety has already been selected for other desirable agronomic traits.

These biochemical markers can also be used to successfully screen early generation selection for CIS resistance. Early generation selection for CIS resistance will drastically reduce the time and efforts and speed up new potato variety development.

AcInv Activity Scale (units1)	Cold-Induced Sweetening (CIS) Resistance
0 – 1	Class A - Best resistance. For long term cold storage (42°F). Acceptable fry and chip color.
1-3	Class B - Intermediate resistance. For long term cold storage (45°F). Acceptable fry and chip color.
>3	Class C - Very low or no resistance to CIS resistance. Unacceptable fry and chip color.

Use for national projects

Various national programs are focused on developing promising potato clones for french fry, chipping potato and low acrylamide. In these programs, promising potato clones are screened and evaluated for their reducing sugar accumulation potential or CIS resistance. The focus of all these programs is to identify potato clones with low reducing sugar accumulation potential during long term cold storage. The biochemical markers can play a pivotal role

in such programs to narrow down the number of potato clones that should be evaluated for CIS resistance. The markers can significantly reduce the number of clones for further characterization. This will translate into enormous savings in terms of time and money. The information generated using these techniques will directly contribute to advancement of promising potato clones having resistance to cold-induced sweetening.

Use to growers and storage managers

This is the area that still needs to be exploited for its full potential. Environmental conditions, abiotic stress during growth and development and chemical maturity at harvest play an important role in the storability of potato tubers. Growers can expect differences in crops grown in different fields or lots. Generally, storage managers monitor fry color and sugars at harvest and regular intervals during storage. This test is destructive, time consuming and expensive, and provides the color quality at that time only. The information cannot be used to predict the quality change over time. Abiotic stresses like heat or water stress during growth and development affect the sugar metabolism in growing tubers. These stresses are known to increase sugar levels in potatoes. Increased sugar levels due to environmental stress may not be a good indicator of potato storability. The new biochemical markers can be used at the time of harvest to make storage management decisions like time and temperature for reconditioning, and storage for the new and existing potato varieties. The markers will potentially help make decisions for storage of different potato lots for long term, medium or short term. Also, the markers may reduce or eliminate regular testing of lots for fry or sugar color.

These markers are available for use through the University of Minnesota's office of technology commercialization.

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CRACKED TUBERS AND PVY

Growers who produce specialty potatoes for the fresh market must meet high tuber quality standards. Numerous potato diseases and defects can negatively affect tuber appearance and interfere with sales expectations. One highly undesirable tuber defect is cracking, which happens when the potato splits while growing. Rapid tuber water uptake after re-wetting a dry field, sudden temperature changes and herbicide injury are known causes, and cracking of potato tubers also has been associated with viruses like potato virus Y (PVY) (Gray et al., 2010; www.potatovirus.com). One study done in Scotland (Carnegie and McCreath, 2010) describes shallow, suberized cracks on potatoes infected with mosaic viruses, ie., PVA, PVV, and PVY^{N}.

In the last few years, suberized, canoe-shaped cracks have been evident on certain potato cultivars grown at various locations in the United States. In some cases, there has been a strong association between tuber cracking and infection by PVY. Usually, the cracking is external without internal discoloration, as is typical for potato tuber necrotic ring spot disease (PTNRD) caused by PVY^{NTN}.

Because an association does not necessarily denote causation, our program is investigating whether tuber cracking is a direct result of PVY infection. In one study (Benedict et al., 2015), field-grown plants of Chieftain were tracked over a growing season. At season end, healthy-appearing plants had significantly fewer cracked, discolored or malformed tubers compared to plants either mildly or highly symptomatic for PVY. During the subsequent winter greenhouse grow-out, tubers from plants that tested negative for PVY were not cracked, while tubers from plants that tested positive were 22 percent to 32 percent cracked.

In a separate screen house experiment, cracked progeny tubers of the Chieftain variety, saved from plants that tested positive for PVY$^{N\text{-}Wi}$, were planted, as were pre-nuclear seed tubers that were virus-free. Strict sanitation protocols were maintained, so no unintended mechanical or aphid transmissions would occur. All plants from the cracked seed tubers became symptomatic and tested positive for PVY, while all plants from the pre-nuclear seed remained healthy and tested negative. Strikingly, cracking only was observed for PVY-positive plants, and occurred on nearly 40 percent of the total number of progeny tubers.

Even more convincing in a mechanical inoculation trial, cracked seed tubers from PVY$^{N\text{-}Wi}$ positive plants of Chieftain were cut (through newly sprouted eyes) using a sterile knife in order to accumulate a small amount of sap on the knife. A recipient, virus-free, pre-nuclear seed tuber was immediately cut in half using the same knife, and the halves planted in a replicated greenhouse experiment. The controls in the experiment consisted of pre-nuclear seed serving as both source and recipient tubers. Twenty-five percent of resulting plants that originated from the pre-nuclear seed cut with the PVY-contaminated knife showed obvious symptoms of PVY, tested positive for PVY, and averaged 4 percent cracked tubers compared to zero percent cracked tubers in the controls.

In an experimental field trial in 2015, planted to both cracked and pre-nuclear seed tubers of Chieftain, neither high or low irrigation amounts nor slow or rapid vine kill altered the extent of tuber cracking. Instead, the main factor contributing to the formation of cracked progeny tubers was the planting of cracked seed tubers that led to infected plants. In a companion field trial also planted to cracked and pre-nuclear seed tubers of Chieftain, sampling at different