Genetic Engineering and Risk in Varietal Selection of Potatoes

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The objective of this case study is to examine the farm management decision of whether to adopt a new, genetically engineered potato variety. We describe the potato supply chain from seed production to final consumer products and explore how price and production risk interact to influence decision making at each link in that chain. We provide extensive supplemental material as well, including a teaching note with assignment and/or discussion questions, an introduction to and application of stakeholder theory, and a tool that assists students in calculating expected and simulated actual returns from their choice of potato variety.

Key words: Agricultural pests and diseases, farm management decisions, genetic engineering, potatoes, risk analysis, seed production.

JEL codes: Q12, Q13, Q16.

Genetic engineering, or the direct manipulation of an organism's genome, has been a source of debate ever since the 1970s when scientists developed the first genetically modified organisms. More recently, Danny Hakim's (2016) *New York Times* article "Doubts about the Promised Bounty of Genetically Modified Crops," was followed by heated debate (e.g., Senapathy 2016; Brester and Atwood 2017). In particular, the pace of development and introduction of new processes (e.g., gene editing) for genetically engineered (GE) potato seed has fueled continued discussions (Chang 2017). In March of 2017, commercial use of three new GE potato varieties was approved by the USDA. The new varieties have potential human health benefits over other potato varieties, resist browning and bruising, and also resist Late Blight, the disease that caused the Irish Potato Famine. If these new potato varieties are adopted, they would represent one of the first GE crops primarily consumed in a low-processed form in the United States. Currently, most GE crops such as alfalfa, corn, soybeans, and sugar beets are either highly processed into final consumer products or fed to livestock. This case describes the potato industry with a particular reference to seed potatoes and discusses issues surrounding GE potato varieties. The case is built around a leading seed potato grower in Montana.

Kimm Brothers Farming

The importance of the southwestern Montana potato seed industry within the scope of U.S. potato production is not at the forefront of Martin Kimm's mind as he grabs his favorite work cap and Carhartt® coat and

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walks out the door of his home near Manhattan, Montana. Martin has spent this early-January morning organizing his QuickBooks™ record-keeping system for the coming year. After several hours of organizing and updating expense categories, he needs a break. Although the temperature outside hovers near 0°F as he walks from his house to his machine shop, the clear blue sky, sparkling white snow, and views of the Bridger Mountains make him glad that he decided to investigate the progress occurring in his heated shop. He and one of his employees are fabricating a new multi-station seed potato-slicing table. The new table will improve the efficiency of his seed potato production process, improve worker safety, and reduce the potential of disease contamination as he propagates new generations of potato seed.

As Martin crunches across the snow, he smiles at the contrast between the temperature at his farmstead and that which he experienced just a week ago.

Martin has just returned from helping the Montana Certified Seed Potato Laboratory plant potato seed produced in Montana into test plots in Hawaii. The laboratory is housed at Montana State University as part of the Agricultural Experiment Station and Montana State University Extension, and is largely funded with grower fees. Similar public-private relationships exist as part of the land grant university research and extension system, including other certified seed certification, bull testing, crop breeding programs, and research facilities. The Montana seed potato program has done much to increase potato yields and quality over its 50-year existence (Kimm 2015). Samples of seed potatoes are planted in Hawaii near the beginning of the calendar year to take advantage of the tropical climate. These test plots are harvested in early spring and tested for the presence of various potato diseases. The test results are used by seed potato growers selling specific potato varieties during the coming year. The testing in Hawaii gives a preview of crop health and disease status before U.S. spring planting. It helps with the culling of seed potato batches that display disease problems prior to their sale to seed growers who might plant the seed for recertification, and commercial producers. Although tests are conducted for all seed potato growers in Montana, individual producers are always welcome to visit the test plots and help with planting the samples. Martin decided that after 30 years of producing seed potatoes, he wanted to visit the Hawaiian operation and help with the test plots.

While the history of seed potato production in his region is certainly important, Martin has a host of other issues that demand his consideration over the next several months. He reminds himself to focus his thoughts on personal safety as he uses his plasma cutter, grinders, and MIG welder to fabricate his new potato-cutting table. He will return to strategic considerations of his farm operation later this evening.

Background Information on the Potato Industry

Historically, potatoes were predominantly purchased by consumers in the form of whole baking potatoes and used for home consumption. Over the past several decades, however, the majority of potatoes have been consumed in a variety of processed forms, including hash browns, chips, tater tots, and French fries. Potatoes are grown in 36 states, with Idaho and Washington representing the largest producers (USDA NASS 2016). Seed potato growers in many states grow seed used to produce commercial potatoes. Approximately 10% to 15% of all potato seed grown in the United States is produced in Montana (Potato Association of America 2016). Climate, a topography that fosters disease isolation, and coordination among producers combine to create competitive advantages for seed production in this region.

The Commercial Potato Industry

Potatoes are a starchy vegetable rich in carbohydrates and potassium. Potatoes sold in produce sections of grocery stores are referred to as table stock or "fresh pack" potatoes. These potatoes are packaged and sold based on variety, size, grade, and other features. Fresh potatoes can be baked, mashed, fried, roasted, and browned. Many potatoes, however, are not of sufficient quality to be sold in the table market. In addition, many consumers prefer further-processed potato products that require less preparation. As a result, over one-half of U.S. potato production is processed into frozen, chipped, or dehydrated products (National Potato Council 2016; see figure 1).

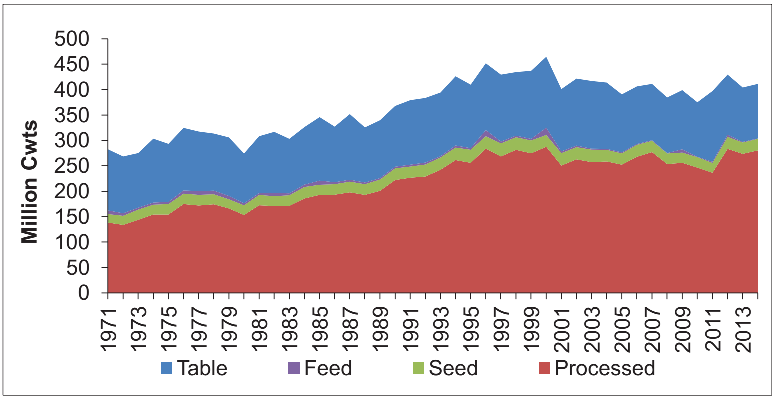

Figure 1. Table stock, feed, seed, and processed potato usage, 1971–2014

Source: National Potato Council (2016).

Potato products are also used in non-food applications. Dehydrated potato starch is used in paper manufacturing, textiles, pastes and glues, and detergents. Potato peels, the largest byproduct of potato processing, can be used as cattle feed or fertilizer, and many additional uses for potato peels and potato peel extract have been proposed.

The Potato Market

Per capita consumption of potatoes and potato products reached its peak in 1996 at 145 pounds (figure 2). Since that time, however, consumption has trended downward; in 2016, per capita consumption was 111 pounds. During that time, the composition of potato product consumption has shifted. Fresh pack consumption has declined from 50 to 33 pounds per capita. While the consumption of processed potato products has declined as well, its proportion relative to total potato consumption has remained relatively flat (USDA ERS 2016a). The decreasing trend in table stock potato consumption has been attributed to increased away-from-home food consumption, increased demand for processed products, and dietary trends (Thorne 2012).

Although domestic potato consumption has declined, total potato production has increased over time, rising from 282 million hundredweights in 1971 to 411 million hundredweights in 2014 (figure 1). Since 2005, the United States has experienced a trade surplus in potatoes and potato products. The top U.S. potato product export is frozen French fries, which account for more than one-half of total potato export volume, driven by fast food restaurants that have globally recognized brands and franchises. About 9.5 million hundredweights of fresh potatoes are exported from the United States primarily to Canada and Mexico. Access to other fresh potato export markets is generally restricted because of phytosanitary import regulations instituted by foreign countries (USDA ERS 2016a).

Production Processes and Storage

Relative to many other crops, potato production is time-consuming and expensive. Significant capital investments in specialized planting and harvesting machinery, storage cellars, and irrigation equipment are required. Relatively long crop rotations are recommended to produce potatoes because of disease vectors and soil quality degradation. Because of these long rotation schedules, potato producers must have large acreages upon which they can rotate other crops. In addition, potatoes grow best in sandy soils that foster the formation of consistently-sized tubers and facilitate harvest operations. Potatoes have substantial irrigation requirements because they require small but frequent amounts of water. Storage is another large cost. Depending on a grower's contract with buyers, potatoes may need to be stored for several months. Because potatoes are living plants while in storage, they are susceptible to sprouting. Potato piles produce heat that can cause tubers to rot, creating the need for climate-controlled facilities and the application of sprout inhibitors. The per-acre production cost of irrigated commercial potatoes

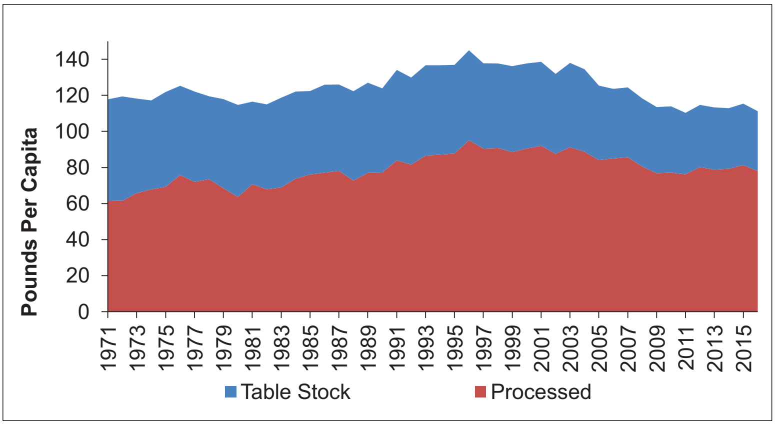

Figure 2. U.S. per capita consumption of potatoes, 1971–2016

Source: USDA ERS (2016a).

ranges between $1,500 and $3,000 (Potato Association of America 2010).

Potato Diseases

Potatoes are susceptible to many pathogens and fungi and one of the biggest challenges facing potato farmers is disease prevention. Throughout history, potato farmers have struggled with disease control—the most famous example being the Irish Potato Famine between 1845 and 1852, which was caused by the fungal disease *Phytophthora infestans*, or Late Blight. The Irish were highly dependent on potatoes as their primary food source, and mass starvation followed after Late Blight destroyed potato crops for several years. Potato diseases cause a variety of symptoms that are troublesome for farmers, including reduced yield, complete destruction of the crop (in the case of Late Blight), reduced size, and other quality effects. Leafroll virus can cause potatoes to discolor as they are cooked or fried. Whitworth, Hamm, and Mcintosh (2010) show that Potato Virus Y (PVY) and Potato Virus A (PVA) decrease yields, while some strains of PVY cause tuber necrosis (dead spots). Potatoes produced by a diseased plant will generate disease in future generations if planted as seed. Because of the prevalence of potato diseases, producers of commercial potatoes use seed that has been certified as having disease below a certain threshold by seed certification programs.

Grower/Processor Contract Relationships

Producers of commercial potatoes target two major market outlets—the processing market and the fresh pack market. As farm size has expanded over the past thirty years, growers have reduced sales on the open market and increased their use of contracts as a means of managing risk (Bolotova et al. 2010). Open market sales of large volumes of potatoes create substantial marketing and transactions costs. Contracts can reduce those costs and assure market access and a known base price. Given the high cost of inputs required to produce potatoes, price and production risk management is especially important. Price risk management is especially pertinent since a domestic futures market for potatoes does not exist (Bolotova et al. 2008).

Production contracts are typically signed in the spring, when exact harvest crop yields are not yet known. As a result, commercial growers contract an amount that they are almost certain to achieve—typically 80% of expected yield. If production is greater than the contracted amount, the overage is sold to the highest bidder on the open market. Annual contracts generally commit producers to supply a specific tonnage of potatoes to a processor at a specified base price. In addition to the base price, incentives and penalties are stipulated depending upon potato quality. Common criteria include the percentage of bruised, rotten, and green potatoes, average potato size, and specific gravity. Final potato sale prices are determined by inspections at the time of delivery. Because of the importance of these incentives in grower profitability, potato growers often enlist a representative to observe the sampling and quality determination process.

Major potato processors such as The J.R. Simplot Company, McCain Foods, and Frito-Lay (owned by PepsiCo) supply French fries, potato chips, dehydrated potatoes, and frozen potato products to retail consumers and restaurants. Another market for commercial growers is the fresh pack market. In fresh packing sheds, potatoes are washed, graded by quality, sorted by size, and packaged. Packing sheds may be owned by a single producer or cooperatively by several growers. Fresh pack providers often negotiate contracts with larger restaurants and grocers. Smaller potato buyers will sometimes enlist the services of brokers.

The Seed Potato Industry

Unlike most annual crops, commercial potato growers plant portions of seed potato tubers rather than individual seeds. The "eyes" of seed potatoes sprout in the presence of light or warmth. When tubers are planted, the sprouts become viable potato plants that grow throughout a season and produce more potatoes. Seed potatoes are not physically different from table potatoes except that they are generally harvested while relatively small. Smaller seed potatoes are easier to slice into portion sizes needed for planting; they also sprout faster and produce hardier plants.

If it were not for the persistence of diseases and the degradation of plant vigor across generations, a commercial potato producer could withhold tubers from one crop year and plant them the next. However, disease vectors are so prolific that commercial producers generally prefer to obtain certified seed potato tubers from regions that do not produce commercial potatoes. Seed potato farms must be carefully managed to mitigate disease incidence. Because of the need for extensive management, farms that specialize in seed potatoes are usually much smaller than commercial potato farms. Seed potato producers develop seed over several years using a variety of often labor-intensive processes to reduce disease, such as "roguing," or the removal of plants that show disease symptoms.

Certification

Fifteen states and four Canadian regional agencies operate certified potato seed programs (Potato Association of America 2016). Most of these programs are financially supported by fees paid by growers for certification services. In many cases, these programs were developed as a component of land grant university systems to support agriculture. Certification programs monitor, test, and report on the performance and disease status of specific lots grown by individual seed producers. Roughly 27% of the 19 million hundredweights of seed used in 1980 originated from the farm where it was grown (USDA NASS 2012). In 2015, only 15% of the 26 million hundredweights of seed used was obtained from on-farm sources (USDA NASS 2016).

Montana Seed Certification Program

The Montana Potato Improvement Association (MPIA) was formed in 1921 by the Montana Department of Horticulture in cooperation with Montana State University. The MPIA eventually formed the Montana State University Seed Potato Certification Program (McCarver 2006). In Montana, inspectors walk through each seed field three times during the growing season and calculate the percentage of diseased plants. The results of these inspections are published in directories that are made available to commercial growers. Along with field inspections, leaf tests are conducted in the lab for all early generation seed (see www.montanaspud.org for a list of requirements for the seed grower). If a seed producer meets certification requirements they are allowed to harvest, store, and sell their crop as certified seed (Potato Association of America 2010). If the seed fails to meet the requirements, it can sometimes be sold as table stock or for livestock feed. In both cases, the product is heavily price discounted and often must be disposed (Montana Potato Improvement Association 2015).

Another common procedure of certification programs is winter seed testing to detect late-season, undetected diseases that could become a problem the following year. During harvest, producers randomly select tubers that are sent to a sub-tropical or tropical region to be grown and tested. In Montana, winter test plots are grown in Hawaii.

The final steps of the certification process occur when seed potatoes are shipped to commercial growers for spring planting. As seed potatoes are loaded onto trucks, a state or federal inspector samples seed to verify grade and size requirements. After this final inspection, potatoes receive an official certification tag. This tag contains information about each truckload, including the state of origin, variety, class, and generation level. Trucks then deliver seed to commercial growers.

Seed Plots/Generations

Subsequent generations of seed potatoes accumulate pathogens that reduce vigor even if adequate crop rotations are being used. To minimize the risk of disease infections and maintain vigor, certification agencies limit the number of generations that seed can be certified. Because the number of seed generations that can be planted is limited, seed growers must replenish their seed stock. The source for replenishment stock is tissue-cultured plantlets that have been cut from meristems or other clean material in a laboratory. Most certification agencies maintain plant growth laboratories that produce pathogen-free plantlets (Potato Association of America 2010).

Plantlets that have been tested and confirmed to be pathogen-free are purchased by seed producers from certification agencies and then propagated in seed plots or greenhouses. In the case of seed plots, plantlets are first planted into trays in late May and placed in a controlled environment for 4 to 6 weeks. These “pre-nuclear” plantlets are then transplanted to seed plots, where they grow until fall. During this time, if a plant shows any sign of disease, it is removed. The tubers harvested from these plants are considered the “nuclear” generation.

The following year, first generation (G1) seed is produced from nuclear seed in field plots. The nuclear seed is planted in family units; all tubers obtained from each nuclear plant are separated from those produced by other plants. The separation allows for an entire family of nuclear plants to be removed if they show signs of disease. The G1 seed is harvested with small potato harvesters, stored separately from other generations, and then planted in larger fields the following year. The G2 seed produced during that year is harvested with standard potato harvesting equipment and is stored in cellars, and the process is repeated the next year, producing G3 seed. The process can then be repeated one last time; the Montana certification program ends with G4 seed.

An alternative approach to generating nuclear seed is to grow plantlets obtained from certification labs in a controlled greenhouse environment rather than in test plots. The tubers produced from this process are called “minitubers” and do not require separation by plant source when first used to produce nuclear seed. This “pre-nuclear” generation of minitubers is then planted in seed plots the following year to produce nuclear seed.

The business models of seed growers are diverse. Some seed growers start with nuclear generation seed and propagate seed stock over each generation. Others purchase seed and grow it for just one generation before selling it to commercial or other seed growers. A formal or informal agreement with the person who will buy the seed is crucial to managing the market risks of seed production.

The Innate Potato™ and Advances in Genetic Engineering

In March 2017, three new genetically-engineered (GE) potato varieties were approved for commercial production (Ridler 2017). These new varieties have potential human health benefits and they resist browning, bruising, and Late Blight. The J.R. Simplot Company, the developer of the new varieties under the name Innate™, has estimated that their new variety will require one-half of the typical fungicide applications of conventional varieties (Alvarez and Shelman 2014). The combination of less waste and fungicide use may result in substantial environmental benefits (Ridler 2017).

These are not the first GE potato varieties. Monsanto developed and introduced a variety resistant to the Colorado potato beetle in 1995 when genetic engineering of crops was in its infancy, but market resistance was fierce. Monsanto discontinued the variety six years later. However, GE crop use has grown substantially since that time. In 1997, 17% of U.S. soybean acreage was planted using a genetically engineered variety, but today, 93% of soybeans have been genetically engineered (Glenza 2014).

In addition, advances in technology have changed some of the discussion surrounding genetic engineering itself. In the past, genetic engineering has largely meant introducing genes across genomes. Newer technologies, however, allow gene editing and suppression within a genome. CRISPR is one such technique that can be used to edit, rather than add to, existing gene structures. The speed and accuracy with which DNA can be edited using CRISPR surpasses other previous technologies, but also opens the door to new concerns. According to an overview of the technology in the journal *Nature*, "CRISPR's ability to precisely edit existing DNA sequences makes for more-accurate modifications, but it also makes it more difficult for regulators and farmers to identify a modified organism once it has been released," (Ledford 2015). Regulation of varieties created by DNA editing is another new challenge and, in many cases, they are not governed by current regulations (Chang 2017). Colson and Huffman (2011) note that intragenic methods can move traits from primitive to commercial varieties and be fast-tracked into the breeding processes for new potato varieties. The authors suggest that there will be a low regulatory hurdle for potatoes.

The Innate™ varieties were developed over more than a decade. Simplot used RNA interference technology (RNAi), which controls the expression of certain genes (Simplot 2015). The use of this particular technology was no accident; Simplot specifically used it to distinguish the breeding process from other types of genetic engineering (Alvarez and Shelman 2014). Similar to advances made with CRISPR, Innate™ potatoes contain only potato genes. But GE dissent groups have voiced concerns about the use of the technology, many of which are focused on a desire for more research and testing. McDonalds and Frito-Lay, among others, have stated that they will not use Innate™ potatoes in their products (Charles 2015). Simplot's own research suggests that there might be greater consumer acceptance if the Innate™ potatoes were available for purchase, and that they would rank very close to other new potatoes developed by traditional breeding if the choice were offered (Alvarez and Shelman 2014).

Decisions at Kimm Brothers Farming

Since the late 1940s, farms surrounding Amsterdam, Churchill, and Manhattan, which are communities within Montana's Gallatin Valley, have produced potatoes. The short growing season of these high mountain valleys limits the ability of growers to compete with commercial potato producers yields, but the short growing seasons are perfect for producing smaller seed potato tubers and the valleys provide some natural disease and insect barriers.

Martin Kimm operates Kimm Brothers Farming as a third generation family farm (Martin recently purchased his brother's share, but still operates under the name Kimm Brothers Farming). Their father, Stanley, who recently passed away at the age of 89, produced his first commercial potato crop in 1958 and his first seed potato crop in 1967. Martin farms approximately 500 acres near Manhattan and about 1,800 acres near Toston, Montana, approximately 30 miles away. Together the two locations produce about 350 acres of Ranger and Burbank seed potatoes, about 1,000 acres of spring wheat, and the remaining land is used to produce corn silage, alfalfa hay, and feed barley. Kimm Brothers Farming sells G3 seed to commercial growers in Idaho, Maine, Minnesota, Oregon, Washington, and Wisconsin. Many of these potato buyers have been long-term customers. Martin also sells G2 seed to other seed potato producers in Idaho, Montana, Oregon, and Washington.

Martin's Manhattan operation includes seed plots, early generation tuber storage, and a packaging facility. The packaging facility is used to clean, size, and grade tubers that are too large for the seed market. Boxed potatoes are sold to a grocery distributor in Butte, Montana. Martin faces two major issues common to all seed growers: disease concerns and selecting varieties to propagate. Seed potato growers are dependent on commercial potato producers who buy their seed. Both commercial and seed potato growers need to be aware of current market trends and anticipate emerging consumption trends. Due to the lengthy process of producing seed, varietal selection is an important decision, but can be complicated because of uncertainty regarding disease, logistics, identity preservation, and storage issues, and unknown yield performance.

Martin is considering whether to grow a GE variety—perhaps one of the new Innate™ varieties, if a buyer requests it. Two of the three Innate™ varieties are versions of Russet Burbanks and Ranger Russets, which Kimm Brothers already grow (Ridler 2017). These new varieties could reduce costs of production because less fungicide is required, as well as reduce worry about Late Blight. These varieties may also have marketing benefits. Lacy and Huffman (2016) provide evidence of higher consumer willingness-to-pay for low-acrylamide potatoes. Acrylamide, which creates the browning effect in fried potato products, has been linked to cancer (Lacy and

Huffman 2016). The Innate™ potato varieties may also have other potential marketing benefits. If advertisers can effectively communicate that the new varieties produce less waste because they do not brown and reduce fungicide use, they might be marketed as a more environmentally friendly option. Commercial growers have also shown interest because of reduced fungicide costs, which amount to nearly 10% of operating costs (Patterson 2015; calculations by authors). However, if consumers will not purchase these potatoes because of concerns about GE, or must be convinced to purchase them through lower prices, these benefits may not exceed costs.

Risk

The USDA defines five different types of risk in agriculture: production, market, financial, institutional, and human or personal risk (USDA ERS 2016). The decision of whether to plant a new GE variety with consumer-relevant or producer-relevant attributes must account for both market and production risks. In the case of the currently available Simplot varieties, a grower must consider both reductions in disease risk, as well as increased market risk—price differences from market resistance to GE products.

To explore how commercial and seed potato producers viewed these different risks, we conducted an experiment at the Montana Seed Seminar in November of 2016. A group of 83 seed and commercial potato growers completed a risk tolerance assessment and were then asked to choose between a more expensive seed selection with a relatively low disease risk and a less expensive option with more disease risk. While on average, growers with lower risk tolerance scores were willing to pay more for the less-risky option, the results were not statistically significant. Growers selected the more expensive, less risky option approximately 75% of the time among all choices. Slightly more than half (53%) stated that their selection either would not change or 'would depend' if one of the choices was GE. As a part of the same experiment, growers reported the relative importance of a series of traits in determining which seed to grow. Disease risk played an important role and, in fact, was the number two determinant in seed selection. But the relationship between the seed buyer and seller was by far the most important characteristic. This finding underscores both the importance of trust in variety or technology adoption and market development.

Conclusion

After three hours of metal fabrication, Martin leaves his shop and walks back to his house. He notices that the temperature has declined further as the sky has remained clear and a full moon rises over the mountains to the east. Although the break from setting up his accounting system for the coming year was much needed, it is time to return to the task. Martin knows that varietal selection—and the associated market, disease, and other production risks—require careful weighing of tradeoffs. Whether or not he decides to plant one of the Innate™ varieties, other GE options are most likely on the horizon. Martin will develop these thoughts further as he moves towards the coming planting season.

Supplementary Material

Supplementary material are available at *American Journal of Agricultural Economics* online.

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