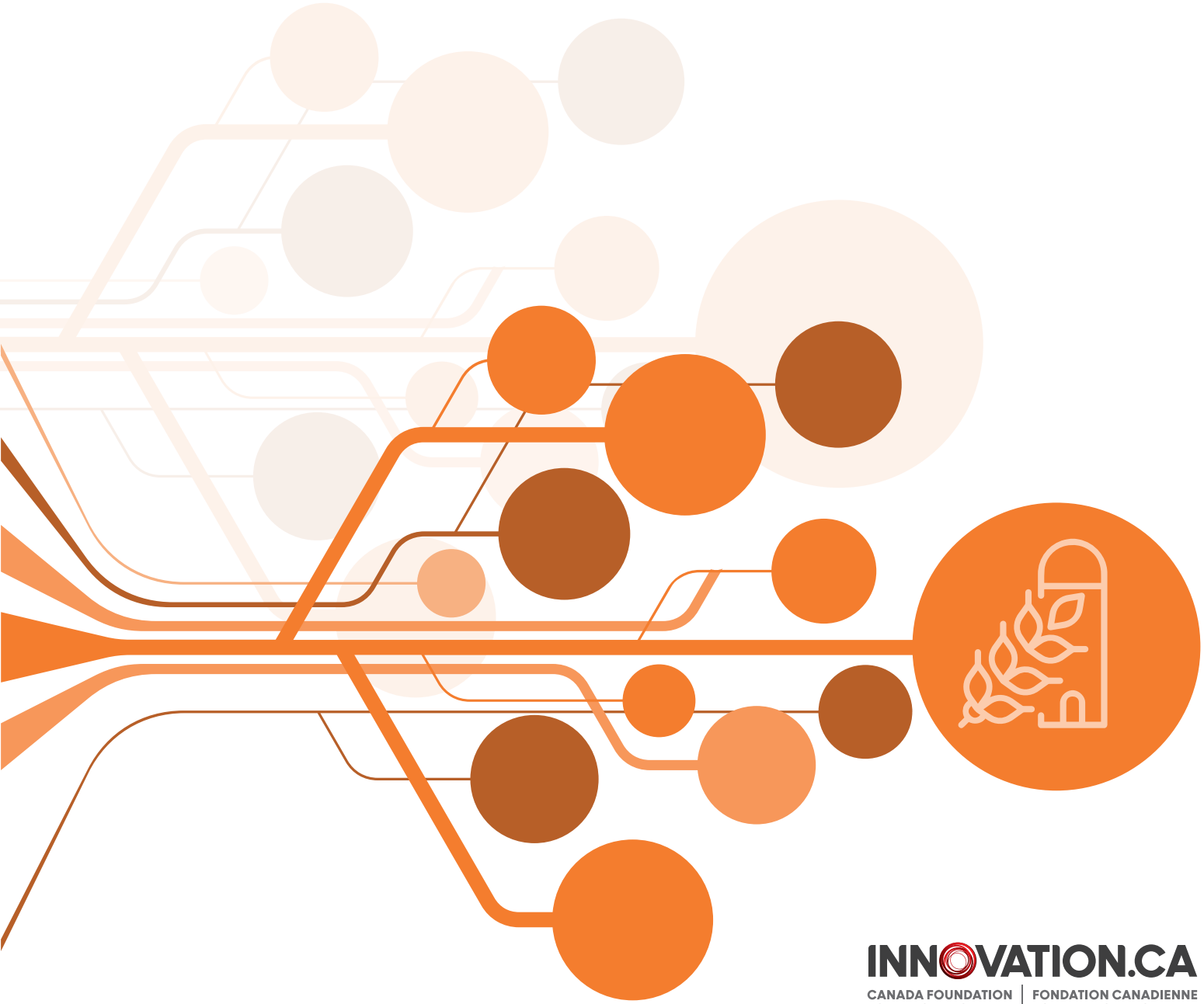
MAPPING INVESTMENTS TO IMPACTS: **AGRICULTURAL RESEARCH**

Grain storage

April 2018



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ACKNOWLEDGEMENTS

The Canada Foundation for Innovation would like to thank the institutional administrators as well as the many researchers who contributed their time and thoughts to this project.

The CFI would also like to thank Frédéric Bertrand and members of our Advisory Committee, composed of representatives from 20 organizations including universities, federal and provincial government departments and agricultural associations, for their time, expertise and advice in the development of this project.

METHODOLOGY

Using a data collection framework, administrative documentation and performance data on selected projects were reviewed, including project proposals, budgets, financial, progress and final reports as well as bibliometric analysis of publications authored by project leaders. Findings from interviews and the document review are integrated to assist in the interpretation of findings and to guide the logical flow from CFI funding to research evidence leading to possible outcomes with social, economic and environmental benefits. A subset of projects within each area of study were selected for detailed analysis through the above methods. This selection was made using multiple criteria to maximize the collection of evidence on impact pathways while confining the scope of the study.

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KEY FINDINGS: Pathways from grain storage research to impacts

Resource sharing between researchers enables collaborations across disciplines and with industry stakeholders.

- Multidisciplinary research centres created through Canada Foundation for Innovation (CFI) funding enable researchers working in grain storage to collaborate nationally and internationally.
- The infrastructure enables collaborations with organizations and companies with interests in grain, while involving end-users in the research process.

Trainees are involved in, and maintain collaborations with, the private sector and academia.

- Multinational collaborations provide trainees opportunities to work in companies and academia.
- Capacity development in agricultural research occurs when trainees become employed in the agriculture sector.
- Former trainees continue to collaborate with researchers at CFI-funded facilities through their employment.

Grain manufacturers, including farmers, benefit from evidence produced through research involving the infrastructure.

- Including end-users in the research process enables researchers to tailor experiments to the challenges faced by Canadian grain farmers and manufacturers.
- Research contributes to the establishment of best practices and guidelines in grain storage management systems used by manufacturers and farmers in Canada and abroad.
- Based on the work conducted through CFI-funded research centres, opportunities are created to reduce food loss due to ineffective grain storage processes thereby improving food security.

GRAIN STORAGE

CFI has made important investments across the spectrum of grain storage research, from the creation of multidisciplinary research facilities to spectroscopy equipment, enabling researchers to improve grain identification, handling and storage processes.

BACKGROUND

Canada produced nearly 70 million tonnes of grains in 2016[1], making it one of the world's major grain exporters. Crops are subjected to many processes to help reduce losses in the field and during harvest and storage. After a grain crop is harvested, it may need to be stored in warehouses, silos or bags at different stages of the distribution chain between producer and consumer. Grain needs to be stored for varied durations because of differences in locations of production, processing and consumption. Grain storage is also required since crops are produced seasonally but consumed year-round.

Grain stored in bulk can be considered a man-made ecosystem with interactions between biological, chemical and physical elements related to the storage environment. Factors such as insects, moisture, moulds, gas and temperature conditions can impact the quality and preservation of grain.

To prevent losses, storage facilities should ensure appropriate conditions by monitoring and managing the interactions occurring in this ecosystem.

Canada's grain quality standards are overseen by the Canadian Grain Commission, a federal government initiative that is part of the Agriculture and Agri-Food Canada (AAFC) portfolio. The agency is responsible for enforcing laws outlined under the Canada Grain Act and regulations listed under the Canada Grain Regulations to establish and maintain standards of quality for Canadian grain, regulate grain handling in Canada, and ensure the dependability of grain as a commodity for domestic and export markets.

This report examines CFI-funded research projects relating to grain storage techniques, processes and structures as well as post-harvest techniques used to improve the quality of grain stored and the economic, environmental and social benefits resulting from those projects.

CFI INVESTMENTS

The CFI makes financial contributions to Canada's universities, colleges, research hospitals and non-profit research organizations to increase their capability to carry out high-quality research. Of the $245.8 million that the CFI has invested in infrastructure for agricultural research overall, two percent has been devoted to grain storage research over a 16-year period.

The CFI invested $7.3 million in infrastructure related to grain storage research through four projects at two institutions from 1999 to 2015, as shown in **Figure 1**.

The largest CFI funding to an individual project in this area of research was $5 million awarded to the University of Saskatchewan in 2006 to support the construction of the Canadian Feed Research Centre (CFRC), led by Bernard Laarveld, PhD.

The facility provides infrastructure necessary to conduct research in several areas including feed processing, crop breeding, animal nutrition and feed development.

The remaining $2.3 million of CFI funds was awarded to three projects at the University of Manitoba. CFI supported the construction of the Canadian Wheat Board Centre for Grain Storage Research (CWBCGSR) at the University of Manitoba in 1999.

1 Statistics Canada. (2016, August 23). *Production of principal field crops*, July 2016, CANSIM table 001-0010. Retrieved from The Daily: http://www.statcan.gc.ca/daily-quotidien/160823/dq160823a-eng.htm

The project was led by Digvir Jayas, PhD, and involves interdisciplinary research looking at various aspects of stored grain management including engineering and biology. The other two projects led by Jitendra Paliwal, PhD, that obtained CFI funding in 2003 and 2015, enabled the acquisition of specialized cameras and other spectroscopy equipment to automate detection of grain spoilage.

Infrastructure supported by the CFI includes:

Research equipement:

- Near infrared hyperspectral imaging cameras
- BoMill TriQ seed sorter
- Industrial scale lines
- Grain drying technology (thin-layer and near-ambient)
- Insect growth chambers
- Scales
- Computers

Construction:

- Canadian Feed Research Centre
- Canadian Wheat Board Centre for Grain Storage Research
- Laboratory renovations

MATCHING FUNDS

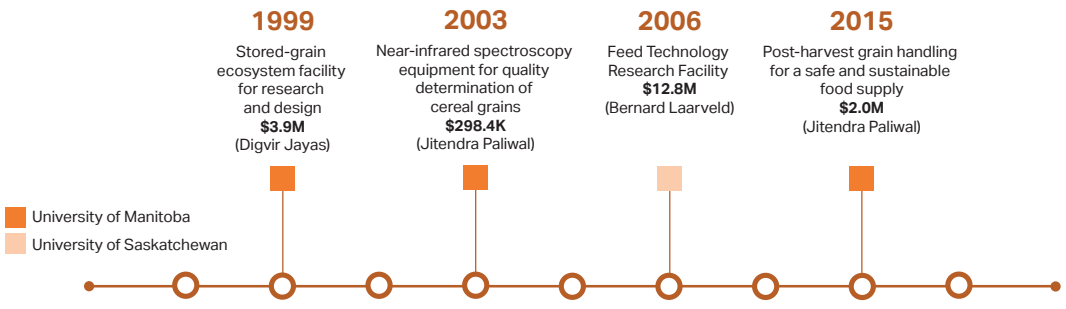
CFI contributions can represent up to 40 percent of the project costs with matching funds secured from provincial governments in combination with institutions, or private partnerships as shown in **Figure 2**. Across all four projects, there were significant funds from all sectors, with numerous partnerships and investments from the private sector. For example, Paliwal's project, approved for CFI funding in 2015, received in-kind investments from 13 separate corporations to support infrastructure for the laboratory as well as new optical equipment and sensors for use in storage facilities. The CFRC, led by Laarveld, received significant contributions from the Saskatchewan Ministry of Agriculture, Western Diversification and Cargill Animal Nutrition, totalling $9 million in matching funds.

RESEARCH FUNDS

The availability of CFI-funded infrastructure has enabled all three project leaders to secure additional funding. Sources of leveraged funding are varied and come from federal and provincial governments, non-profits, industry, industry associations and academia as shown in **Figure 3**.

Researchers at the CWBCGSR and CFRC have secured funding from various sources such as the Natural Sciences and Engineering Research

Figure 1: Timeline of CFI projects in grain storage



Note: CFI administrative data as of April 15, 2016. Dollar amounts reflect the total project cost of which only 40 percent is the CFI contribution. Amounts for some projects are based on interim financial reports and are therefore provisional.

Council of Canada (NSERC), Western Economic Diversification Canada, provincial Agricultural and Rural Development Initiatives, Manitoba Rural Adaptation Council (MRAC), Canola Council of Canada, Pulse Canada, Saskatchewan Pulse Growers, MITACS, AAFC, Agriculture Development Fund, and the University of Manitoba. Students working in the laboratories at the CWBCGSR were supported through fellowships from the university and NSERC as well as through funding from industry.

NETWORKS, COLLABORATIONS AND LINKAGES

Researchers in the CFRC and CWBCGSR collaborate extensively with other groups at the local, national and international levels. These include researchers within academia, industry and non-profit organizations. The world is connected by the import and export of major food products, and international collaborations emerge from a joint desire to reduce post-harvest losses and improve the quality of shipped and domestic goods. In many situations, international relationships are formed when members of the research team network with attendees at conferences outside of Canada. Collaborators who have worked with, or who are currently working with, the grain storage research centres include:

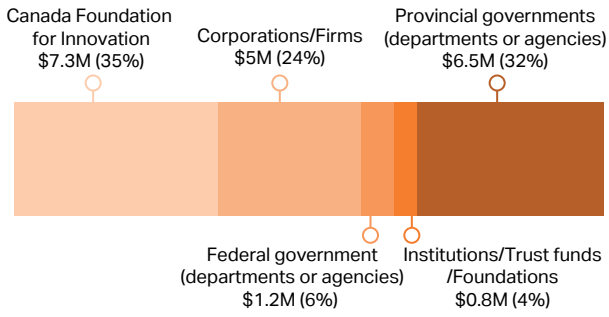
Industry associations
- Pulse Canada
- Animal Nutrition Association of Canada
- Canadian International Grains Institute
- Canola Council of Canada
- National Agriculture Cooperatives Federated of Korea

Government
- National Research Council of Canada
- Agricultural Research Services (U.S.)
- Agriculture and Agri-Food Canada

Academia
- Purdue University
- Canadian Light Source
- Central Scientific Instruments Organisation of India
- University of Port Harcourt
- Wageningen University
- Seoul National University
- National Feed Engineering Technology Centre, China Agricultural University
- Universidad de las Américas Puebla

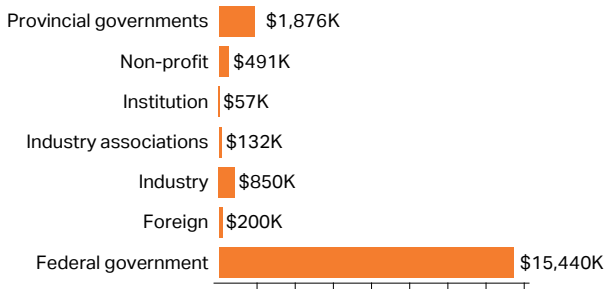
Private
- Perten Instruments
- 151 Research Inc.
- Spectrum Scientific
- Channel Systems Inc.
- Ag Growth International
- Fortek
- Cargill Ltd.

Figure 2: Matching funds of CFI investments in grain storage projects



Note: CFI administrative data as of April 15, 2016. Amounts for some projects are based on interim financial reports and are therefore provisional.

Figure 3: Research funds obtained by grain storage project leaders since initial CFI award



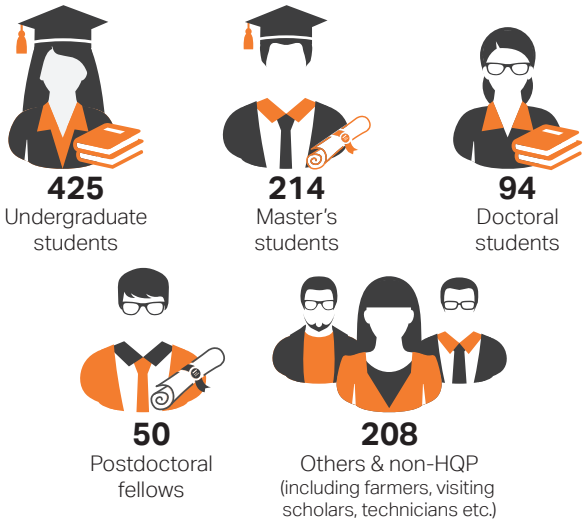
Note: Awards and amounts included were reported and validated by project leaders and only include funds obtained since year of initial CFI award. Awards and amounts may not be unique counts due to the co-applicant status of the project leaders.

TRAINING, ATTRACTION AND RETENTION

Research infrastructure enhances the training environment and contributes to the development of undergraduate, graduate students and postdoctoral fellows conducting research in grain storage at the facilities examined, many of whom have secured employment in academia and industry. The infrastructure at the CFRC has been used in undergraduate and graduate classes since 2013.

In the undergraduate classes alone, approximately 160 students have used the infrastructure to learn about classification, processing and storage techniques of feed primary products and processing of concentrated swine feeds.

CFI infrastructure has helped train Highly Qualified Personnel (HQP)[2] including:



The knowledge and skills developed through the training environment at the CWBCGSR has resulted in a number of individuals attaining employment in academia and industry. Many former trainees continue to collaborate on projects with researchers at the CWBCGSR while other former trainees have obtained academic positions within their former departments. For example, both Paliwal and Fuji Jian, PhD, are professors in the Department of Biosystems and Engineering at the University of Manitoba and work as part of the CWBCGSR team, having completed their training or graduate studies at the centre under the supervision of Jayas.

Many former students also find jobs in industry. For example, Mahesh Sivakumar holds the position of Process/Biosystems Engineer at POS Bioscience, and was a former Master's and doctoral student at CWBCGSR. Wenbo Wang also found employment in industry at the BC Cancer Agency and at Intellectual Ventures in Seattle after completing his postdoctoral fellowship at the centre.

The retention of Paliwal at the University of Manitoba through his training under Jayas to his position as a faculty member was facilitated by infrastructure at the CWBCGSR. The CFRC facility helped recruit Tom Scott, PhD, a researcher who relocated to the facility from a European global animal nutrition company because of the availability of the new research infrastructure.

KNOWLEDGE TRANSFER

The research conducted at the CWBCGSR and CFRC has advanced knowledge in the field of grain storage research. Project leaders funded by CFI are ranked among the top researchers in agriculture in Canada in terms of publication output. All three project leaders at CWBCGSR and CFRC have published papers with high citations with close to 90 percent of their papers cited on average.

2 Highly qualified personnel (HQP) include technicians, research associates, undergraduate students, graduate students and postdoctoral fellows. Numbers as reported by project leaders.

Data from 2008 to 2014 show that both Jayas and Paliwal were ranked above the world average by normalized citation impact, with Jayas having produced the largest number of publications.[3]

The results of research conducted by the team at the CWBCGSR have been published globally and have had a broad influence on the practices adopted for grain storage management and research in countries such as the Ukraine, China, India, the United States and Canada. Nanjing University of Finance and Economics in China is a collaborator with the group and the institution has built a grain research lab which replicates fully the system first implemented at the CWBCGSR. Other Canadian laboratories have also installed similar infrastructure used by the centre for their grain storage research.

At the CFRC, researchers evaluate different conditioning techniques used to prepare animal feed and the effects of humidity, temperature and other storage conditions on the quality of the feed. They also research ways to reduce toxins and other potentially harmful crop diseases through sorting and identification before storage. All members of the animal feed sector and the livestock industry have benefitted from the research and workshops provided through the CFRC. They test the safety and effectiveness of the feed for approval by the Canadian Food Inspection Agency to help find cost-effective alternatives while improving the health and output of production-based livestock.

The CFRC provided a hands-on training workshop on feed processing for the Animal Nutrition Association of Canada and a hands-on workshop on grain sorting using the BoMill grain sorter.

Beyond academic publications, researchers participate in dissemination targeting Canadian farmers and grain producers who can benefit directly from the results of the research. For example, at the CFRC, in December 2014, an industry information event was held to educate 37 farmers and members of the western canadian grain trade on new methods of removing Fusarium mould from wheat and durum. Additionally, Jayas' team created a CD-ROM that contained information and practices for grain storage. This was later distributed to Canadian farmers and international agricultural collaborators by Agriculture and Agri-Food Canada and the University of Manitoba. The group has influenced grain storage management practices in Canada and across the globe and has developed several key tools and devices like the CD-ROM that can lead to environmental and economic benefits.

"We participate in a lot of farmer-organized events and publish in local papers and magazines. It helps us stay engaged in the community and is another way for our research to be accessible to them."

Jitendra Paliwal, University of Manitoba

BENEFITS TO CANADA

CFI's investments in infrastructure for grain storage research have resulted in social benefits through job creation and collaboration with farmers, economic impacts through the use of sorting technologies and increased productivity, as well as environmental benefits from new technologies to reduce pesticide and chemical use on crops.

3 Bibliometric analysis conducted by the CFI from Web of Science In-Cite over the time period of 2008-2014. Publications and citations may not be unique counts due to co-authorship of publications between project leaders.

Automation in the grain industry has been slow to develop, however, the establishment of the CWBCGSR and the work performed by its researchers have helped to address this issue. Their research contributes to the improvement of the quality of grain exports resulting in economic benefits through reduced financial losses suffered by the producers of Canadian grain. For example, the team developed the Grain-O-Bot, a robot used to automate the inspection of grain in railcars. This considerably reduces the human resources needed, allowing workers to focus on other aspects of the grain-delivery process.

"When CFRC received the results, we did a workshop for industry, producers and government. A company, Standard Nutrition in Manitoba, built a plant specifically for these sorters. In 2014, there were millions of tonnes of Fusarium-infected grain. It ties into global food security and our solution will have a lasting impact."

Rex Newkirk, Ministry of Agriculture Endowed Research Chair Feed Processing Technology, University of Saskatchewan

Recently, Paliwal's team adapted cancer-screening technology to offer a better and safer way to check for grain bin moisture. By using electromagnetic imaging to create a 3D profile of a bin, they can see pockets of moisture which can overheat and spoil. This system to detect potential spoiled grain will help farmers deal with post-harvest spoilage losses, estimated to cost more than a billion dollars a year in Canada.

Further economic benefits were achieved through the development of an approach to managing Fusarium mould, western Canada's worst crop disease. Fusarium is toxic to humans and animals, is difficult to detect and, even in low levels, the infected grain is unusable and the associated costs with the loss and disposal can be high for farmers.

To help manage this problem, researchers from the CFRC adopted infrared imaging technology developed by the collaboration between the CWBCGSR and Cargill Animal Nutrition and combined it with sorting technology from BoMill. The initial test of this approach was performed on five tonnes of wheat from a Saskatchewan farmer, of which seven percent was infected with Fusarium. The technique successfully identified and removed Fusarium-infected kernels, reducing the infected crop to less than one percent. By doing so, the value of the wheat tested increased from $0 (since the infection made the crop unusable) to $260 per tonne. The results of this work will yield significant economic benefits to farmers who may now be able to use and profit from crops that would have previously been entirely discarded.

CONCLUSION

CFI investments in grain storage research infrastructure have yielded important research achievements and benefits in Canadian and international agriculture practices. CFI project leaders leverage funding support from a wide range of organizations and sectors to advance research in the area of grain storage and improve management practices, particularly through technological innovation and automation. The contributions of the research centres to enhancing capacity through training of skilled personnel has led to a number of former students and postdoctoral fellows pursuing employment in the field in academia and the private sector, with many continuing to work for or with the centre after their training.

Achievements related to CFI's investments in grain storage research directly translate into job creation in the manufacturing sector and the training of skilled personnel. The reduction in post-harvest grain losses through improved technologies and sharing of best practices directly benefits producers and grain companies, and leads to increased availability of grains that meet Canadian standards.