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Canadian plant breeder opinions regarding changes to plant breeders' rights

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In 1991, Canada became a member of the International Union for the Protection of New Plant Varieties (UPOV). To further incentivize plant breeding research and development, Canada updated its plant breeders' rights framework in 2015 to become compliant with UPOV-91 (the latest Act of the Treaty). This article reports the results of a survey assessing the impacts of UPOV-91 on Canadian plant breeders, and their knowledge and openness to move to a DNA-based plant registry system. Canada's adoption of UPOV-91 has not had a significant effect on public plant breeding programs; however, it is not expected to facilitate additional public sector innovation investments as envisioned.

Key words: Innovation, intellectual property rights, plant breeders' rights, R&D, research funding, Union for the Protection of New Plant Varieties (UPOV).

INTRODUCTION

Plant breeding is the process through which plant characteristics are enhanced or improved to perform new and desired roles. For modern plant breeding programs to be successful (yield adoptable cultivars), access to plant genetic resources must be coupled with the development and application of breeding technologies. The process also requires knowledge of several scientific disciplines, such as agronomy, plant physiology, plant pathology, entomology and molecular biology to name a few, as well as the use of capital. Plant breeding is a laborious and resource intensive process; therefore, plant breeders need to protect their efforts by using intellectual property rights (IPRs). The *sui generis* legal protection system with which plant varieties and plant materials are protected are known as plant breeders' rights (PBRs).

Attracting international investments in agriculture is globally competitive as governments are constantly readjusting and creating policies to further support innovation investments, enhancing research and

development (R&D), and increasing product commercialization. Canadian governments are committed to this goal, funding about 80% of the \$700 million directed towards agri-food bioscience R&D in 2012 (Agriculture and Agri-Food Canada, 2012). However, despite the government's significant contribution to Canadian agricultural innovation, when accounting for inflation, total public research investment has actually been decreasing over the last three decades (Agricultural Institute of Canada, 2018). Yet, governments have made a good start with some new and renewed programming. Renewal of the federal-provincial-territorial Canadian Agricultural Partnership, in cooperation with a host of partners in the private industrial sector, has locked in \$3 billion in funding for 2018-2023. Perhaps as important, ministries that have historically ignored agriculture are now engaging in this initiative. As a department of the Canadian federal government, Innovation, Science and Economic Development has opened a range of their

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granting programs to agri-food research and development and rolled out commitments of \$950 million to support five regionally-anchored innovation super clusters.

In 2016, the Ministers of Agriculture of the G7 countries committed to improving sustainable agricultural production, productivity, and food supply by investing in research and governance innovations. While greater investment in agriculture is crucial, less than 1% of agri-food innovations succeed (Graff et al., 2009) and regulatory delays are increasing (McDougall, 2011). These represent significant challenges for global agriculture. Even though the quality of Canadian agriculture R&D was high, Canada has failed to meet its innovation potential because the conversion of innovative ideas into commercial products is less efficient. The Global Innovation Index (2018) ranked Canada in 61st position in terms of innovation efficiency, comparing innovation investments to innovation commercialization.

As part of the effort to investigate Canada's challenge to narrow the gap in its innovation pipeline, a survey of Canadian public and private plant breeders was undertaken to gain insights into whether recent changes to plant breeders' rights would incentivize greater R&D investment and more importantly, result in an increased rate of commercialization. This article reports the results of a survey that assessed Canada's adoption of UPOV-91 (International Union for the Protection of New Plant Varieties), the impacts it has had on Canadian plant breeders, and their knowledge and openness to move to deoxyribonucleic acid (DNA) based plant registry systems. First is a brief overview of Canada's PBR framework and the importance of this protection in incentivizing innovation. Afterwards, the methodology used to analyze the survey results, as well as participant demographics is discussed. Results are then presented, implications explored and the study concluded.

Canadian plant breeder's framework and importance

Plant breeders' rights are forms of national legislation, with the three main components of most systems being: (1) the definition or demarcation of what is protectable; (2) requirements that need to be met for protection to be granted; and (3) what are the rights of the variety owner. International regulation of PBRs is through UPOV, established in 1961 by the International Convention for the Protection of New Varieties of Plants (Jefferson et al., 2014). The treaty has been revised several times; the latest version being the 1991 text (UPOV-91). Lesser (2007) noted that in the latest revision of the treaty, if a plant was considered to be "...essentially derived from a protected variety, it cannot be commercialized without the permission of the initial variety's owner." Thus, in the latest version of the text, exception to breeders' rights was explicitly considered.

The mission of UPOV was to "provide and promote an

effective system of plant variety protection, with the aim of encouraging the development of new varieties of plants, for the benefit of society" (UPOV, 2011). While necessary, assigning IPRs to agriculturally important plants have raised public policy issues. Chief among these was assuring open access to germplasm resources so that new crop varieties can be continually developed. UPOV-91 allows breeders to use any plant variety to produce novel plant varieties. However, when a new plant variety was in great part the result of an existing variety, this similarity must be acknowledged, meaning the novel plant cannot be commercialized without the original variety owner's permission.

Canada enacted the Plant Breeders' Rights Act (PBRA) in 1990 and became a member of UPOV in 1991. In Canada, varietal protection under the PBRA is voluntary and breeders are responsible for seeking this protection. For a breeder to be granted a PBR, the variety must be new, distinct, uniform, and stable when compared to a reference variety (Carew et al., 2017). One key difference between the IPRs for new plant varieties in Canada and the United States was that in Canada, living organisms, or 'higher life forms', cannot be patented. However, while Canadian breeders do not have the opportunity to patent the final product of their breeding efforts (that is, the new plant variety), the protection offered by protein, gene, and cell patents allowed breeders the possibility to patent the methods used to reach the final product without patenting the final product itself (Smyth and Gray, 2011). If the possibility to patent the process to develop a new variety was not an option, then the scope of new variety protection was limited to PBRs. One of the main reasons for this distinction in Canada, and in many countries, was ethical considerations over ownership of life (Ye, 2007). A common criticism of this system was that PBRs are unlikely to ever offer the coverage levels of patents because they were specific to the individual variety, and do not cover novel plant breeding techniques (Carew, 2000).

In 2015, Canada updated its PBR framework to conform with UPOV-91 as part of the introduction of the Agricultural Growth Act (Government of Canada, 2015). This most recent version of the convention contained new elements providing stronger protection for plant breeders. Prior to making the amendment, Canada was one of only three developed countries that had not adopted the most recent UPOV convention, the others being New Zealand and Norway (Senate of Canada, 2015). The adoption of the most recent convention brought Canada's framework into line with those of key trading partners and global competitors. The purpose of adopting UPOV-91 was to create an environment which encourages investment in plant breeding, with an emphasis on incentivizing investment from the private sector (Dawson, 2013), subsequently providing farmers with new and innovative plant varieties and increasing access to foreign varieties (Government of Canada, 2014). The amendment was

also made with the goal of increasing Canada's competitiveness in the global agricultural marketplace (Government of Canada, 2015).

Amendments to Canada's PBRA in 2015 were significant. Under the new Act, sale of new varieties within Canada was allowed for one year prior to filing a PBR application, and for four years prior to filing outside of Canada, to test the market, advertise, or increase stock (Government of Canada, 2014, 2019). For tree and vine varieties, this period was extended to six years. The duration of protection for trees and vines was extended from 18 to 25 years, and for other plant varieties to 20 years. The extent of exclusive rights held by the rights holder was also increased to include reproduction, exportation, importation, conditioning, and stocking of propagation material (Government of Canada, 2019).

Two key exemptions to the exclusive rights of breeders were included in Canada's PBR framework. The first exemption was termed 'farmers' privilege', and allowed farmers to save and sow their own seed of protected varieties on their land (Carew et al., 2017; Hervouet and Langinier, 2018). Member countries of UPOV-91 were given the option of whether or not to uphold farmers' privilege, or impose further restrictions (Carew et al., 2017). Farmers' privilege was upheld in Canada's updated PBRA, yet the potential elimination of farmers' privilege raised concerns over the new legislation from some farmers and producer groups (Cross, 2014). The other important exception to breeder's exclusive rights, known as the 'research exemption', allowed researchers to use protected varieties to create and commercialize new varieties without a license or agreement (Hervouet and Langinier, 2018). Both the public and private research sectors have embraced the research exemption due to the balance it brings between rewarding innovation and using new varieties in a socially beneficial way (Jefferson et al., 2014).

The importance of protecting PBRs has been widely recognized. Costs associated with developing a new plant variety are high and the return on investment may take many years. Alston (2010) has estimated the lag between commercialization and the peak of adoption benefits is greater than 20 years in agriculture. In the absence of IP protection, once a new variety is developed and ready for market, other companies could easily copy the process, resulting in the production of a similar variety. This copier, without the high R&D costs faced by the initial developers, would be able to sell the new variety at much lower costs and still realize profits, essentially undercutting the initial developer to the point where they are unable to capture profits from their innovation (Siebrasse, 2010). The implementation and enforcement of PBRs encourages investment in R&D by incentivizing investors with the ability to capture returns on their investment (Ye, 2007). This increased investment leads to the further development of new and innovative cultivars for farmers to adopt. In the agricultural

industry, previously dominated by public breeding programs, a strong PBR framework has facilitated increased investment in private plant breeding (Carew and Devadoss, 2003). This can be seen through the development of the canola seed industry in Canada. Following the enactment of the PBRA in 1991, and the subsequent approval of transgenic canola varieties in 1995, private and public canola breeding programs expanded rapidly (Carew and Devadoss, 2003). Private investment in canola research grew from C\$7 million in 1987 to C\$42 million in 2007, and C\$95 million by 2017, receiving over 55% of private crop research investment (Canadian Seed Trade Association, 2019).

Although less frequently documented than in private industry, the issue of PBRs in the public research sector was also very important. It was commonly thought that public breeding programs were less sensitive to PBRs, as these programs served the broader interests of society as a whole (Galushko et al., 2012). However, results from a 2017 survey of public and private plant breeders in the United States indicated that, as IPRs become more restrictive, they inhibited the research spillover effects relied on by public breeding programs (Dawson et al., 2018). Similar arguments were put forward by Heisey et al. (2002) in their discussion of the privatization trend in plant breeding. This counter-effect of restrictive IPRs on public breeding programs was supported by results from a 2012 survey of public and private plant breeders. In that survey, wheat breeders, who were predominantly publicly funded, tended to prefer a more open exchange of technologies, while canola breeders, who were more likely to be privately funded, preferred some restrictions in place on technology exchange (Galushko et al., 2012). Restrictions on property and knowledge sharing might also increase the need for further collaboration among public and private organizations in order for public programs to access required technologies and resources. While collaborations were often perceived as a positive undertaking in research efforts, the private sector's profit-driven mandate, and the increased drive for commercialization of the researchers themselves, had the potential to shift the direction and focus of public breeding programs (Azoulay et al., 2009; Galushko et al., 2012; World Intellectual Property Organization, 2011).

Prior to the implementation of changes to Canada's PBRA, Campi and Nuvolari (2015) constructed an index that characterized the relative strength of plant breeders' IPRs among 69 countries. Strength of the IPRs was based on the following five components: (1) ratification of UPOV conventions; (2) farmers' exception; (3) breeder's exception; (4) protection length; and (5) patent scope. On this index, Canada ranked below similar countries such as the United States, Australia, and the United Kingdom. However, the amendments to Canada's PBRA brought into effect in 2015 expanded the protection afforded to plant breeders and harmonized Canada's PBR framework with those of key trading partners (Carew et al., 2017;

Government of Canada, 2014). Supporters of the amendments were encouraged that the changes would bring new investment, both domestic and foreign, in plant breeding, and would provide farmers with new varieties which would produce higher yields and result in greater profits (Cross, 2014). Correspondingly, between 2013-2018, overall crop research expenditures improved significantly, and future investment projections remain strong (Canadian Seed Trade Association, 2019).

Before implementing the amendments to the PBRA in Canada, the CFIA held a public, web-based consultation process to determine how stakeholders perceived the proposed changes to the act (Government of Canada, 2015). Plant breeders, farmers, horticulturalists, seed dealers, and interested citizens, as well as 30 organizations from the agricultural industry, provided feedback to the proposed changes, and the majority of responses were in favor of the amendments (Government of Canada, 2015). However, in a survey of plant breeders conducted by the Canadian Seed Trade Association in 2017, concerns over IP protection were still commonly viewed as an important barrier to innovation despite the amendments to the act coming into force two years prior to the survey (Canadian Seed Trade Association, 2019). These responses indicated that despite the significant improvements to protection of new plant varieties resulting from Canada's adoption of UPOV-91 standards, some plant breeders in Canada still desired further improvements to IPRs for new plant varieties.

METHODOLOGY

To gain insights on changes to PBRs and the R&D incentive effects, an online survey was conducted between April 2019 and February 2020. The survey was designed to collect information about how Canadian plant breeders were coping with, and adapting to, the changes made to PBRs that came into effect in 2015. Specifically, the questionnaire solicited Canadian breeder opinion on the PBRs obtention process, their plant breeding process, and the economic aspects of new PBRs. This study received experimental protocol approval by the Behavioural Ethics Board, Research Ethics Board (BEH-REB 956) at the University of Saskatchewan on April 18, 2019. This survey presented participants with a standard consent statement describing the study, identifying the absence of known risks associated with participation, and a reminder that participation was voluntary, and responses would be anonymous and confidential. Upon expression of consent, participants were presented with the questionnaire. Respondents had the option to skip a question, that is, provide no answer, and still be able to submit a survey.

The survey was emailed to 329 Canadian plant breeders in a contact database that was created by CropLife Canada, and to which personal connections and breeders at various Canadian University Plant Science departments were added. It was estimated that the total number of plant breeders in Canada was less than 500. Of 329 Canadian plant breeders to whom the survey was emailed, 69 responded. However, 17 surveys were incomplete, and only 52 surveys were fully completed. The survey response rate was 21%. The type of sampling done in this survey was known as purposive sampling, which is non-random, or non-probabilistic in

nature. Therefore, results and conclusions here reported cannot be generalized to the entire population of Canadian plant breeders because the type of sampling restricts the range of the inference. Accordingly, due to the non-random sampling and the small sample size (total responses), only descriptive statistics were performed on the results.

Demographics

Respondents were predominantly male (76%), with only 18% of respondents being female. Most respondents were older than 55 years of age (48%); most surprising was that none of the respondents were under the age of 30. Respondents were well educated with 94% having some, or all, of a graduate degree. Twenty-seven per cent of respondents had between 21 and 30 years of plant breeding experience, 20% had between 11 and 20 years of experience, and 20% had 5 or less years of breeding experience. Thus, the survey sample can be characterized as a predominantly middle-aged male sample with varying years of plant breeding experience, most of whom have an advanced university degree.

RESULTS

Participant plant breeding programs

Before investigating how Canadian plant breeders perceive the changes to the PBR framework introduced in 2015, participants were asked general questions about their plant breeding programs. To gauge the variability in type of program and breeding techniques and technologies used, participants were asked to select, from a variety of options, what types of breeding tools and processes they used in their program (Table 1). Participants were asked to select all options that applied. The most commonly selected option was conventional breeding using natural or artificial hybridization and selection based on phenotype (77%), followed by molecular marker assisted selection (58%), classical breeding and predictive markers for selection (52%), and in-bred lines (48%). The least frequent response was commercial varieties with controlled and IP protected hybridization systems (13%). Most survey participants (51%) breed cereals, followed by oilseeds and pulses at 16% each. The financial funding structures of survey participants' breeding programs were also assessed. For 36 respondents (50%), government research grants are the most common funding type, producer check-offs (28%) were the second most reported and redistribution of royalty collections (22%) was third.

Current use of IPRs in breeding programs

An important aspect of determining how plant breeders perceive the PBR framework was determining how important IP protection and its enforceability was to their breeding programs. In response to what types of IP protection are currently used for newly developed

Table 1. Tools, procedures, and crop types in breeding programs.

What tools and procedures do you use in your breeding program?	% Responses
Classical breeding using natural or artificial hybridization and selection based on phenotype	77
Molecular Marker Assisted Selection (MMAS)	58
Classical breeding and predictive markers for selection	52
In-bred lines	48
Speed breeding adjusting to accelerate crop growth and reproduction	38
Foreground (specific trait)	31
Background (whole genome or GWAS)	31
Open pollinated commercial varieties with or without IP protection	27
Classical breeding using induced mutation	23
Marker assisted selection (MAS)	21
Gene editing to change a piece of the genetic code inherent in the target crop kind	19
Genetic engineering and modification to move/rearrange DNA	15
Commercial varieties with controlled and IP protected hybridization systems	13
Other	15
What types of crop do you currently breed?	% Responses
Cereals	51
Oilseeds	16
Pulses	16
Cannabis	10
Root crops	10
Fruit	10
Forages	10
Ornamentals	8
Leafy, stalked fruit or tuber vegetables	6
Spices	0
Other	8

varieties, just over 80% of the 48 participants who answered the question indicated that they use PBRs, 25% use consent forms, 21% use patents, 8% use license agreements, and 6% rely on hybridization for protection (Figure 1). When examining how different types of plant breeders answered this question, responses were fairly similar among public and private breeders relating to the use of PBRs, hybridization, and consent forms. However, a few noticeable differences in responses were observed. First, no public breeders from government institutions make use of patents, while 21 and 25% of public breeders in universities and private breeders, respectively, reported using patents. Secondly, in this survey only public breeders reported making use of license agreements for protection.

Participants were asked if they were confident enough in the distinctness of their newly developed plant varieties to enforce their PBRs in court. The majority (69%) of the 45 respondents answered yes, indicating they were confident, while 7% were not and 24% were unsure. As a follow-up, participants were asked, out of their total annual plant breeding program costs, approximately what

percentage was devoted to enforcing their PBRs (Figure 2). Despite PBRs being the protection method of choice for the majority of participants, 79% of the 34 participants who answered said that the amount spent on enforcing PBRs was less than or equal to 1% of total annual costs. Only 9% answered that they spent 5% of annual costs on enforcing PBRs, and 3% spent 10% or more of their annual costs on enforcing PBRs. Again, some slight distinctions were seen between the types of breeders. All of the public breeders from government institutions who responded to this question reported spending less than or equal to 1% of total costs on enforcing PBRs. Comparatively, 25% of private breeders reported spending 5% on enforcing PBRs, and 16% of public breeders at universities spent 5-6%.

Changes to Canada's PBR framework

Questions regarding how the amendments to Canada's PBR framework introduced in 2015 impacted Canadian plant breeders and their programs were a core focus of

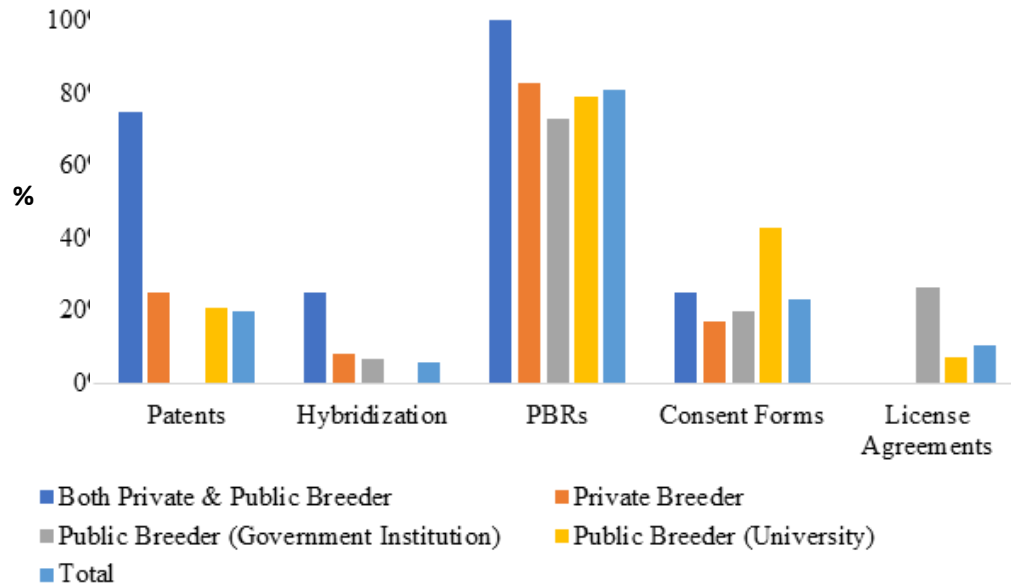


Figure 1. Type of IP protection used.

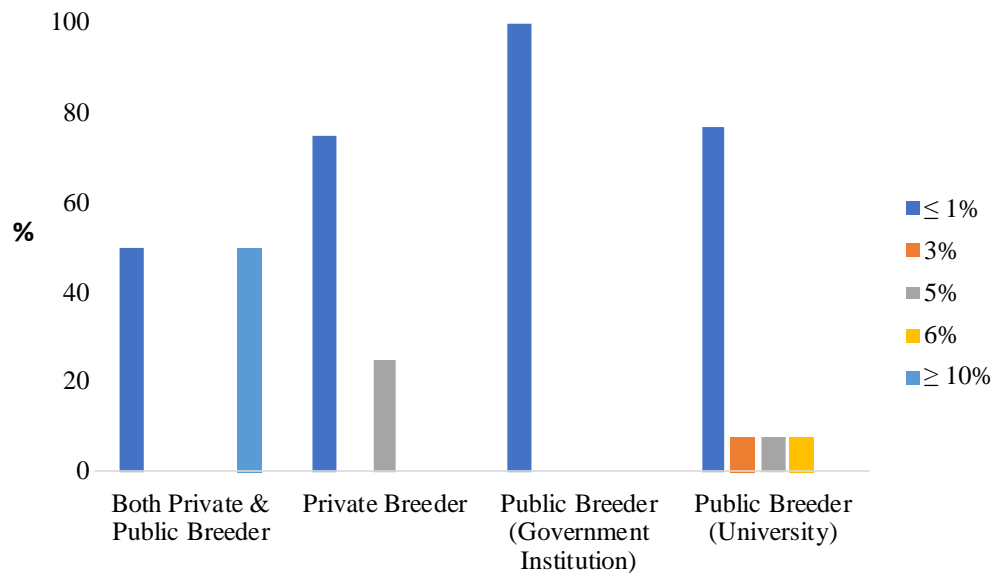


Figure 2. Percent of annual costs spent enforcing PBRs.

the survey. Although the Canadian Food Inspection Agency (CFIA) held a web-based consultation process prior to implementing the proposed changes, only 22% of participants who responded to this question were part of this consultation process. Overall, the majority of participants appeared to be relatively unaffected by the changes that were brought into force (Figure 3). Participants were first asked if they thought the updated periods for which PBRs are granted were appropriate. The overwhelming response from 88% of the 43 respondents was yes. The next question asked if

participants plan to take advantage of the opportunity to sell Canadian plant varieties for one year prior to the filing date of the PBR application, an extension of the PBR framework implemented as part of the 2015 updates. Responses to this question were split, with 57% of the 42 respondents answering yes and 43% answering no.

When looking at how source of breeding program affected responses, some subtle differences were noted. Private breeders, breeders who work both in the public and private sector, and public breeders working for universities all answered similarly. Over 90% of

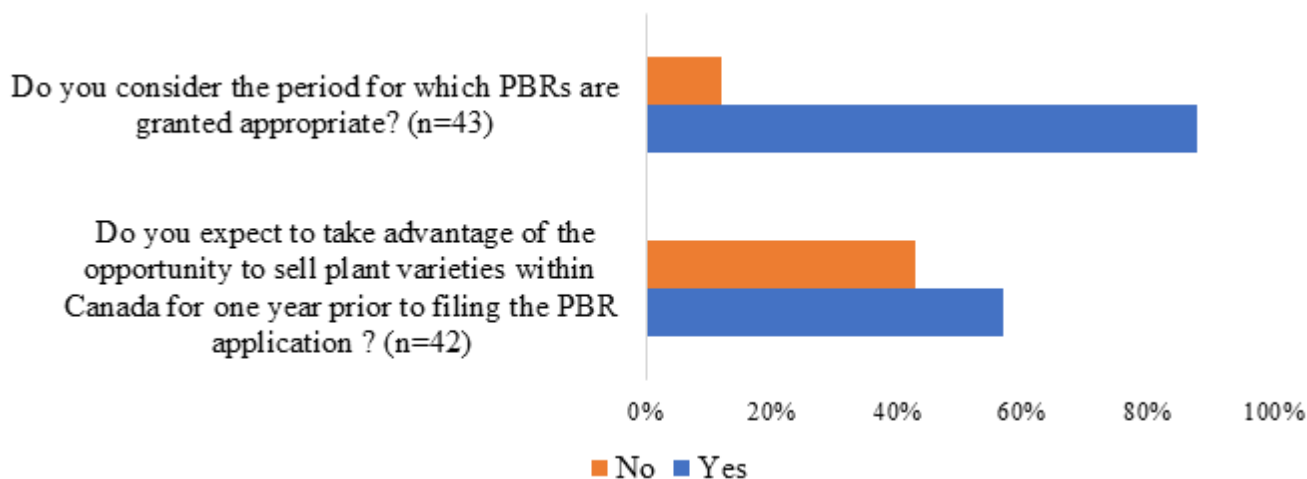


Figure 3. Impacts of PBR amendments on Canadian plant breeders.

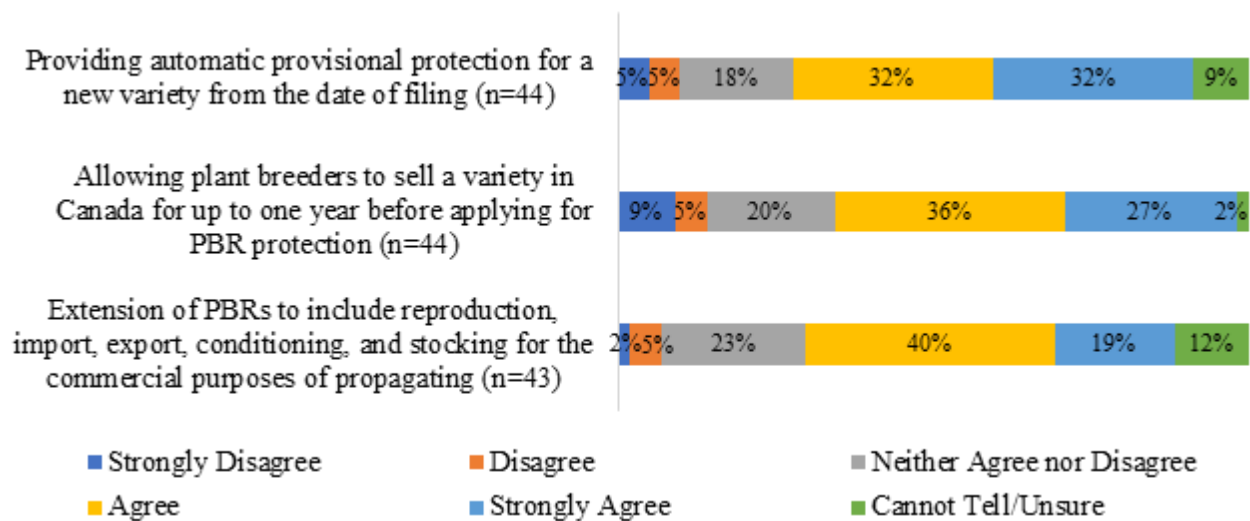


Figure 4. Extent plant breeders agree or disagree with PBR amendments.

respondents in all three of the previously listed categories stated that they consider the period for which PBRs were granted appropriate, and over 60% answered that they expect to take advantage of the opportunity to sell plant varieties within Canada prior to the PBR application filing date. However, only 69% of public breeders who work for government institutions thought the PBR period was appropriate, and only 38% expect to take advantage of the opportunity to sell.

Next, participants were asked to reveal their opinions of some specific items included in the PBR amendments. Based on a 5-point Likert scale ranging from strongly disagree to strongly agree, participants were asked to reveal to what extent they agree or disagree with the changes (Figure 4). The first question asked breeders if they agree with the decision to provide automatic

provisional protection for a new plant variety from the date of filing, which allows applicants to exercise their rights while applications were pending. The majority of the 44 respondents agreed with this amendment (64%), while only 10% disagreed, and 27% have no opinion or were unsure. Next, participants were asked if they agree with allowing plant breeders to sell a variety in Canada for up to one year before applying for PBR protection in order to test the market, advertise, or increase stock. Again, of the 44 participants who answered this question, the majority (63%) were in favour of this change, only 14% disagreed, and 22% had no opinion or were unsure. Finally, participants were asked about the extension of PBRs to include reproduction, import, export, conditioning, and stocking for the commercial purposes of propagating, in addition to the current system that already allows for

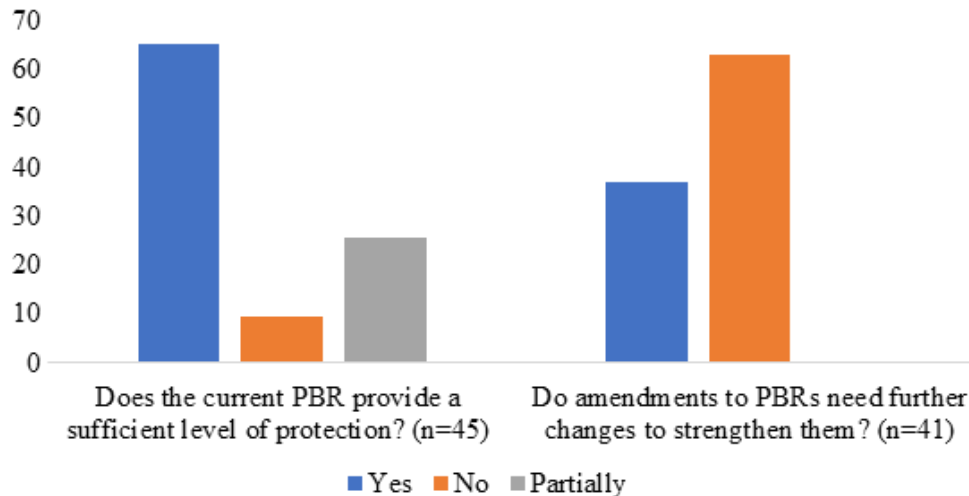


Figure 5. Sufficiency of current PBR system.

the production and sale of propagating material intended for sale. Similar results were seen, as 59% of the 43 respondents agreed with this change, while only 7% disagreed, and 35% have no opinion or were unsure.

Participants were asked to provide their opinions on whether these new changes to Canada's PBR framework are sufficient, or if further amendments will be needed to strengthen IP protection for breeders (Figure 5). When asked if the current PBR system provides sufficient protection for plant varieties, 62% of the 45 respondents answered yes, another 24% responded with partially, and only 9% answered no. Of the public breeders who answered this question, 80% of those working for government institutions and 83% of those working for universities answered yes, the protection was sufficient. Comparatively, only 25% of breeders who work both in public and private institutions and 30% of private breeders who responded said that the protection was sufficient. The second question asked participants if, in their opinion, amendments to PBRs need further changes to strengthen them. The majority (63%) of the 41 participants who responded answered no, while the remaining 37% answered yes. Again, a distinction was seen between public and private breeders. Of public breeders in government institutions and universities who responded, 73 and 64% said no, respectively. Of private breeders who responded, 56% said no, and of those who work both publicly and privately, 50%.

Participants who indicated that the amendments need further changes to strengthen them were encouraged to comment on what provisions they would like to see changed. The responses were varied and included further clarification on a number of amendment items, as well as a request for a working guide to implement UPOV-91. However, the most common suggestion from five of the participants was extended use of DNA fingerprinting and profiling of new varieties. Comments

from a number of participants indicated that this technology would lead to cost-savings. The most common justification for this suggestion, however, was the removal of subjectivity when comparing the developed variety to the reference variety. Results from a question later in the survey supported these suggestions. Participants were asked if, instead of collecting data on the characteristics of their varieties, would they be open to the possibility of a third party identifying their variety through their plant variety's DNA. Of the 46 participants who responded, 83% were open to this opportunity, while 17% were not. No differences were seen in responses between types of breeders. As a follow-up, participants were asked if they are aware of any company offering DNA variety identification services. Only 38% of the 45 respondents answered yes, while the remaining 62% said no.

Finally, the survey turned to the important question of incentivizing investment. Participants were asked if the amendments to PBRs incentivize them to invest more into their plant breeding programs. Surprisingly, of the 45 participants who responded to this question, 36% said that they do, while 62% said they do not. The results of this question were analysed further to determine if type of program and funding structure affect the incentives to invest (Table 2). When looking at how the type of program affects the incentives to invest, 44% of private breeders and 67% of breeders who worked in both the public and private sectors answered that the amendments increased their incentive to invest. Yet, only 18% of public breeders who worked for government institutions and 33% who worked for universities saw increased incentive to invest. A similar distinction was seen between breeders funded by government research grants, producer check-offs, and royalty collection. Of breeders funded by research grants who responded, only 31% said the amendments increased their incentive to

Table 2. Effect of program and funding type on incentive to invest (n=45).

Type of program	Amendments increase incentive to invest (%)	Amendments do not increase incentive to invest (%)
Both public and private	67	33
Private	44	56
Public (government)	18	82
Public (university)	33	67
Type of funding		
Government research grants	31	69
Producer check-offs	50	50
Royalty collection	43	57

invest, compared to 50% of respondents funded by producer check-offs and 43% funded by royalty collections.

DISCUSSION

Despite PBRs being the method of IP protection used by the majority of participants, results from this survey suggest that the significant changes brought into place in the 2015 amendment to Canada's PBRA are having a relatively low impact on most plant breeders. In general, results indicate that Canadian plant breeders are content with the current PBR framework and do not strongly desire further amendments to the IP protection available to them. Most importantly, participants indicated that the amendments do not incentivize them to invest more into their program. Thus, contrary to the anticipated results of the amendment, the key objective of adopting UPOV-91, incentivizing increased investment in Canadian plant breeding, appears unsuccessful. Paradoxically, the majority of participants were satisfied with the level of protection and the time-period covered by the current PBR system and agreed with the amendments put into place. These seemingly contradictory results suggest that increased investment may not be the top priority for many plant breeders when considering changes to IP regulation. Conversely, the results may also suggest that other elements of the plant breeding system already incentivize investment and tighter IP protection was not needed to encourage it.

Canada is not well positioned in terms of innovation efficiency, as Canada was ranked 9th in terms of innovation inputs yet ranked 22nd in terms of innovation outputs (Global Innovation Index, 2018). These rankings indicate that Canada was efficiently investing in R&D and that further efforts and attention to improving investments may only provide, at best, marginal returns. This gap in rankings suggests that resources and efforts would provide a better return by focusing on innovation barriers that products and technologies experience as they move

through the pipeline from laboratory to regulatory approval. The cost of innovation regulation was far greater than might first appear, as the Global Competitiveness Index ranked Canada in 53rd position in terms of the burden of government regulation (World Economic Forum, 2019). Future efforts to incentivizing investments in plant breeding should be focused on the regulatory process as this is presently a bottleneck in Canada's innovation pipeline.

The commonly suggested change to improve the system by respondents was to include further use of DNA identification and profiling technologies as compared to the more subjective phenotyping methods being used for variety identification. Comments from participants indicated that cost-savings from increased efficiency would be achieved through the use of this technology. The increased objectivity when comparing new varieties to reference varieties was the common justification for this technology. While the majority of participants were open to the possibility of using DNA technology to identify varieties, most were unaware of a company offering these services. The increased availability of DNA identification services would help to improve Canada's plant breeding framework, as well as the regulatory systems in place. Directing some of the available funding for agricultural R&D to the increased availability of DNA identification services might help to alleviate the limitations to using this technology faced by many breeders.

The topic of molecular distinction may signal one means of simplifying the regulatory system for new plant varieties. As breeders increasingly turn to utilizing gene editing technologies, the use of DNA analysis to identify varieties could contribute to clearer distinction of a variety's uniqueness. Previously, Canada used kernel visual distinction (KVD) to differentiate crop varieties, however as more varieties of a specific plant species began to be developed and commercially available, KVD was identified as a barrier to the release of varieties, as breeders were challenged to breed for visual distinction in addition to the agronomic characteristics. Specifically,

this was a major barrier in the development of new wheat varieties. In 2008, Canada moved away from the use of KVD. While breeders have familiarity with phenotype identification, combining DNA identification could provide a more comprehensive framework for confirming the distinction of the specific traits of new crop varieties.

Although the sample population surveyed in this study, as a whole, appeared to be satisfied with the PBR framework in Canada, considerable differences in perceptions were seen between public and private breeders with funding structure influencing these perceptions. The observed differences indicate that public breeders are less concerned with the strength of protection offered by PBRs and are also less incentivized by stronger IP protection. Similarly, breeders who received the majority of funding from government grants were less incentivized to invest than those who received funding from royalties or producer check-offs. Programs that received the majority of funding from government grants may not depend as heavily on the market success of the final product, while royalty collections are entirely dependent on the uptake of the new product, and producer check-offs are reliant on farmers' valuation of the breeding work conducted. As most public institutions received some form of government funding, the distinctions seen between public and private breeders are not unexpected. Heisey et al. (2002) argued that private firms were more likely to respond to market incentives. This argument is supported by 44% of private breeders and 67% of breeders who worked both in the public and private sector in this survey who reported an increased incentive to invest.

The importance of knowledge-sharing in the public sector may impact the results of this survey. Strict IP protection can actually inhibit public breeding in some cases. The importance of sharing research results publicly is also important for breeders at universities, where publications were important milestones in an academic's career. Thus, stronger protection is often not desired in the public side of the plant breeding industry. Results from this survey align with previous literature (Galushko et al., 2012; Gray et al., 2017; Siebrasse, 2010) suggesting that PBRs were more relevant and perhaps more important for private breeders. While the results in this survey do not indicate that public breeders desire weaker IP protection for their newly developed varieties, they do indicate that public breeders do not wish for the protection to be strengthened further, and do not necessarily see the value of the changes introduced with the amendments. These insights suggest that, although strong IP protection encourages innovation in the private industry, it may not be effective in encouraging increased public investment in plant breeding.

As discussed by Heisey et al. (2002), as increased investment into plant breeding programs was made by private companies, the role of public plant breeding programs often changed. Public institutions might focus

more of their future efforts on basic research, the development of advanced lines or other genomic material which can be licensed to private companies, or research with clearly defined societal benefits in order to reduce competition with private breeding programs. Public breeders may also focus their efforts on crops with a lower return on investment or small-scale crops such as vegetables or horticultural plants which are largely ignored by private companies. In such a case, IP protection for plant varieties would become less important for public breeders. On the other hand, perhaps more public-private partnerships should be encouraged, closing the gap between private and public breeding programs and bringing together resources, including funding, technologies, and human capital, to maximize efficiency. As the distinction between public and private breeding blurs, IP protection becomes very important for all breeders, regardless of the type of institution they are employed with. In the current Canadian plant breeding environment, public and private breeding programs are distinct, but partnerships and collaboration are becoming more commonplace.

A number of considerations must be taken into account when analyzing these survey results. First, the breeders who participated in this study may not necessarily be the stakeholders investing into their breeding programs in many cases. Agriculture and technology companies, as well as public institutions, producer groups, and other organizations are often incentivized to make investments into breeding programs, which allow breeders to develop new varieties more efficiently. It is possible that the amendments to the PBR framework do, in fact, incentivize greater investment, just not from the breeders themselves. Additionally, based on the relatively low percentage of total annual costs spent on enforcing PBRs revealed on this survey, it is apparent that the enforceability of PBRs may not have been a serious issue for breeders to date. In the last decade, there have been a number of documented cases where PBRs have been breached. For example, in 2013, SeCan (<https://secan.com/about-secan>), a large Canadian certified seed supplier, took legal action against Junop Bros. Seed of Delisle, Saskatchewan (SK) for the illegal sale of two malt barley varieties which were protected by PBRs (Cross, 2013). In 2016, SeCan also reached a settlement with Pasqua Farms of Moose Jaw, SK relating to the unauthorized sale of protected flax and durum wheat varieties (Alberta Seed Processors, 2016). A farmer from Kincaid, SK was also penalized for the unauthorized sale of two protected durum wheat varieties in 2017 (Dawson, 2017). A number of similar cases have been settled in Canada; however, their occurrence was not commonplace. Thus, the breeders may not see enforcing their PBRs as a large concern in comparison to other aspects of plant breeding.

Further research on the topic of PBRs and the Canadian IP framework might include a number of

developments. First, further distinction between breeders at universities and government institutions should be explored. Results from this survey indicate some slight differences between responses of public breeders from government institutions and public breeders from universities. The funding structures of government organizations and universities are very similar, and breeders from these institutions often collaborate on projects. Yet, in an industry that consistently sees changes to its technologies, regulatory system, and funding structures, the gap between types of publicly funded breeding programs may indeed be widening, as alluded to by the survey results. Further investigation of this subject would help to determine if this trend is significant on the national scale, or if the survey results reported here are an exception. Additionally, further investigation into how important PBRs are to plant breeders would help complement the results already gathered through this survey. Determining the value of these forms of protection for plant breeders will help to develop future policies which maximize government and institutional resources, and lead to further innovation within the industry. The combination of the results presented in this study and further results on the suggested topics for development will provide policymakers with concrete evidence of the current investment climate of Canadian plant breeding.

Conclusion

Results from this study suggest Canada's decision to update its PBRA to conform with UPOV-91 has not had a significant effect on the breeding programs of Canadian plant breeders, despite the anticipated increased investment with which the amendments were introduced. Yet, Canadian plant breeders that responded to the survey indicated they were satisfied with the current PBRs framework and do not think it required further changes. While protecting breeders' rights, the amendments also allowed farmers to save and grow their own seed under the 'farmers' privilege' clause. The inclusion of the 'research exemption' also ensures that plant breeders are able to access the genetic material they need to continue developing novel plant varieties.

Though the results indicate general acceptance of the framework, the Canadian system of IP protection is far from perfect. A delicate balance exists between public and private breeding programs, and tighter IP protection in the form of PBRs does little to incentivize public investment. The structure of Canada's plant breeding industry is ever-changing, as evidenced by the once publicly dominated industry becoming increasingly privatized. Achieving the socially optimal level of private breeding, public breeding, and partnerships requires a carefully implemented set of policies and incentives. Further research is required to determine what this socially optimal level of research is in Canada, and how

future amendments to the PBR framework may help achieve this goal.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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