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OPINION & POLICY

Cultivar Development in the U.S. Public Sector

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ABSTRACT

Public plant breeders at land grant universities and USDA play a critical role in the development of improved cultivars for farmers in the United States. Over the past 20 yr, a series of reports have documented the decrease in public plant breeding programs, breeder positions, and government financial support. Publically funded programs allow breeders to focus on crop types, geographic locations, and management systems that are not sufficiently profitable to warrant significant investment from private industry. A survey was conducted in 2015 to understand the current state of cultivar development in the U.S. public sector. The survey respondents were public plant breeders actively releasing finished cultivars and inbred lines, and questions included: (i) demographic and background information; (ii) germplasm usage and exchange; (iii) intellectual property rights; (iv) breeding program funding; (v) institutional support and program size. Results indicate that public cultivar development is in a state of decline, with insufficient numbers of younger breeders working in the public sector today to maintain the current level of cultivar development as the most senior breeders retire. Funding public breeding programs continues to be a challenge, as is access to improved germplasm due to overly restrictive licensing agreements. Potential opportunities include re-distribution of royalty funds to bolster revenue streams, and simplifying the germplasm exchange process to increase the likelihood of successful cultivar releases.

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Abbreviations: ARS, Agricultural Research Service; ERS, Economic Research Service; IP, intellectual property; LGU, land grant university; MTA, material transfer agreement; PVP, plant variety protection; R&D, research and development; ROI, return on investment; SAES, state agricultural experiment station; TLO, technology licensing office.

Twenty years ago, Kenneth J. Frey conducted a survey that revealed the alarming decline of plant breeders working in the public sector relative to plant breeders employed by the private sector. Frey (1996) estimated that in a 5-yr time span (1991–1994), the number of scientist years (calculated as 1 yr of a full-time plant breeder working on research, germplasm enhancement, or cultivar development) at state agricultural experiment stations (SAES) declined by 12.5. During that same period, the private sector experienced an increase of 160 scientist years. This decline was later publicized in a *Nature* article that referred to public plant breeders as "a dying breed" (Knight, 2003). Numerous symposiums have attempted to address this issue with limited effect, as subsequent surveys confirm that Frey's results are more than a passing trend (Sligh and Lauffer, 2004; Gepts and Hancock, 2006; Hancock and Stuber, 2008; Tracy and Sligh, 2014). Traxler et al. (2005), in a follow-up to Frey's report, found that SAES had lost 108 breeders, a decrease of 21%, from 1994 to 2001. The USDA, on the other hand, reported an increase of 41 plant breeders, totaling an overall reduction of public sector capacity by 10% (2005). In a survey conducted by Carter et al. (2014), department heads at land grant universities (LGUs) reported a 31% decrease in cultivar development programs over a 20-yr period (1993–2013).

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Taken together, these three surveys not only suggest that public plant breeding remains in decline, but that the rate of decline is increasing.

Indeed, the shrinking budgets of public plant breeding programs mimic the decline in federal allocations across all sectors of agricultural research and development (R&D). Research funding sponsored by USDA fell by 16% from 2005 to 2012 (Meyer and Ridgway, 2014), and groups such as the President's Council of Advisors on Science and Technology (2012) have called for an annual federal funding increase of US$700 million to ensure that agriculture in the United States is prepared to address the growing challenges of the 21st century. Economists have long argued that public funding of agricultural R&D generates a return on investment (ROI) sufficiently high enough to justify the expenditure. In a thorough review of the literature, Evenson (2001) analyzes more than 200 economic impact studies from a wide range of countries and commodities, and finds that 82% report a ROI that exceeds 20% for applied agricultural research in the public sector, with a 49% median ROI. Such returns are significantly higher than the comparative opportunity cost of investment of public funds in government securities, such as U.S. Treasury Bonds, which historically generate a ROI of 3 to 4% per year (Fuglie and Heisey, 2007). Both Evenson (2001) and Alston et al. (2000) acknowledge that the estimated agricultural R&D ROI reported in the literature varies widely, and percentages are influenced by factors such as the economic models used for the analyses, the location where the agricultural research is conducted (developed vs. developing countries), the scope of the research, and the estimated lag time from research to final product. Similar variability is observed in analyses of the economic value of plant breeding R&D, with estimated ROI typically exceeding 30% (Fernandez-Cornejo, 2004).

Given the high ROI for public agricultural R&D in general, and plant breeding specifically, the decline in funding is all the more troublesome when considering the social impact of such investments. Agricultural R&D leads to increased agricultural productivity and/or reduced input costs that have a positive impact on not just the farmer, but also the food industry and the general population. In addition, agricultural innovations often contribute to spillover effects that occur when successful research financed and developed in one geographic region has useful applications in other parts of the country or world. In plant breeding, public funding allows researchers to focus on crop types, geographic locations, and management systems that are not sufficiently profitable to warrant significant investment from private industry. Economists refer to this situation as a market failure because of the inefficiency of breeding for these systems, and public breeding efforts are a means of market correction. Examples include the use of tax revenue to support the development of cover crops, perennial crops, commodity crops grown in marginal regions, self-pollinated species with seed that can be easily saved and replanted, and cultivars adapted to organic farming systems, (especially outside of large organic production areas such as California). The length of time required for cultivar development, with some crops requiring a decade or more before a new cultivar is released, also affects availability of private sector investment. As a result of this significant time lag, investment shortfalls today have effects that reverberate well into the future.

One response to the public funding crisis, particularly at LGUs, has been to increase the levels of intellectual property (IP) protection applied to public cultivars. With the passage of the Bayh–Dole Act of 1980 (officially called the Patent and Trademark Law Amendments Act), LGUs are now encouraged to patent and license inventions resulting from publicly funded research, including new plant cultivars. Cultivars can be protected through several legal means, including patents for asexually propagated species through the Plant Patent Act (PPA), Plant Variety Protection (PVP) certificates to protect sexually propagated species and tubers, utility patents, and trademarks to assist with the branding of a particular cultivar or series of cultivars. Once a cultivar has been protected with IP, it is typically made available to growers (either directly or through the commercial sector) with a license agreement that requires a royalty payment for use of the cultivar. This model has the potential to generate revenue for many cash-strapped breeding programs. However, the increased prevalence of IP protection comes at the price of more stringent germplasm sharing agreements (both domestically and internationally), restricted access to new breeding material, and potential patent thickets that can be difficult to navigate (Dunwell, 2005; Hancock and Clark, 2009; Carena, 2013; Luby et al., 2015).

The purpose of this study is to explore some of the implications from Frey's 1996 report, 20 yr later. Rather than looking at the downward trajectory of public plant breeding programs over years, which has been sufficiently documented, this study is a point-in-time analysis of public cultivar development today. The current analysis takes a different approach from previous surveys by gathering responses directly from public plant breeders, rather than polling SAES directors and LGU department heads. In addition, this study focuses specifically on plant breeders actively releasing finished cultivars and inbred lines. While basic research and germplasm enhancement are critical functions of many public programs, this pre-breeding work often complements cultivar development in the private sector. However, when public cultivar development occurs in crops that do not have a counterpart in the private sector, the decline of such programs marks the loss of species diversity in the agricultural landscape. For this reason, reversing the disappointing trends in public cultivar development is critical. This article presents the survey results, specifically focusing on crop types, size and scale of programs, plant breeders' interaction with IP, and funding opportunities and challenges for public cultivar development.

METHODS

An online web survey of plant breeders working at public institutions in the United States was conducted in 2015. The survey was designed by the authors, with assistance from the University of Wisconsin Survey Center, who also administered the survey. A pre-notification letter was sent to 380 potential survey respondents on 15 June, followed by an email on 23 June containing the survey web link. A reminder email was sent to non-respondents on 30 June, and a third email was sent on 7 July to non-respondents. The survey was closed on 21 July 2015. All emails contained a web link to the survey, and each respondent was allowed to complete only one survey.

The survey mailing list consisted of 380 potential respondents generated through a thorough review of land grant college and university websites, including institutions established in 1862, 1890 (historically black colleges and universities), and 1994 (tribal colleges and universities). The survey was targeted toward plant breeders actively releasing finished cultivars. After an initial list was generated, a representative from each college or university was selected to review his or her institution's list for accuracy. In addition, the USDA Agricultural Research Service (ARS) website was reviewed by region and location to identify plant breeders releasing finished cultivars, who were also included in the survey.

Survey questions were based on discussion points that arose during the 2014 Summit on Seeds and Breeds for 21st Century Agriculture held 5 to 7 Mar. 2014 in Washington, DC (Tracy and Sligh, 2014). Survey topics included: (i) demographic and background information; (ii) germplasm usage and exchange; (iii) IP rights; (iv) breeding program funding; (v) institutional support and program size. In the first section, we asked breeders to tell us the number of years that they have been working in the public sector, the type of institution that they work for (USDA or LGU), their professional status (untenured, tenure-track, or emeritus), and the crops with which they work. To understand how public plant breeders are accessing and exchanging germplasm, we asked questions about germplasm sources for breeding programs, breeders' use of material transfer agreements (MTA), and the type of activities that are restricted by their institutions' MTA. In the section on IP rights, breeders were asked to identify the forms of IP used to protect their cultivars, and the impact of IP usage by both the public and private sector on their freedom to operate. To understand how public plant breeders are funding their cultivar development, breeders were asked to tell us the annual operating cost of their programs, their funding sources, and the impact of royalty money on their program. Finally, we asked questions about the level of support that breeders receive from their institutions regarding their cultivar development work, including whether or not their position will be replaced when they leave.

Given the objectives of the survey, most of the analysis is confined to descriptive statistics. In instances where relationships are tested using logistic regression, analyses were performed in R version 3.0.0. When analyzing count data, the MASS package glm.nb() function for negative binomial regression was used in R version 3.0.0.

RESULTS

Geographic, Demographic, and Crop Information

We received 229 surveys, a response rate of 60.3%. Of the returned surveys, 192 respondents reported releasing finished cultivars, including inbred lines. All conclusions are drawn from these 192 respondents, for a useable response rate of 50.5%. Geographic representation throughout the United States was evenly dispersed, with responses from 41 states, plus the territory of Puerto Rico. Distribution of respondents based on the USDA Economic Research Service (ERS) Farm Production Regions is shown in Fig. 1. The Southeast had the highest proportion of respondents with 13.5%. The Tropics (Hawaii and Puerto Rico) had the lowest proportion of respondents with 2.6%. The majority of respondents work with field crops (53.4%), with 25.7% working with vegetables and pulses, and 20.9% working with fruits, nuts, trees, and ornamentals (Table 1). When categorized by crop biology, 42.9% of respondents work with pure line crops, 28.8% work with clonal crops, 20.9% work with hybrid crops, and 7.3% work with crops that can be developed as both hybrid and pure line.

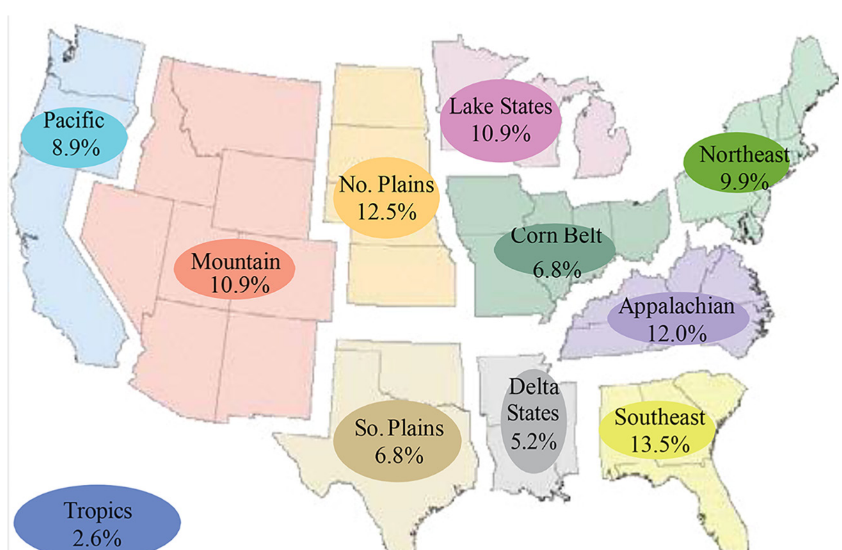

Fig. 1. Percentage distribution of public plant breeding survey respondents developing finished cultivars (including inbred lines) based on USDA ERS Farm Production Regions.

Table 1. Percentage distribution by crop type, crop biology, institution, tenure, and emeritus status for public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015.

Category	N	Percentage of total
		%
Crop type		
Field crops	102	53.4
Fruits, nuts, trees, and ornamentals	40	20.9
Vegetables and pulses	49	25.7
Total	191	100.0
Crop biology		
Both hybrid and pure line	14	7.3
Clonal	55	28.8
Hybrid	40	20.9
Pure line	82	42.9
Total	191	99.9†
Institution		
LGU/SAES	159	83.7
USDA–ARS	31	16.3
Total	190	100.0
Tenure		
Yes	137	72.1
No	53	27.9
Total	190	100.0
Emeritus		
Yes	9	4.8
No	178	95.2
Total	187	100.0

† Percentage does not equal 100 due to decimal rounding.

The number of years worked as a plant breeder in the public sector was skewed, with more than half of respondents (55.0%) working for 21 yr or more (Fig. 2). The percentage of breeders who have worked in the public sector for 0 to 5, 6 to 10, 11 to 15, and 16 to 20 yr were 6.3, 15.2, 11.0, and 12.6%, respectively. The majority of respondents had been awarded tenure at their institution (72.1%), and only 4.8% held emeritus status (Table 1). Most respondents worked at LGUs or SAES (83.7%), with the remaining 16.3% employed by USDA ARS (Table 1). This distribution is consistent with Frey's observation that the USDA had made a commitment to minimize its role in cultivar development in the 1970s (Frey, 1996). Frey's report found that 12% of USDA scientist years were dedicated to cultivar development, with the remainder focusing on basic plant breeding research and genetic enhancement (Frey, 1996).

Respondents reported releasing 3703 finished cultivars, including inbred lines. Not surprisingly, as the number of years worked as a plant breeder increased so too did the average number of cultivars released, ranging from 1.5 (±0.4) cultivars released by respondents working in the public sector for 0 to 5 yr, to 25.7 (±3.1) cultivars released by respondents working in the public sector for 21 yr or more (Fig. 3). Regression analysis demonstrated that

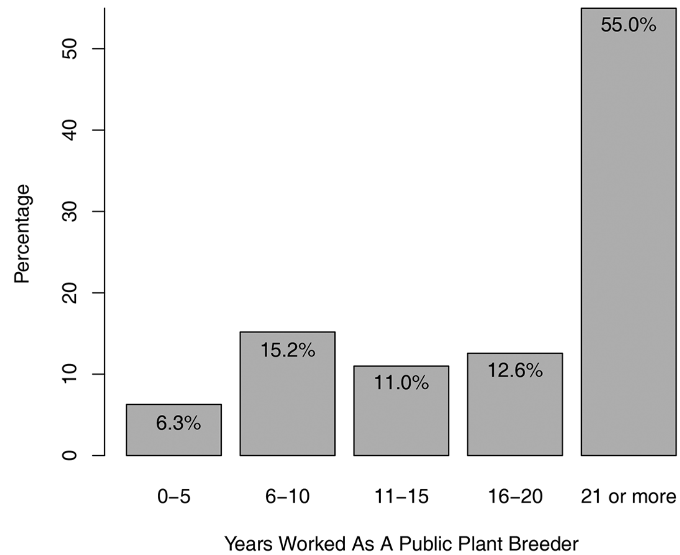

Fig. 2. Percentage distribution† of number of years worked as a public plant breeder for respondents releasing finished cultivars (including inbred lines) and surveyed in 2015 (*N* = 191).

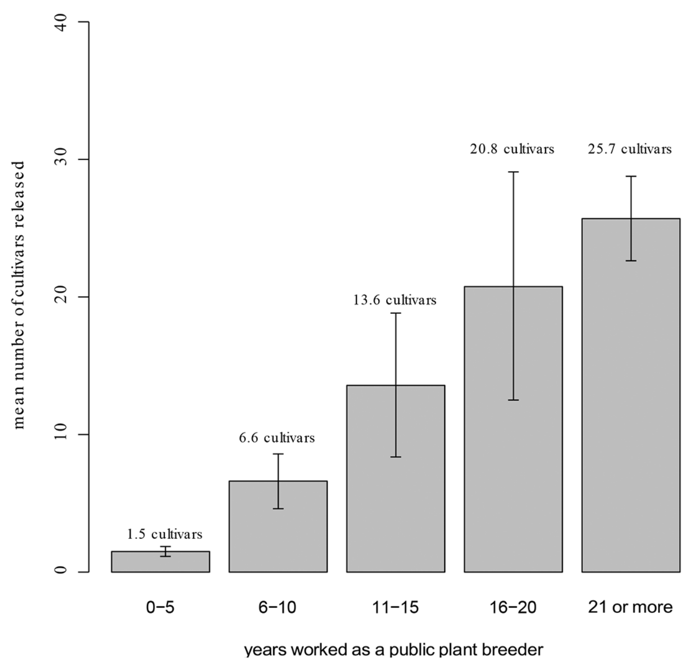

Fig. 3. Mean number of finished cultivars (including inbred lines) released by respondents surveyed in 2015, distributed by number of years worked as a public plant breeder (*N* = 191).

the number of cultivars released was significantly affected by years worked as public plant breeder ($p < 0.001$), annual operating budgets ($p < 0.001$), and crop biology ($p < 0.001$).

Germplasm Usage and Exchange

Nearly half of respondents (49.4%) reported that germplasm from other public breeding programs was their most used source for breeding material (Fig. 4). Another 24.7% reported that material from the USDA national

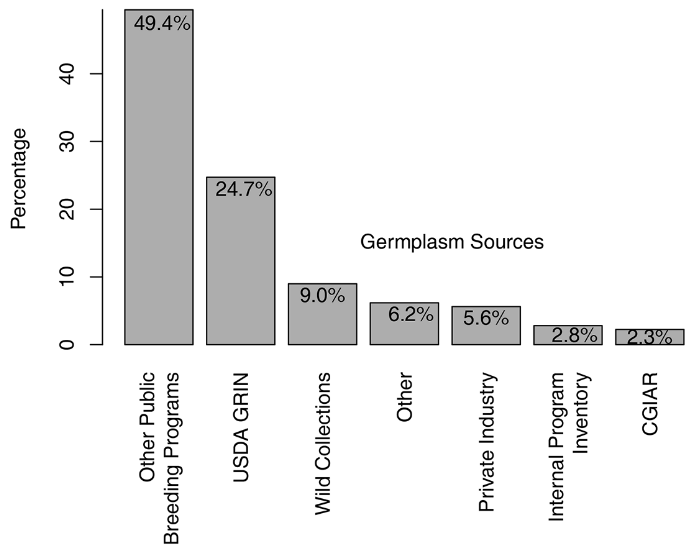

Fig. 4. Percentage response to the question "Which of the following germplasm sources do you use the most?" by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015 (*N* = 179).

plant germplasm system was their most used source. The remaining germplasm sources (private industry, CGIAR genebanks, field collections, internal program, and other) constituted the main source for <10% each of respondents. Respondents overwhelmingly reported sharing their germplasm with other breeders (94.8%), and 61.0% indicated that their germplasm was "always" or "mostly" shared with an accompanying MTA (Table 2).

When asked how the language of the MTAs impacted their freedom to operate as a plant breeder, 67.7% of respondents indicated that their freedom to operate was either "strongly" or "somewhat" restricted (Table 2). Only 4.8% of respondents indicated that their freedom to operate was either "somewhat" or "strongly" improved by the MTA language. Further investigation of specific components of MTAs indicated that the likelihood of restrictive language varied by both the type of germplasm usages allowed and the type of crop to which it applied (Table 3). In general, MTAs were likely to restrict the recipient of the germplasm from using the material for commercialization of shared and derived material, as well as further selection. However, MTAs for vegetables and pulses had only a 55% likelihood of restricting usage on the commercialization of derived material and further selection. Field crop MTAs were the most likely to be restrictive on use of the germplasm as a recipient for gene transfer and as a recurrent parent (70.8 and 74.2%, respectively) relative to the other crop types. Among all crop types, there was a somewhat equal likelihood that saving seed would be either allowed or restricted. Fruits, nuts, trees, and ornamentals had a 70.1% likelihood of using restrictive language on further crossing and selection, while field crops and vegetables and pulses were less likely to be restrictive (47.9 and 45.0%, respectively). Finally, among all crop types, MTAs tended to not be restrictive on field testing or phenotyping, marker based genotyping, and use of sequences or genes.

Intellectual Property Rights

More than two-thirds of survey respondents (71.7%) indicated that their cultivars were protected with IP "always" or "most of the time" (Table 4). The IP for plant cultivars include utility patents, plant patents, plant variety

Table 2. Germplasm usage and exchange reported by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015.

Survey question	N	Percentage
		%
Do you share germplasm with other breeders?		
Yes	182	94.8
No	10	5.2
Total	192	100.0
How do often does germplasm leave your institution with a material transfer agreement (MTA)?		
Always	48	26.4
Mostly	63	34.6
Sometimes	48	26.4
Rarely	13	7.1
Never	10	5.5
Total	182	100.0
How does the language of the MTA that you receive impact your freedom to operate as a plant breeder?		
Strongly restricts	25	15.0
Somewhat restricts	88	52.7
Neither restricts nor improves	47	28.1
Somewhat improves	4	2.4
Strongly improves	3	1.8
Total	167	100.0

Table 3. Likelihood of restrictive language found in material transfer agreements used to exchange germplasm by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015.

Specific uses for germplasm exchanged	Likelihood of restrictive language	Log odds	SE
	%		
Commercialization (derived material)			
Field crops	65.9	0.66**	0.22
Fruits, nuts, trees, ornamentals	79.4	1.35**	0.42
Vegetables and pulses	55.0	0.20	0.32
Commercialization (shared material)			
Field crops	77.8	1.25***	0.25
Fruits, nuts, trees, ornamentals	97.1	3.50***	1.02
Vegetables and pulses	80.5	1.42***	0.39
Further selection			
Field crops	83.9	1.65***	0.28
Fruits, nuts, trees, ornamentals	67.6	0.74*	0.37
Vegetables and pulses	55.0	0.20	0.32
Use as a recipient for gene transfer			
Field crops	70.8	0.89***	0.23
Fruits, nuts, trees, ornamentals	61.8	0.48	0.35
Vegetables and pulses	51.3	0.05	0.32
Use as a recurrent parent			
Field crops	74.2	1.06***	0.24
Fruits, nuts, trees, ornamentals	64.7	0.61	0.36
Vegetables and pulses	47.5	–0.10	0.32
Saving seed			
Field crops	48.9	–0.04	0.21
Fruits, nuts, trees, ornamentals	63.6	0.56	0.36
Vegetables and pulses	52.5	0.10	0.32
Crossing and selection			
Field crops	47.9	–0.09	0.21
Fruits, nuts, trees, ornamentals	70.1	0.88*	0.38
Vegetables and pulses	45.0	–0.20	0.32
Field testing or phenotyping			
Field crops	14.0	–1.82***	0.30
Fruits, nuts, trees, ornamentals	32.4	–0.74*	0.37
Vegetables and pulses	10.0	–2.20***	0.53
Marker based genotyping			
Field crops	24.2	–1.14***	0.24
Fruits, nuts, trees, ornamentals	20.6	–1.35**	0.42
Vegetables and pulses	15.4	–1.70***	0.44
Use of sequences or genes			
Field crops	36.8	–0.54*	0.22
Fruits, nuts, trees, ornamentals	30.3	–0.83*	0.38
Vegetables and pulses	30.8	–0.81*	0.35

* Significant at 0.05 probability level; ** Significant at 0.01 probability level; *** Significant at 0.001 probability level.

protection (PVP) certificates, trademarks, and licenses. Not surprisingly, breeders of fruits, nuts, trees, and ornamentals are most likely to protect cultivars with plant patents (86.5%), which are available only for clonal crops, and trademarks (65.7%) (Table 5). Breeders of field crops and vegetables and pulses are most likely to protect cultivars with PVP certificates (85.4 and 85.3%, respectively). The likelihood is low among all crop groups that public plant breeders will use utility patents, ranging from 3.3% for fruits, nuts, trees, and ornamentals to 20.9% for field crops. However, the likelihood is high among all crop groups that public plant breeders will use licenses, ranging from 77.1% for fruits, nuts, trees, and ornamentals to 79.4% for vegetables and pulses.

To assess the effect of IP, plant breeders were asked if their freedom to operate was impacted by the IP currently used by the public seed sector and the private seed industry. More than half of respondents (55.7%) reported that the IP currently used by the public seed industry "strongly" or "somewhat" restricts their freedom to operate, and only 4.3% of respondents reported that it "somewhat" or "strongly" improves their freedom to operate (Table 4).

Table 4. Intellectual property (IP) usage and effects reported by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015.

Survey question	*N*	Percentage
		%
How often are your cultivars protected with IP?		
Always	85	44.0
Most of the time	53	27.7
Sometimes	28	14.7
Rarely	4	2.1
Never	22	11.5
Total	192	100.0
How does IP in the public seed sector impact freedom to operate?		
Strongly restricts	24	13.0
Somewhat restricts	79	42.7
Neither restricts nor improves	74	40.0
Somewhat improves	3	1.6
Strongly improves	5	2.7
Total	185	100.0
How does IP in the private seed industry impact freedom to operate?		
Strongly restricts	57	30.5
Somewhat restricts	63	33.7
Neither restricts nor improves	62	33.2
Somewhat improves	3	1.6
Strongly improves	2	1.1
Total	187	100.1†
Describe your relationship with the technology licensing office.		
Extremely negative	8	4.3
Somewhat negative	18	9.8
Neither negative nor positive	31	16.8
Somewhat positive	64	34.8
Extremely positive	63	34.2
Total	184	99.9†

† Percentage does not equal 100 due to decimal rounding.

Table 5. Likelihood of usage of various forms of intellectual property rights to protect cultivars (including inbred lines) released by public plant breeder respondents and surveyed in 2015.

Forms of intellectual property rights	Likelihood of usage	Log odds	SE
	%		
Utility patent			
Field crops	20.9	−1.33***	0.30
Fruits, nuts, trees, ornamentals	3.3	−3.37***	1.02
Vegetables and pulses	6.7	−2.64***	0.73
Plant patent			
Field crops	12.5	−1.95***	0.38
Fruits, nuts, trees, ornamentals	86.5	1.86***	0.48
Vegetables and pulses	9.7	−2.23***	0.61
Trademark			
Field crops	11.1	−2.08***	0.40
Fruits, nuts, trees, ornamentals	65.7	0.65	0.36
Vegetables and pulses	25.8	−1.06*	0.41
Plant variety protection certificate			
Field crops	85.4	1.78***	0.31
Fruits, nuts, trees, ornamentals	34.4	−0.65	0.37
Vegetables and pulses	85.3	1.76***	0.48
License			
Field crops	78.2	1.28***	0.27
Fruits, nuts, trees, ornamentals	77.1	1.22**	0.40
Vegetables and pulses	79.4	1.35**	0.42

* Significant at 0.05 probability level; ** Significant at 0.01 probability level; *** Significant at 0.001 probability level.

When asked about the impact of the IP currently used by the private seed industry on their freedom to operate, 64.2% felt that it "strongly" or "somewhat" restricts their freedom to operate, and 2.7% of respondents reported that it "somewhat" or "strongly" improves their freedom to operate. Approximately one-third of respondents remained neutral on both questions, in part because of an error in the question wording that referred to the "public seed sector" and "private seed industry", which unintentionally excluded breeders of clonal crops that do not work with seeds.

Finally, plant breeders were asked to describe their relationship with their technology licensing office (TLO), which is an agency associated with most public institutions that is responsible for the application, execution, and enforcement of any IP. In general, survey respondents reported a good relationship with their TLO, with 69.0% describing the relationship as "somewhat" or "extremely" positive, and 14.1% describing the relationship as "somewhat" or "extremely" negative (Table 4).

Breeding Program Funding

Across all crop types, almost a quarter (24.1%) of public plant breeding programs releasing finished cultivars (including inbred lines) had annual operating costs between $100,000 to $199,000 (Table 6). Another 22.5% of programs had annual operating costs less than $100,000. The remaining distribution included $200,000 to $299,000 (19.3%), $300,000 to $399,999 (10.2%), $400,000 to $499,000 (10.7%), and $500,000 or more (13.4%). When broken down by crop type, field crops and vegetables and pulses followed this distribution somewhat closely. Operating costs for fruits, trees, nuts, and ornamentals, however, had a higher percentage of programs operating at the tail ends of the distribution, with 61.6% of programs with operating costs of $199,000 or less, and 20.5% of programs with operating costs of $500,000 or more. When analyzed by years work as a public plant breeder, some interesting trends emerge. For respondents that have worked as a public plant breeder for 0 to 5 yr, none had programs with operating costs of more than $500,000 (Table 6). For those that have worked for 6 to 10 yr, the highest percentage of respondents (39.3%) had an annual operating cost of $200,000 to $299,000. The majority of respondents working for 11 to 15 yr and 16 to 20 yr had annual operating costs of $100,000 to $199,999 (30.0 and 41.7%, respectively). Not surprisingly, the highest percentage of respondents with operating costs of $500,000 or more had

Table 6. Cross tabulation of annual operating cost of public breeding programs for various factors including crop type, survey respondents' view of how well funded their breeding program is, royalties generated, satisfaction with royalty distribution, and years worked as a public plant breeder.

		Annual operating cost of public breeding program					
Crop type	*N*	Less than $100,00	$100,000–$199,999	$200,000–$299,999	$300,000–$399,999	$400,000–$499,999	$500,00 or more
		%					
All	187	22.5	24.1	19.3	10.2	10.7	13.4
Field crops	100	20.0	22.0	23.0	12.0	12.0	11.0
Fruits, trees, nuts, and ornamentals	39	30.8	30.8	15.4	2.6	0.0	20.5
Vegetables and pulses	48	20.8	22.9	14.6	12.5	16.7	12.5
Years worked as a public plant breeder							
0–5 yr	11	27.3	27.3	9.1	9.1	27.3	0.0
6–10 yr	28	25.0	14.3	39.3	10.7	0.0	10.7
11–15 yr	20	20.0	30.0	25.0	15.0	5.0	5.0
16–20 yr	24	20.8	41.7	12.5	8.3	8.3	8.3
21 yr or more	103	22.3	21.4	14.6	9.7	13.6	18.4
Do you feel your program is:							
Very or somewhat under-funded	100	34.0	30.0	17.0	10.0	4.0	5.0
Neither under nor well funded	37	13.5	27.0	18.9	8.1	16.2	16.2
Very or somewhat well funded	48	6.3	10.4	22.9	12.5	20.8	27.1
Does your program generate royalties?							
Yes	133	15.8	22.6	22.6	9.8	13.5	15.8
No	48	43.8	31.3	4.2	12.5	4.2	4.2
Satisfaction with royalty distribution:							
Very or somewhat dissatisfied	43	14.0	18.6	16.3	18.6	18.6	14.0
Neither dissatisfied nor satisfied	23	8.7	30.4	21.7	0.0	13.0	26.1
Very or somewhat satisfied	62	19.4	22.6	25.8	6.5	11.3	14.5
Will your position be replaced?							
Yes	77	9.1	13.0	23.4	14.3	15.6	24.7
No	43	41.9	25.6	9.3	11.6	2.3	9.3
Unsure	59	27.1	39.0	18.6	3.4	11.9	0.0

been working as public plant breeders for 21 yr or more (18.4%).

When asked if public plant breeders felt that their program was under or well-funded, 54.1% felt that their program was "very" or "somewhat" under-funded, and 25.9% felt that their program was "very" or "somewhat" well-funded. Not surprisingly, 64.0% of respondents with breeding programs that had annual operating costs of $199,000 or less felt their program was "very" or "somewhat" under-funded, while 47.9% of respondents with breeding programs that had annual operating costs of $400,000 or more felt their program was "very" or "somewhat" well-funded (Table 6). Respondents reported various funding sources for their breeding programs, with an average distribution of 24.1% (±2.2%) funding from employers, 17.8% (±2.2%) from commodity check-off programs, 14.2% (±1.3%) from USDA competitive grants, 12.3% (±1.5%) from royalty money, 12.3% (±1.4%) from private industry, 11.6% (±1.5%) from federal formula funds, and 7.6% (±1.3%) from other sources (Table 7).

Nearly three quarters of respondents (73.5%) released cultivars or inbred lines that generated royalties. Royalty money was distributed, on average, to the following recipients: 29.9% (±2.3%) to the plant breeder's institution, 26.1% (±2.4%) to the plant breeder's program, 19.1% (±1.5%) as personal income to the plant breeder, 10.3% (±1.2%) to the plant breeder's department, and 14.6% (± 2.1%) to other recipients (Fig. 5). Almost half of the respondents (48.4%) were either "somewhat" or "very" satisfied with the distribution of royalty money at their particular institution (Table 6).

Table 7. Mean percentage distribution of funding sources for breeding programs based on public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015 (*N* = 177).

Funding source	Mean	SE
	%	
Employer	24.1	2.2
Commodity check-off programs	17.8	2.2
USDA competitive grants	14.2	1.3
Royalty money	12.3	1.5
Private industry	12.3	1.4
Federal formula funds	11.6	1.5
Other	7.6	1.3

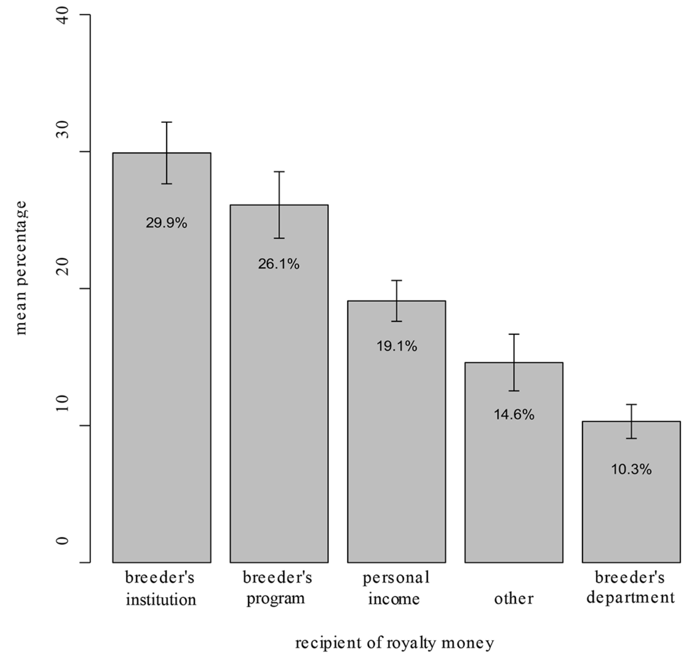

Fig. 5. Mean percentage distribution of royalty money earned by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015 (*N* = 129).

Finally, public plant breeders were asked if particular funding sources from grants, private industry, and royalties impacted the focus of their breeding work. Grant funding appears to have the biggest impact, with 30.0% of respondents indicating that it impacts the focus of their breeding work "quite a bit" (Table 8). While 29.0% of respondents chose "not at all" when asked the impact of private industry funding on their breeding work, another 46.2% indicated that it had "a little" or "some" impact. Royalty money has the smallest influence, according to respondents, with 52.9% choosing "not at all" when asked about its impact on their breeding work (Table 8).

Table 8. Impact of funding sources on focus of breeding work reported by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015.

	Funding sources					
	Grants		Private industry		Royalties	
Impact on focus of breeding work	N	Percentage	N	Percentage	N	Percentage
		%		%		%
Not at all	23	12.3	54	29.0	99	52.9
A little	38	20.3	41	22.0	37	19.8
Some	52	27.8	45	24.2	19	10.2
Quite a bit	56	30.0	27	14.5	23	12.3
A great deal	18	9.6	19	10.2	9	4.8
Total	187	100.0	186	99.9†	182	100.0

† Percentage does not equal 100 due to decimal rounding.

Institutional Support

Public plant breeder respondents developing finished cultivars (including inbred lines) reported spending, on average, 15.6% (±1.2%) of their time on basic research, 37.9% (±1.6%) on applied research, and 46.5% (±1.8%) on cultivar development (Table 9). They also reported employing an average number of 2.9 (±0.2) undergraduate students, 2.2 (±0.1) graduate students, 1.7 (±0.1) field technicians, 0.7 (±0.1) lab technicians, 0.5 (±0.1) post-doctoral students, and 0.4 (±0.1) other positions in their plant breeding programs (Table 10). Among the public plant breeder respondents that work for institutions that offer tenure (n = 153), 85.0% reported that cultivar development counts toward the tenure process (Table 11). In addition, 80.7% of respondents stated that their institution either "somewhat" or "strongly" encourages their cultivar development work. However, when asked if their institution would continue their cultivar development work if they were to leave their job for any reason, 43.3% responded "yes", 23.9% responded "no", and 32.8% were unsure (Fig. 6). Looking more specifically at the annual operating cost of breeding programs and its impact on institutional support, 40.3% of respondents who believed that their position would be maintained managed breeding programs with budgets of $400,000 or more, while 67.5% of respondents who felt that their position would be eliminated operated breeding programs with budgets of $199,999 or less (Table 6). Among respondents who were unsure if their position would be replaced, 66.1% operated breeding programs with budgets of $199,999 or less, and 0.0% ran breeding programs of $500,000 or more (Table 6).

Table 9. Mean percentage of time distribution for public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015 (N = 155).

Time distribution	Mean	SE
	%	
Basic research	15.6	1.2
Applied research	37.9	1.6
Cultivar development	46.5	1.8

Table 10. Mean number of people employed by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015 (N = 176).

Position within plant breeding program	Mean no.	SE
Undergraduate students	2.9	0.2
Graduate students	2.2	0.1
Field technicians	1.7	0.1
Lab technicians	0.7	0.1
Post-doctoral students	0.5	0.1
Other	0.4	0.1

DISCUSSION

The objective of this study was to understand the current state of public cultivar development in the United States. Results indicate that public cultivar development is in a state of decline. With more than half of survey respondents (55%) employed as public plant breeders for 21 yr or more, there are not enough younger breeders working in the public sector today to maintain the current level of cultivar development as the most senior breeders retire. Developing finished cultivars is an iterative process than can take many years, so even a surge of new hires will not have an immediate impact on public cultivar development. Yet such an influx is unlikely, with 57% of respondents choosing either "unsure" or "no" when asked if they think that their institution will hire another breeder to continue their cultivar development work when they retire or otherwise leave the job. Breeders that felt sure that their position would continue often cited stakeholder support from commodity groups as a main motivation, as well as the positive image that accompanies plant breeding programs: "our breeding program has brought in excellent visibility to the university." For those that were less positive about the future of their position, funding challenges were often cited: "administrators say that plant breeders do not get enough grants to fund their work, so they have

Table 11. Institutional support reported by public plant breeder respondents releasing finished cultivars (including inbred lines) and surveyed in 2015.

Survey question	N	Percentage
		%
If you work for an institution that offers tenure, does cultivar development count towards the tenure process?	153	100.0
Yes	130	85.0
No	23	15.0
How much does your institution encourage your cultivar development work?	181	100.1†
Strongly discourages	1	0.6
Somewhat discourages	5	2.8
Neither encourages nor discourages	29	16.0
Somewhat encourages	65	35.9
Strongly encourages	81	44.8

† Percentage does not equal 100 due to decimal rounding.

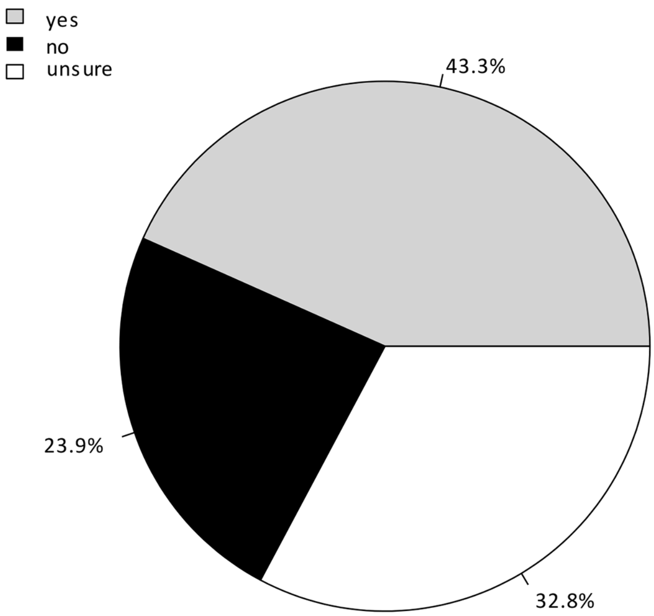

Fig. 6. Percentage response to the question "If you were to leave your job for any reason, will your position be replaced?" by public plant breeders respondents releasing finished cultivars (including inbred lines) and surveyed in 2015 (N = 180).

not been replaced. Twenty years ago my institution had seven plant breeders; we now have three."

In addition, based on number of survey respondents, certain regions of the United States appear to have fewer plant breeders releasing finished cultivars, including the Corn Belt, the Delta States, the southern Plains, and the Tropics. Areas such as the Corn Belt, in particular, have a large number of private breeders working on corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.], but this survey suggests that there are few public breeders releasing finished cultivars for alternative species such as cover crops or perennial crops for these regions. This narrow breeding focus encourages monoculture cropping systems, which have less resilience against increasing climactic and price fluctuations (Heinemann et al., 2013).

The expanded use of IP and restrictive licensing agreements in both the public and private sectors was a source of frustration for many survey respondents. As one respondent commented, "the change in the last 20 yr has been dramatic. In the 1990s, I could send a postcard to a research director or president of a major company and receive seed (with no or minimal restrictions) by return mail. Today such seed is simply unavailable." For public plant breeders working on crops that are also developed in the private sector, exchanging germplasm appears to be particularly challenging when genetically engineered varieties are available on the market. Soybean is a good example of this, with multiple respondents observing that "soybean germplasm sharing with the private industry is nonexistent." Such lack of access to elite germplasm places public breeders at a disadvantage for developing useful varieties for growers. This trend is evident when looking at farmer seed usage patterns. In 1980, 70% of the U.S. soybean land area was planted with seeds developed by the public sector, and by 1997, 70 to 90% of the land area was planted with private sector seeds (Fernandez-Cornejo and Caswell, 2006).

Survey respondents also reported difficulties when accessing germplasm from other public programs. Almost three-quarters (74.1%) of respondents indicated that their primary germplasm source came from other public breeding programs or the USDA national plant germplasm system. Yet 67.7% of survey respondents stated that the MTAs that they receive either "somewhat" or "strongly" restrict their freedom to operate. Specifically, there is a strong likelihood that the MTA will be restrictive on further selection—the very foundation of a breeding program. In addition, inconsistency in the way that technology transfer is handled at different universities adds to the challenge of germplasm exchange. As one survey respondent wrote, "universities have recently become more aggressive in protection of germplasm which requires more record keeping and a great deal of complexity in utilizing germplasm from different programs. There is no uniformity in regional nurseries MTAs or standard crop MTAs such as MTAs like the Wheat Workers Code of Ethics used to provide."

The majority of respondents (71.7%) reported that their cultivars were released with IP "always" or "most of the time." However, the likelihood of utility patent usage was low, and PVP certificates, plant patents (when applicable), and licenses were much more prevalent. Protecting cultivars with intellectual property provides an opportunity for income generation, and indeed royalties comprised, on average, 12.8% of the operating budget for public plant breeding programs. Yet IP also comes at a cost by hindering the exchange of germplasm as is noted above. With all forms of IP, the benefits of encouraging innovation with the reward of limited monopoly rights and a financial return on investment must be weighed against the cost incurred by society when competitors are excluded from producing, selling, and, in some cases, breeding with the protected cultivar (Boyle, 2008). Identifying the socially optimal level of IP for cultivars developed with public funds remains an unanswered question.

Yet there is no question that funding levels must increase for more public cultivar development programs to remain viable. Funding levels are positively correlated with the number of cultivars released, and the highest percentage of breeders (24.7%) who stated that their university would maintain their position had operating budgets of $500,000 or more. Increasing USDA grant funding opportunities and federal formula fund allocations are possible avenues, although federal and state allocations to agricultural research and development are in decline. Re-distribution of royalty funds could potentially off-set some of these funding challenges, with survey respondents reporting that only 26.1%, on average, of royalty money is returned to the plant breeder's program. Simplifying the MTA and IP processes that are used by the technology licensing offices, and re-evaluating the efficacy of returning royalty funds to the plant breeder as personal income, could allow for a higher return of royalty money directly to cultivar development programs. With a majority of public plant breeders (69.0%) reporting a positive relationship with their technology licensing offices, and an even higher percentage (80.7%) indicating that their university either "somewhat" or "strongly" supports their cultivar development work, negotiating these changes seems feasible.

The challenges are formidable, however, especially in regards to translating words of support into the actual dollars required to hire support staff, equip labs with modern technology, and maintain the field locations and machinery that every breeder needs to successfully develop new cultivars. Some inconsistencies of the survey responses suggest the relationships that public plant breeders have to their institution, one another, and the private industry are complex. For example, more than half of the survey respondents were not confident that their position would be maintained once they retired or otherwise left their job, yet they overwhelmingly indicated that their institution supports their cultivar development work. Survey respondents were guaranteed anonymity, so it is unlikely that they feared retribution for responses that reflected negatively on their employer. Perhaps this incongruity suggests that currently breeders feel supported, but anticipate a darker future with fewer breeders and institutional resources. When asked about germplasm exchange, 5.2% of respondents reported that they do not share germplasm with other breeders. While this percentage is quite low, it still is somewhat surprising. Without further conversations with these respondents, it is impossible to know if this is because the question was misunderstood, or if breeders have had such negative experiences with germplasm sharing that they are no longer willing to do so. While it is beyond the scope of this survey or the intentions of the authors to further speculate, it does indeed suggest that individual experiences of public plant breeders vary widely and no single solution will solve the diverse needs of public breeders throughout the United States. Yet there is no doubt that a significant increase of funding dedicated to public cultivar development would be a good start.

CONCLUSION

Public plant breeders play a critical role in determining the future of agriculture. Their work is varied, and includes long-term research in areas such as assessing and broadening genetic diversity, introgression of traits from wild species, development of new breeding methodologies, and expanding applications for genomic tools. Public plant breeders are responsible for the education of the next generation of plant breeders (both public and private), and require active breeding programs to provide hands-on learning for students, from initial crosses through the release process. In this study, we have focused on their role in cultivar development. Plant breeders in the public sector often focus on minor crops, cover crops, perennial crops, and geographies and farming systems that are under-served by the private sector. By improving these crops, regions and systems with well-adapted varieties, public plant breeders create a more resilient agricultural landscape that buffers against the increasing climactic and economic fluctuations of the 21st century. Yet plant breeding in the public sector is in a current state of crisis due to lack of sufficient funding to support this public good. In addition, the increasing use of restrictive IP limits public plant breeders' access to useful germplasm necessary for the development of improved cultivars. Public plant breeders have an opportunity to address this challenge by working with their universities and technology licensing offices, and one another to reduce the restrictive nature of their licensing agreements, especially for germplasm exchange with other public programs, and by redistributing royalty money allocations to increase support directly for cultivar development.

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