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Engaging Farmer Stakeholders: Maize Producers' Perceptions of and Strategies for Managing On-Farm Genetic Diversity in the Upper Midwest

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Abstract: Debates about the genetic diversity of cultivated crops have riled the scientific community. While there have been studies on measuring genetic diversity among crop types, none have described on-farm genetic diversity in U.S. maize (*Zea mays*) because of patent restrictions. The approximately 36.5 million hectares of U.S. maize planted by farmers annually is carried out largely without them having knowledge of the seed genetic background. The literature shows a shrinking of genetic diversity in commercially available hybrids over time. Given the restrictions on the genetic information given to farmers about their maize seed and the risk it poses to their landscape, we conducted twenty exploratory interviews with farmers in the Upper Midwest regarding their perspectives of and strategies for managing on-farm genetic diversity in their maize crop. The data gathered suggest five themes: (1) managing surface diversity by planting multiple varieties; (2) navigating seed relabeling; (3) lacking clear access to genetic background information; (4) reliance on seed dealers when selecting varieties; and (5) limited quality genetics for organic systems. This study concludes that the lack of access to genetic background data for public researchers, including the United States Department of Agriculture and farmers, does not allow for vulnerability assessments to be carried out on the landscape and puts farmers at risk to crop failure.

Keywords: maize; corn; *Zea mays*; monoculture; on-farm diversity; genetic diversity

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1. Introduction

The maize (*Zea mays*) germplasm has changed from a public resource that co-evolved with humans for the past 9000 years to a privatized commodity in the last 100. Patent restrictions are enabling private companies to control the management of these resources that humanity relies on for survival. Today, approximately 92% of maize planted in the U.S. is genetically modified and patented [1]. These patents mean that the seed and details about the genetic background of the seed planted on farms is not controlled by farmers but by four agrochemical companies whose patents restrict research on the genetic basis of the standing crop [2]. Furthermore, when farmers have control of their seed and knowledge of their genetic background, this plays an important role in both maintaining and evolving the genetic diversity of maize [3]. Over twenty years ago, before we saw the highest levels of concentration in the seed industry at any time in history, the literature showed a concerning narrowing of diversity in the genetic background of maize grown in the U.S. This begs the question: where are we now? The narrowing of crop species diversity at the landscape level has been a trend in the U.S. from 1978 to 2012 [4]. This narrowing, along with increased reliance on monoculture production, is particularly acute in the case of U.S. maize production in the Upper Midwest.

"Corn is King" in the Upper Midwest [5] and it blankets much of the agricultural landscape, with over 19.5 million hectares concentrated in the region in 2017. Additionally, its "queen" is unarguably soybean [6]. Seventy percent of the region's cropland is planted continuously as maize or in a maize–soybean rotation [7].

Over the last fifty years, the Upper Midwest region has radically transformed [5,8]. In Iowa, for example, the diverse cropping systems of the past and the extreme change in landscape have occurred over a relatively short time period. Keller and Brummer [8] showed a 9-square-mile aerial image of a Humboldt County, Iowa, farmscape in 1953 and 1999. The landscape was transformed from one planted with five or six crops to one planted with predominately maize and soybean and consolidated by the loss of 12 farmsteads [8].

This is a cause for concern, as planting only one species on the landscape exposes farmers to biological and climatic risks and decreases water quality [6]. Today, farmers have the added struggle of the increased intensity and frequency of extreme weather events resulting from the changing climate. Projections suggest that maize and soybean yields will decline with the increasing temperatures, droughts, and severe storms occurring in the region [6,9,10]. One agronomic tool at farmers' disposal to deal with these challenges is to expand the plant diversity in their fields, which could improve the quality of the soil, water, and air and reduce the incidence of pests and diseases [6,9,11].

However, crop diversity and monoculture are only the aspects we can see at the surface level. Below the surface is genetic diversity, and describing this in maize monoculture concentrated in the Upper Midwest is of particular interest because the region is planted with hybrid varieties.

The first hybrid maizes were developed and commercialized in the 1920s. These varieties were largely tailored to the Upper Midwest region, though farmers were slow to adopt them, instead continuing to plant open-pollinated varieties [12]. Anecdotally, the severe droughts of 1934 and 1936 drove farmers to rapidly adopt maize hybrids because the plants performed well in the drought conditions. From then, farmers' adoption of maize hybrids and the seed industry grew rapidly in the 1930s and 1940s both in size and in regionality [12,13]. By 1960, ninety percent of U.S. maize planted was hybrid varieties [14].

The U.S. regional diversity of on-farm maize hectares drastically changed with the shift from open-pollinated to hybrid varieties [15]. Prior to the broad adaption of hybrid maize in the 1930s and 1940s, farmers planted open-pollinated maize. According to Martin and Leonard [16], there were over 1000 different maize cultivars grown throughout the U.S. in the early 1900s. Early in the development of hybrid maize, plant breeders selected popular open-pollinated varieties that were widely adapted to the region to develop inbred lines for hybridization. This original selection and self-pollination of open-pollinated plants began the narrowing in genetic diversity that today's hybrid development is built upon [17].

The relationship between maize hybrid monoculture and on-farm genetic diversity cannot be ignored. Hybrids are created by crossing two genetically different inbreds. Inbreds are highly homozygous and developed by double haploid technology or the iterative process of self-pollination. [13,18]. Crossing two unrelated inbreds results in a hybrid in which all the plants are highly heterozygous but the population of plants is highly homogeneous. This offers farmers and processors a high degree of uniformity and predictability in terms of crop and product performance. However, when replicated across expansive landscapes, narrow parental diversity also amplifies the risks of monoculture and makes farmers vulnerable to major yield and crop losses [15].

About 95% of U.S. maize grown today is hybrid, and most varieties are protected under U.S. patents and/or Plant Variety Protection (PVP) [19]. Proprietary hybrids protected by PVP expire (ex-PVP) and become available to the public for breeding and research after 20 years [19]. The availability of inbreds has allowed public sector researchers to assess the genetic composition of ex-PVPs, and this literature indicates a trend in narrowing diversity in the hybrids sold over 20 years ago and the need for more analyses [19–21].

Mikel and Dudley [19] surveyed the genetic lineage of 908 inbreds with expired PVPs representing 80% of the protected germplasm and 90% of hybrids being sold. They found that of the 43 inbreds with the most patent "hits", three are public founder lines: B73, A632, and Mo17 [19]. Of these, B73 received the most patent hits of any commercial or public line and was the pivotal contributor to all Stiff Stalk lines surveyed [19]. They concluded that breeders were largely recombining the most elite lines to develop new products, which would decrease genetic diversity over time. Their research was a snapshot of germplasm diversity from 20 years before their publication and 35 years prior to this article.

Van Herwaarden et al. [21] analyzed the effects of diversity, ancestry, and selection on the North American commercial maize genome. They used germplasm from the USDA National Plant Germplasm System and divided the accessions into four eras: early landraces, inbreds pre-1950, inbreds from the 1960s and 1970s, and ex-PVP commercial inbreds from the 1980s and 1990s [21]. They found that the modern heterotic groups were largely derived from one common landrace population. In line with Mikel and Dudley's findings, their data showed that while breeding efforts created differentiation among breeding pools, breeding consisted of intermating elite and closely related inbreds and selecting among the progeny. The result was decreased diversity in the ancestry of individual lines [21]. Their 2012 findings are just a snapshot of the diversity.

Coffman et al. [20] conducted a high-density haplotype analysis on 212 maize inbreds to understand the haplotype sharing between ex-PVPs and major founding lines. A haplotype is a group of genes within an organism that are inherited together from a single parent. They found that 81.6% of the ex-PVP genome is shared with one of 12 founder lines. Further, their data show that 59.6% of the ex-PVP genome is shared with three lines: B73, Mo17, and Ph207 [20]. Three companies own 143 out of the 157 ex-PVPs that Coffman et al. [20] analyzed: Corteva, Bayer, and Syngenta. Within these three companies, B73, Mo17, and Ph207 share haplotypes with ex-PVPs in 53% of the DowDuPont germplasm, 62.9% of Monsanto's, and 69.7% of Syngenta's [20]. Recent mergers and acquisitions have resulted in three companies owning the majority of the germplasm from the most important legacy breeding programs of 19 individual companies [20].

Analyses of genetic diversity of the ex-PVP germplasm, offering a snapshot from 20 years ago, have elicited concerns and calls for additional research. However, more analyses, particularly of hybrids planted in farmers' fields today, are not possible outside of the highly consolidated private sector. In the U.S., federal intellectual property policies have helped to create the most concentrated seed industry in recent history, and the concentration levels are particularly significant in maize [22,23]. Four major companies controlled 85% of all maize seed in 2015, a nearly 35% increase in market share since 1988 [2]. These unprecedented levels of concentration, taken with the ex-PVP research literature, beg the question: what is the genetic diversity of maize in farmers' fields today?

The USDA's Maize Crop Germplasm Committee is charged with asking this question about the diversity of maize in farmers' fields, genebanks, and national collections. The National Plant Germplasm System (NPGS) creates crop germplasm committees to serve as subject matter experts to guide curatorial staff on best practices, including the priorities and techniques used for characterizing the collections. They also help review proposals that fund plant explorations and evaluation grants for scientific rigor. The Crop Germplasm Committees (CGC) are comprised of NPGS users and experts providing technical support to NPGS genebanks and collections. Perhaps the most important duty of the CGCs is to "Develop comprehensive Crop Vulnerability Statements and concise Crop Vulnerability Updates that assess a crop's or group of crop's vulnerabilities to specific threats, and the adequacy of the germplasm base for a crop or group of crops. These reports inform appropriate governmental and private agencies of the needs for broadening and strengthening each base via additional exploration, collection, acquisition of private collections, and evaluation" [24]. The most recent 'Maize Crop Vulnerability Statement' issued by the USDA's Maize Crop Germplasm Committee states: "The genetic health of the maize crop is a matter of National security. Thus, it is imperative that there is publicly available knowledge of the genetic diversity of the standing US maize crop. The genetic diversity of the standing US maize crop should be evaluated using DNA based tools. The maize crop germplasm committee recommends that such an evaluation take place as soon as possible" [24].

Despite these recommendations, patents on the U.S. maize supply restrict the USDA Maize Crop Germplasm Committee from assessing the genetic vulnerability of maize on the landscape. These same patents also restrict farmers from assessing the genetic vulnerability on their own hectares and yet they, and the food supply, are the ones at risk. Without access to genetic background information about the maize seed they plant, farmers' ability to understand and manage genetic diversity on their farm is limited and reliant on seed dealer recommendations. As the de facto managers of diversity on the land, farmers' opinions and capacity to manage that diversity are critical factors to understand.

The ability of farmers to manage surface-level diversity by planting multiple varieties in U.S. maize is complicated by seed relabeling. This marketing practice results in seed companies labeling the same maize hybrid under different names. The practice and its risks are so prevalent in the U.S. maize industry that the Farmers Business Network (FBN) has built a business offering farmers tools to navigate seed relabeling and genetic diversity. The company offers farmer members analytic tools, marketing products, seed and chemical inputs, financing, crop insurance, and health coverage. According to its website, "The FBN farmer-to-farmer network helps producers level the playing field by creating unprecedented transparency and competition . . . " [25].

FBN presents its analytic tools as "democratizing farm data". Among its many offerings is the FBN Seed Finder. The Seed Finder database is populated with information from seed tags submitted to the company by farmers in the network. Farmers send photos of their seed tags to FBN; these tags include the original variety name as per federal and state seed labeling regulations. The FBN analyzes the seed tags and uses this information to populate the Seed Finder database. According to their data, about half of all maize and soybean seed on the market is relabeled [26].

Due to the risk to the landscapes farmers manage and their livelihoods, as well as to provide data for a broad survey of farmers in the region, we conducted exploratory interviews with 20 maize producers regarding the degree to which they are able to assess and manage on-farm diversity in their maize hectares without this information about their seed. The participants represented a wide range of farm sizes and practices in Illinois, Iowa, Michigan, Minnesota, and Wisconsin. Interview data suggest five salient themes among farmer interviewees, including different perspectives and management techniques: (1) managing surface level diversity by planting multiple maize varieties each season; (2) awareness of and strategies for navigating seed relabeling; (3) no clear access to genetic background information about the maize seed they purchase; (4) importance of and reliance on relationships with seed dealers for selecting varieties for on-farm use; and (5) limited access to quality maize genetics for organic growers. Notably missing from these strategies is farmers' capacity to thoroughly manage the genetic background of maize hybrids on their landscape. Our findings provide important farmer perspectives that public researchers need to know in order to develop strategies for mitigating the risks of severe crop failure associated with genetic uniformity.

2. Materials and Methods

Interviews were exploratory in nature and farmers self-selected to participate in the research; therefore, these data are not generalizable. Instead, the goal of this research was to identify salient themes and unique perspectives among the subjects of the interviews to inform future research needs and questions. Interviews set out to answer the following questions: (1) What are Upper Midwest farmers' perceptions and strategies for managing on-farm diversity on their maize hectares? (2) Do farmers have the genetic information they need to make decisions about which maize varieties they plant? (3) What role are farmers playing in managing on-farm diversity in their maize hectares? Participant recruitment and interview methods followed approved Institutional Review Board (IRB) protocols.

Interview participants were identified by university researchers in Iowa, Minnesota, and Wisconsin who focus on conventional and/or organic farming and regional farmer organizations, including the Practical Farmers of Iowa (Iowa), the Minnesota Corn Growers

Association (Minnesota), the Wisconsin Farmers Union (Wisconsin), Organic Valley (Wisconsin), and Pipeline Foods (Minnesota). Research recruitment language was shared on the Organic Grain Resource and Information Network listserve and the Midwest Organic and Sustainable Education Service (MOSES) listserve and newspaper. All interested farmers who contacted the research team and were currently growing maize in the Upper Midwest participated in the interviews.

Interviews were conducted in person between July 2018 and March 2019 at locations chosen by the participants. Twelve interviews were conducted on participants' farms, two in restaurants near their farms, one at the University of Wisconsin-Madison, and five at the MOSES conference in La Crosse, Wisconsin. All interviews were conducted by one interviewer (McCluskey) using 16 standard questions. Questions did not follow the same order for each interview because of the exploratory nature of the research. Each farmer told their story and brought up themes and concepts in their own ways. The interviews lasted between one and two hours, were audio recorded, and were professionally transcribed.

Farmer participants represented a wide spectrum of farming practices and farm sizes, with the largest grower operating 2023 hectares and the smallest grower operating 32 hectares, as shown in Table 1. Collectively, the interview participants managed approximately 9451 hectares in this region. There is a considerable amount of demographic similarity among the interviewees. All the participants were white and all but one were male. Among the interviewees, 65% were between the ages of 35 and 64, 20% were under the age of 35, and 15% were over the age of 65. Three interviewees under the age of 35 were operating land with their parents and one was operating land with an older farmer as part of a transition plan. Nine interviewees farmed conventionally, eight were certified organic, and three practiced both conventional and organic farming methods.

Table 1. Farmer interviewee demographics.

Name	Location	Hectares *	Farming Practice	Gender	Age			Race
					<35	35–64	65<	
D.H.	Iowa	32	Organic	Male		X		White
M.B.	Illinois	34	Organic	Female		X		White
A.H.	Wisconsin	117	Organic	Male		X		White
D.K.	Wisconsin	121	Organic	Male		X		White
F.A.	Iowa	162	Conventional	Male		X		White
M.S.	Wisconsin	202	Conventional	Male		X		White
P.G.	Minnesota	263	Both	Male		X		White
R.R.	Iowa	283	Organic	Male			X	White
J.W.	Wisconsin	304	Organic	Male	X			White
J.B.	Iowa	324	Conventional	Male			X	White
D.M.	Minnesota	364	Conventional	Male		X		White
L.G. & K.G.	Iowa	486	Conventional	Male Male	 X	X		White White
R.H	Wisconsin	567	Conventional	Male		X		White
A.K.	Minnesota	607	Conventional	Male	X			White
M.D.	Wisconsin	728	Organic	Male		X		White
R.P.	Iowa	728	Conventional	Male		X		White
J.L.	Michigan	850	Both	Male		X		White
K.W.	Wisconsin	1255	Organic	Male			X	White
W.H.	Wisconsin	2023	Both	Male	X			White

* Hectares rounded to the nearest whole number.

Due to the amount of data and the exploratory nature of both the interviews and the research questions, a thematic analysis was conducted on the transcribed interviews [27–29]. Drawing on grounded theory, an inductive lens was used in coding and analysis to determine themes as presented by the farmers rather than fitting the farmer interview data into existing theories [27–29].

3. Results and Discussion

This section includes a summary and brief discussion of the five themes that emerged from the coding and analysis of the interview participant data, including: (1) planting multiple maize varieties as a surface level diversity management technique; (2) making management decisions informed by awareness of the seed relabeling practiced by industry; (3) lacking clear access to maize seed genetic background information; (4) purchasing maize varieties with reliance on seed dealer relationships; and (5) struggling to find quality maize genetics for organic systems.

The interviewees identified several practices for managing on-farm diversity in their maize, which largely consisted of rotating varieties. Nobody wanted to put "all their eggs in one basket" on the farm by planting a limited number of varieties. Additionally, some, but not all, considered the second level of diversity in their hybrids: the parental background. All farmers discussed some sort of management practice for their maize hectares, be it diligent record taking and long conversations with seed dealers or putting full faith in their dealers to make variety decisions. Taken together, these farmers had many nuanced perceptions about on-farm genetic diversity in their maize hectares. Their concerns varied based on the size of their farms and markets and they all had some sort of strategy for managing on-farm diversity, be it delegating another person to make those decisions or struggling to access information to manage it on their own.

3.1. Managing Surface Level Diversity by Planting Multiple Maize Varieties

All interviewees, whether conventional, organic, or a combination of both, planted multiple maize varieties on their land each year. When asked why, the majority of the farmers identified this as a management practice to spread risk. This was the case for farmers growing three or four varieties and in farmers growing six or seven varieties on a similar number of hectares, as presented in Table 2.

Table 2. Average total hectares, total maize hectares, and number of maize varieties planted per year by the interviewees.

Total Hectares *	Maize Hectares *	Number of Maize Varieties	Farming Practice
32	8	10–11	Organic
34	16	1	Organic
117	32–45	3	Organic
121	20	2–4	Organic
162	57	3	Conventional
202	45	3–5	Conventional
263	81–101	2–4	Both
283	73–81	6 or more	Organic
304	40–61	3–4	Organic
324	162	3–4	Conventional
364	243–283	4–5	Conventional
486	263	6–8	Conventional
567	263	2–10	Conventional
607	304	7	Conventional
728	121–243	5–6	Organic
728	656	4–5	Conventional
850	142	4–6	Both
1255	283	16	Organic
2023	850	5–7	Both

* Hectares rounded to the nearest whole number.

Regardless of the variance in the number of varieties planted by each grower per year, planting multiple varieties was clearly identified as a management strategy for diversifying maize hectarage.

Farmer R.P. worked as a Pioneer sales representative for 32 years before retiring recently before our interview. He shared this story about a local customer:

> *I had a customer and he was a large farmer. We had a very high-yielding hybrid and he wanted 100% of that. And it was 100% of his acres and I strongly discouraged him and told him every year is different even though it may have been the best for the last couple years. He decided he wanted all of that—he loved it. So, he plants 100% of it and we–this was before fungicides and stuff—and we got some diseases came in. And this hybrid happened to be very susceptible to one of them that came in. So, I get a call on Labor Day'—[R.P.], my corn just died.' So, I went over there, and it was dead. Obviously, if he wouldn't have 100% of that corn, he would only have 50% of the entire whatever—I mean another one may have been more resistant.*

Planting multiple varieties of maize represents the surface level of genetic diversity—the number of different varieties grown on the landscape each season. Only one of the farmers, who grew the second smallest number of maize hectares among the interviewees, discussed planting one maize variety across all of their hectares. This strategy emerged as a core management practice and is important to consider in the context of relabeling.

3.2. Awareness of and Strategies for Navigating Seed Relabeling

Smith [30] highlights the lack of genetic background information available to farmers and relabeling, which is the practice of multiple seed companies selling the same maize variety under different names. Our interview data indicate that relabeling is a practice that farmers should be aware of and that they must develop strategies to avoid unknowingly planting the same maize variety. This is important to farmers who manage surface-level on-farm diversity by planting multiple varieties each year, and in particular for those planting a limited number of varieties on their farms.

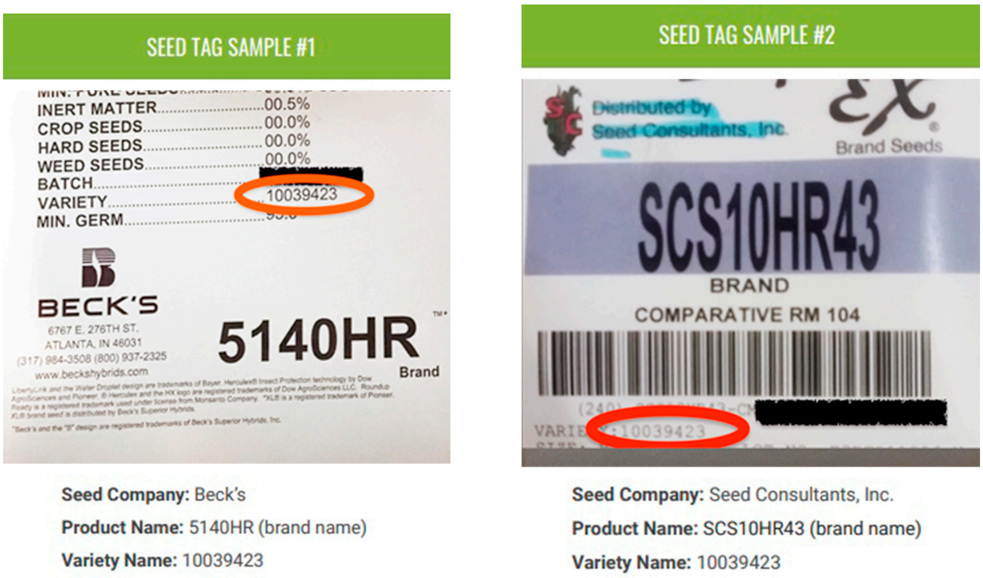
Five of the twenty interviewees shared that they had worked for seed companies in the past and drew on their own experiences to inform certain aspects of their management. This included the practice of seed relabeling, which one farmer talked about at length.

Farmer F.A. has lived and farmed in an area of Iowa where companies produce hybrid maize seed. He shared the following about working at a seed maize company in the area:

> *Two winters I worked for them. Bagging corn and I mean, you tell people that it's the same corn, but it went in four or five different companies' bags and they* [other farmers] *say, 'no, that's not possible.' They can't believe it . . . They figure each company has got their own germplasm and they don't want to believe it. And that's why I buy my corn from* [NAME OMITTED], *because when I went to school at Hawkeye, that's what the one instructor told us. Buy all your corn from one company and buy all your soybeans, because you're not going to be getting mixed.*

F.A. referred to the company where he purchased his maize seed from as a "mom and pop" establishment. He clearly identified seed relabeling, which some companies practice. As F.A. described, it is possible for a farmer to unknowingly purchase the same maize variety from different companies that has been labeled under different names. Given the strategy of planting multiple varieties to manage surface-level diversity, relabeling is a practice that farmers should be aware of and they must develop strategies to avoid unknowingly planting the same maize variety. This is important to farmers who manage surface-level on-farm diversity by planting multiple varieties each year, in particular for those planting a limited number of varieties on their farms.

About two months after we interviewed him at his farm office in Iowa, we received a text message from R.P. about FBN's Seed Finder (Figure 1): "*Got the login to get trait info on corn hybrids. Email is* [OMITTED]. *Password is* [OMITTED]. *Go to seed finder. Click on also sold as*."



(**a**) (**b**)

Figure 1. Two seed tags sent to FBN by farmers in their network. These tags are from two different seed companies who have given the same maize variety (10039423) two different product names: (**a**) seed tag sample from Beck's seed of variety 10039423 being sold as 5140HR; (**b**) seed tag sample from Seed Consultants, Inc. of variety 10039423 being sold as SCS10HR43 [31].

Farmer members can search varieties within the Seed Finder database and access a breadth of information to inform their planting choices. Among these details is the ability to see if a variety is being sold under different names and, if so, what they are. This helps ensure growers who purchase seed from multiple companies or multiple brands owned by the same company (Table 3) are not buying the same varieties relabeled as something else.

Table 3. Seed companies and their brands [31].

Bayer	Syngenta	Corteva Agriscience	Agreliant
Dekalb	NK Seeds	Pioneer	AgriGold
Channel	Golden Harvest	Mycogen	LG Seeds
Fontanelle	Phoenix	Brodbeck *	Producers Hybrids *
Gold Country Seed	Innotech	Dairyland	Great Lakes *
Jung Seed Genetics	AgriPro	Pfister *	Wensman *
Kruger Seeds		Prairie Brand *	Golden Acres Genetics *
Lewis Hybrids		Agventure	Pride
REA Hybrids		Curry Seed Company *	
Specialty Hybrids		Hoegemeyer Hybrids	
Stone Seed		NuTech Seed	
Stewart Seeds		Terral Seed	
Hubner Seed		Doeblers Pennsylvania Hybrids *	
Westbred		XL Brand Distributed by Beck's Hybrids	
Asgrow		Power Plus Distributed by Beck's Hybrids	

* Indicates the company/brand has been phased out.

While the FBN's Seed Finder database offers farmers the ability to avoid relabeling among the varieties submitted to FBN by farmer members, this tool is only effective in managing surface-level diversity and does not provide information about the genetic background of varieties in the database.

3.3. Lacking Clear Access to Maize Genetic Background Information

Overall, the farmer interviewees said that they do not have access to genetic background information about the maize seed varieties they plant. This caused little surprise and was one of the motivations for conducting these interviews: to understand how, if at all, this was impacting farmers and what management strategies they employ in light of it. Within this theme, it is important to note the varied responses given by the conventional growers. Two of the conventional farmers said that they definitely did not have access to this information. Another two of the farmers said they were unsure if they had access to this information. Of these, one said they were fairly sure that they could obtain that information if they asked their dealer. The other had not considered this level of detail and jotted a note to himself that he should ask his dealer about it.

Farmer L.G. was particularly adamant that pedigree information was not important to him and that his seed dealer had access to this information if he wanted to know it.

> *I've been to meetings all the time, they say, we need to have the genetic family on the tag so we can read it. So, we know that if I'm buying Pioneer and whatever, company X, so I can compare the tags and see that it's different genetics ... I'm sure we could find it out. I just never have. It's not a big deal to me. Our dealer could tell us.*

His reliance on his seed dealer to make seed choice recommendations based on his knowledge of the genetic diversity of the hybrids was so prevalent throughout the interview that he called him and asked him to come to the farm so that he could be interviewed. This is discussed further in the following section.

Farmer M.S., who operates approximately 202 hectares of cropland, including 45 hectares of maize each year, shared a very different opinion to that of L.G. about access to genetic background information. In preparation for our interview, M.S. pulled out several seed catalogues to illustrate the lack of information available to him.

> *I used to do very detailed analysis that compared everything ... But for the past probably three years, the seed companies do not show you the base genetics anymore ... I don't have access ... If you look at the Cropland manual across the top, you'll see the internal traits they're selling to farmers. This is really marketing materials. This is not science and its subjective opinion ... So this is all I have to deal with.*

M.S. spoke many times about his frustration over only having access to what he considers marketing materials to make seed selection decisions on his farm.

Farmer A.K., however, said that while genetic background information was somewhat challenging to find out, he was having good success in sorting it out on varieties that are important to him. He described having good conversations about it with his "dealer network", and stated that while he cannot know exactly the details of the varieties' genetic backgrounds, he can obtain enough information for his purposes. When asked why he was interested in this information, he said that it is " ... the next step in managing the risk of trying something new". When asked why he thought some companies were willing to share these details, he answered that he thought it was related to marketing. A.K. is considering upgrading to a multi-hybrid planter. Knowing how these varieties differ and by how much is an important component in selling these tools, and relationships between farmers and dealers emerged as an important theme in variety selection decisions.

This dynamic of farmers' reliance on private seed companies for seed and the management of on-farm genetic diversity is a radical change in the history of agriculture [32]. The shift from U.S. maize seed as a public resource to a private commodity has allowed corporate seed companies to replace farmers as the custodians of maize genetic resources [32]. Glenna and Bruce [33] document recent research misconduct by a corporate seed company, raising concerns about whether private maize research and management is being conducted in the public's best interest.

3.4. Purchasing Maize Varieties with Reliance on Seed Dealer Relationships

The majority of the farmers, both conventional and organic, spoke in detail about the importance of relationships with their seed dealers in making decisions about what maize varieties to plant. The interviewees were not directly asked what role their seed dealers played in on-farm management. Rather, they identified this relationship in response to questions about who they most often consulted with when making decisions about which varieties to plant, or what information about genetic backgrounds they have access to for informing their choices. Interviewees used words such as "trust" and "faith". One said, "I think the relationships are more than anything" when describing their reliance on seed dealers for selecting varieties. The relationship with seed dealers was a strong theme among interviewees and appears to be an important, if not central, strategy for managing on-farm diversity.

Several of the farmers believed their seed dealers have access to genetic background information and that they were using it to inform appropriate levels of genetic diversity on their farms. R.P., who spent 32 years as a Pioneer sales representative, said this in response to a question about looking into the background of hybrids in his selection process:

> *I think on the label it does actually tell a little or you can have them traced back. I mean, they're not going to tell you exactly what it is but they're going to say, you know, you could ask your rep, 'Does any of these—you know, I've got four hybrids here, how many of them have the same—one of the same parent?' … They could find that out.*

He clarified that this information was not unique to him as a retired Pioneer dealer and that an average farmer without those ties to the company could find out the genetic background information. R.P. reiterated the reliance on the relationship between farmers and dealers later on when he stated, "I also know from working with a lot of farmers that they rely on me to keep that straight for them". Here, he is referring to his former farmer customers relying on him to select maize varieties back when he was a Pioneer representative.

Farmer J.B. operates about 324 hectares, including 162 hectares of maize, and spoke of his relationships with seed dealers as being important in how he selects the three or four maize varieties he plants each year.

> *A lot of it is based on relationships I have with the local seed dealers. Part of it is based on my history with a particular variety. Part of it is on the history of the piece of property it's going to go on … But it's largely a relationship, I think.*

J.B. and his wife own the century farm that he runs and he mentioned the importance of his relationships with seed dealers and neighbors throughout our interview.

Let us return to farmer L.G. and his insistence on having his seed dealer M.G. join the interview. M.G. lives down the street from L.G. and works for a seed company that markets itself as having a genetically diverse catalogue of offerings.

> Interviewer: *M.G., do you know the genetic background, does* [COMPANY NAME OMITTED] *tell you that?*
>
> M.G.: *No, not really. No, but if you've been in it long enough, I can normally tell what germ pool they're coming out of.*
>
> Interviewer: *The parents?*
>
> M.G.: *Following the traits … They normally don't disclose that. Now, there's a lot of people that know what that is, and if I asked our corn breeder, I could probably find out what that background …*
>
> L.G.: *They don't put genetic information on a seed tag?*
>
> M.G.: *No.*
>
> L.G.: *Because I thought they did.*
>
> M.G.: *I can follow it by traits, normally … But they don't disclose that to us. In fact, they don't even want the farmers* [to know], *but most farmers understand the traits, and*

> *so they know where it's coming from anyway. And some don't care. L.G. doesn't care, probably, as long as it yields on his farms.*

This interaction was the moment when L.G., who said that his seed dealer had this information readily available to him and was using it to make decisions, heard differently directly from M.G.

By "traits", M.G. was referring to biotechnology traits that have been incorporated into the hybrid. Such seed is often referred to as "traited" and includes some type of insect or herbicide protection, such as resistance to glyphosate injury or the European maize bore. Most varieties today have several traits incorporated in them, or are what some interviewees referred to as being "stacked". M.G. described following the traits, which are often cross-licensed among companies, as a way to decipher which company the hybrid is from because traits are proprietary.

Conventional and organic farmers alike identified relationships with their seed dealers as important in making variety selections. This makes sense, particularly considering that a farmer's success is in the best interest of their seed dealer, who wants to keep the farmer as a customer. What is concerning, however, is that many of the interviewees perceived their dealers as having access to and using genetic background information to inform their variety selections, and M.G. says that is not the case with his company.

3.5. Struggling to Find Quality Maize Genetics for Organic Systems

For many organic farmer interview participants, strong relationships with their seed dealers did not address concerns around the lack of organic maize genetics on the whole. Many interviewees said that they did not have high-quality maize varieties bred to thrive in organic systems. They perceived the conventional seed companies as holding genetics back from organic growers and breeders. Farmer M.D. described what he sees as the current state of seed in the U.S. as having " … gone backwards a lot. We really took the breeding programs out of the land grant universities and let big chemical companies hijack all the germplasm".

Farmer P.G. shared a related sentiment, saying, " … the way I understand how hybrids become available there are probably only a few actual people that actually put out the genetics that these seed companies get to fight over and there probably is not all too much difference". P.G. manages conventional and organic hectarage and went on to describe his frustration with the quality of organic maize seed.

> *The organic I try to pick one that's proven … I'm not really sold on buying organic seed just because it's organic. I've seen and done that and paid way more for organic seed and put it in trial next to untreated conventional seed and it's behind by 20–30 bushels. You know and … I can't afford I mean I'm losing money not just buying the seed but planting. I'm taking a yield hit.*

P.G. manages about 263 hectares and the maize hectarage is split into half conventional and half organic. He plants one variety on his organic hectarage and two to three on the conventional land. He attributed this to the "headache of the paperwork", in reference to the paperwork associated with organic certification, and reiterated the lack of quality in the organic maize seed. The result is that his conventional hectares are more diverse on the surface level than his organic hectares.

Farmer W.H. operates 2023 hectares with his family. The farm is about three quarters non-GMO conventional and one quarter organic, and it grows 850 hectares of maize each year. Like P.G., W.H. talked about the differences in seed quality between the conventional and organic varieties available to him and identified investments in research funding as the reason.

> *There's just a bigger market, there's more money in research and development. What it comes down to is the conventional side has more customers, so they have more money to do research and development, and plant breeding. Additionally, the organic side is just getting there. I think in maybe 20 years the difference between the two might not be so*

much, but in my experience, it seems like the conventional markets just have stronger genetics that are more vigorous.

W.H. talked about the issues he has had with finding organic seed for his farm and said, " . . . we are able to get everything we need on the conventional side."

None of the conventional farmer interviewees talked about issues in finding quality seed that performs well on their farms. Two discussed losing access to older varieties that have been replaced with newer ones and that this could be frustrating at times. The subject of the availability of certain varieties in certain regions was brought up by two of the farmers and one noted the related practice of regional pricing. These issues were lightly discussed, and interviewees did not express more than low levels of frustration about them.

4. Conclusions

This study set out to understand farmers' perspectives of and strategies for managing on-farm genetic diversity. In particular, we aimed to examine if farmers have the genetic information they need to make decisions about which maize varieties they plant and what their roles are in managing on-farm diversity on their maize hectares. These data will inform a broad survey of Upper Midwest maize growers on the same themes. The interview data and analysis suggest that farmer participants hold nuanced perceptions about on-farm genetic diversity in their maize hectares, their concerns vary based on their size and markets, and they have some sort of strategy for managing surface-level diversity. Importantly, farmer interviewees indicated that they lacked clear access to the genetic background information about the maize seed they purchase, inhibiting their capacity to manage on-farm genetic diversity.

Instead, the participants described a range of strategies they use to manage surface-level diversity and spread the risk of crop failure on their maize hectares. The most salient strategy identified was planting multiple varieties each year. The next steps for research should include collecting data on the top maize variety sales in the Upper Midwest to better understand the surface level of on-farm diversity. These data could be triangulated with seed company offerings to determine whether there are differences between availability and planting.

Given that the farmer interviewees identified planting multiple varieties each year as a core strategy for managing surface-level diversity, a deeper understanding of seed relabeling in the maize seed industry is needed. Farmers planting a limited number of varieties on their hectares are particularly at risk of narrowed diversity if they unknowingly plant the same variety listed under different names.

Maize monoculture is embedded on the Upper Midwest landscape and understanding the in-species diversity can help us understand how drastic and vulnerable it is. An assessment of parental genetic diversity in hybrid maize seed sold to U.S. growers annually is needed in order to analyze the likelihood of biological epidemics occurring in the landscape. Given the current intellectual property restrictions on seed, policies that allow public entities to measure on-farm genetic diversity in major crops should be developed [33].

Contemporary research focusing on measuring the on-farm genetic diversity of maize in the U.S. is limited, due in part to patent restrictions. In the U.S., the bulk of the commercial maize germplasm has been privatized and with this comes the privatization of germplasm management and monitoring of on-farm genetic vulnerability. The shift from maize seed as a public natural resource to a privatized commodity is a new development in human existence [32]. We need to understand how seed systems are being managed in the U.S. and globally as well as the implications for on-farm genetic diversity in order to inform vulnerability assessments and strategies for mitigating the risks of severe crop failure associated with genetic uniformity.

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