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Influence of the Seed Loophole and Bottleneck on Quantity and Quality of Organic Maize Seed in the U.S. Midwest

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A case study in the U.S. Midwest explored factors likely to be limiting organic maize, aka corn seed quality and quantity. We sought to learn about the influence of the regulatory loophole which allows use of conventionally produced, untreated, non-GMO seed for organic production when an organic equivalent is unavailable and, the organic sectors' concerns about access to quality seed, and seed price. Two farmer focus groups, a workshop with seed producers, a survey of merchants of organic maize seed, and a research project advisory board suggested that the degree of concern about the loophole and seed quality varied according to participants' priorities. Farmers equate seed quality with agronomic traits impacting grain yield and crop establishment (vigor, emergence and tolerance to cultivation). Traits influencing grain quality or composition for specific uses, and the ability to satisfy consumer wants were more important to buyers. Seed price was of greater concern to farmers and buyers catering to commodity markets than to producers and buyers serving de-commodified markets. Producers that prized yield most highly were less concerned about the loophole or interested in participatory on-farm breeding and testing networks than farmers catering to specialty markets. Despite interest, little information about nutritional quality, rhizosphere function, and ecosystem service provision is circulated outside of academic groups. A workshop with leaders in the organic seed improvement industry and advisory board input identified the inability of inbred lines to withstand weed, pest, and disease pressure as the main bottleneck increasing costs and limiting investment in organic seed improvement. The cost differential between organic-and conventional non-treated seed, and competition from organic grain imports, were believed to be limiting the price of certified seed, thus making it difficult to garner investment and innovation needed to develop desired agronomic, environmental, or grain-quality traits. An audit of seed sales reported by >90% of U.S. vendors of certified seed found that the volume of organic seed being sold may account for as much as 75% of organic maize acreage planted in the U.S. Costs of non-treated seed sourced through the loophole are 40-100% less than certified seed. With 75% of U.S. organic corn being produced using certified organic seed, we conclude that the loophole is not altering seed quality by undercutting organic seed sales. Substantially higher costs of organic seed production and challenges associated with organic seed production appear to be the most likely barriers to maize seed improvement for the organic sector.

Keywords: maize diversity, parent lines, organic maize seed, organic seed loophole, participatory networks

INTRODUCTION

Legal Basis for the Loophole: Regulations and Certification

To frame a nuanced discussion regarding adequacy of the organic seed supply, it is helpful to first understand the regulatory framework for certified organic production and specific rules regarding seeds. The US Department of Agriculture's (USDA) organic regulatory program—the National Organic Program (NOP)—mandates the application of various cultural, biological, and mechanical practices designed to support resource cycling, promote ecological balance, and conserve biodiversity (NOP, 7 C.F.R. § 205.2). The intent of the NOP was to create national uniformity through a single, federal standard for the production and processing of organic food and fiber to facilitate interstate commerce and, therefore, encourage expansion of the organic market (Endres, 2007; Clark, 2015). With respect to seeds, the NOP specifies that the "producer must use organically grown seeds, annual seedlings, and planting stock," which are produced by an organically certified operation (USDA, 2000). Determination of what is or is not organic seed in the U.S. is based on NOP rules (NOP, 7 C.F.R. §205.204(a)). Approved methods for plant production include seed developed by classical selection and crossing methods such as traditional breeding, conjugation, hybridization, *in vitro* fertilization, or tissue culture. Moreover, current organic guidelines allow all breeding steps to take place in fields that use synthetic amendments (e.g., fertilizers, herbicides and insecticides), but the production of commercial seed must be conducted in organically certified fields.

The explicit requirement to use organic seed, however, is subject to exceptions. One such exception, commonly referred to as the organic seed loophole, directly impacts market incentives for investment in improved organic seeds. Third-party certifiers may authorize use of an equivalent conventionally produced seed, so long as it is untreated and has no GMO traits, if a desired organically produced variety is not commercially available (NOP, 7 C.F.R. §205.204(a)(1)). The NOP regulations define commercial availability as the "ability to obtain a production input in an appropriate form, quality or quantity... as determined by the certifying agent in the course of reviewing the organic plan." (NOP, 7 C.F.R. §205.2). Individual certifiers determine this annually on a case-by-case basis. Evidence of producer efforts to procure seed of organic varieties that would meet the required characteristics includes documentation of contacting at least three sources of organic seed. Equivalent varieties should be of the same type or possess similar agronomic or marketing characteristics that meet the site-specific requirements for individual farm operations. While seed price cannot be a formal consideration, virtually any other characteristic, including buyer specifications for contract farming or seed quantity limitations, will qualify for the exception. These rather formulaic requirements for documentation, coupled with certifiers' difficulty to know the organic seed availability for each variety and region, make it possible for farmers to select and utilize conventionally grown seed if they so choose.

Is it a problem that the regulatory loophole created to address concerns that the existing supply of certified organic seed was inadequate to support the expansion of organic production (Hubbard and Zystro, 2016) persists after two decades? The European Union (EU), which applies a similar set of exemptions for the use of conventionally produced seed in certified organic operations, added a 2020 amendment to the EU law requiring member states to collect and list in a database the number of exemptions, varieties, and explicit justifications including research purposes, lack of suitable organic varieties, conservation purpose, or other reasons for invoking an exemption (Hubbard and Zystro, 2016). Unlike the U.S., which has no deadline to close the loophole, the EU has set December 31, 2035 as the terminal date for the use of conventionally produced seeds on organic farms (Hubbard and Zystro, 2016). In 2028, the EU Commission will decide whether to extend this deadline or, potentially, end the use of exemptions before 2035 (Hubbard and Zystro, 2016).

The Loophole

The persistence of the loophole and lack of development of an organic-seed production pipeline have raised concern about the organic sector's access to high quality seed (Roseboro, 2013; Chable et al., 2014; Cornucopia Institute, 2019). Unease about the quantity and quality of organic seed availability in the U.S. is in part due to the use of genetic engineering and the oligopolistic structure of the seed supply chain. The consolidation of the seed industry has led some to fear that the private sector would capture and exclusively produce high quality genetics for the conventional market, while offering lesser quality, or genetics selected primarily for conventional cropping systems, to the organic seed markets (Gurian-Sherman, 2009). This shift has corresponded with a rise in seed costs (Heisey and Fuglie, 2018) and restricted innovation and investment in crop improvement (Hubbard, 2019). Private sector dominance of plant breeding has

Abbreviations: EU, European Union; GMO, Genetically Modified Organisms; IFOAM, International Federation of Organic Movements; NOP, National Organic Program; NOSB, National Organic Standards Board; U.S., United States; US-EPA, United States Environmental Protection Agency; USDA, United States Department of Agriculture.

also resulted in the application of stronger intellectual property rights, such as utility patents (IPRs) (Endres, 2004; Pray and Fuglie, 2015; Luby et al., 2018). This is the case for most corn grown today, where privatization and vertical integration of seed production with input sales by agribusiness has been intense (Schrager and Suryanata, 2018). Approximately 80% of the US corn seed market is owned by a handful of companies (Corteva, Bayer, Syngenta, Becks Hybrids, AgReliant) (Howard, 2009; MacDonald, 2017; Heisey and Fuglie, 2018; Hubbard, 2019). As much as 95% of the corn varieties grown by organic farmers originate in conventional breeding backgrounds selected in regions with benign climates, optimal or high levels of fertility, and unconstrained use of seed and herbicide treatments to reduce insect, disease and weed pressure (Murphy et al., 2007; Gurian-Sherman, 2009; Hubbard and Zystro, 2016). Given the size of the conventional corn market, most large breeding companies focus their efforts on cultivars with broad adaptation, discounting the opportunity to develop locally adapted cultivars or varieties potentially more suitable for organic systems that are nutrient-use efficient, disease-resistant, and able to compete well with pathogens and weeds (Wolfe et al., 2008; Dawson et al., 2011). The State of Organic Seed Report (Hubbard and Zystro, 2016) asserted that while many U.S. farmers were satisfied with their seed supply, they also believed that varieties specifically bred for organic production would be essential for the future success of organic agriculture (Howard, 1945; Luby et al., 2018). Collaborative networks that engage public sector R&D in breeding and testing have been proposed as a way to overcome challenges posed by consolidation in the seed sector (Chiffoleau and Desclaux, 2006; Löschenberger et al., 2008) and accelerate development of regionally adapted organic cultivars (Adam, 2005; Luby et al., 2018). Participatory plant breeding, testing, and research networks and client-oriented breeding programs achieve this by engaging farmers, researchers, and product end-users in the process (Morris and Bellon, 2004; Dawson et al., 2011; Chable et al., 2014; Witcombe and Yadavendra, 2014).

MAIZE-BASED CASE STUDY

We conducted a participatory maize-based case study by coupling educational efforts with on-farm comparisons of maize varieties using an iterative process carried out over a two-year period. Through a series of focus groups, workshops, and consultation with our advisory board we considered whether or how factors including the regulatory loophole and seed production and supply influence organic maize seed quality and availability in the Midwest where U.S. corn production is concentrated.

Focus Groups and Perceptions of Quality

We began our inquiry through consultations with network participants to understand their perceptions of seed quality and adequacy and gauge their interest in participatory breeding and testing. Previously identified quality traits (i.e., days to harvest, grain color, flavor, nutrient profiles, vigor, yield, regional adaptation, disease and pest resistance, amino acid composition, overall protein and starch composition, and GMO incompatibility) asserted to be of interest to premium organic markets, consumers and in identity preserved products that trace ingredient origins (Elbehri, 2007; USDA-AMS, 2013) were used as starting points and shared in a list format at two gatherings held during the summer of 2018. The facilitated discussions were designed to better understand regional expectations for seed quality and seed needs of farmers in Illinois and Indiana who produce organic grain corn for the food market, and farmers in Wisconsin who produce grain for the feed industry. The Illinois-Indiana field day, attended by over 40 people, estimated to be 65% farmers, 10% breeders and buyers, and 25% academics and students, was followed by a focus group with network members (15) that included farmers and buyers along with members of the research team. The field day held in Wisconsin was attended by 40 participants, estimated to be 20% farmers, 8% research team members, and 7% breeders based on information gathered at registration. Twenty individuals participated in focus groups that followed the field day. While we did not include customers in these focus group conversations, we considered whether qualities were sought to sa1tisfy agronomic, user or consumer wants. A summary of these quality attributes is included in **Table 1**.

When asked about priorities for seed quality, farmers in both regions prioritized agronomic performance (i.e., yield, plant emergence, lodging resistance, and competitiveness against weeds) (**Table 1**). The top quality concern of farmers in Illinois and Indiana was seed corn condition and consistency (cracked or contaminated with weeds or dirt- particularly when purchased from smaller suppliers) (**Table 1**). Seed corn qualities identified are associated directly and indirectly with plant attributes that contribute to yield and stand establishment. Wisconsin farmers jokingly requested 'resistance to iron worm' in reference to seed that has vigor at emergence and tolerance for tillage and weed competition. Yield was particularly emphasized by farmers selling into commodity organic markets that tend to require uniformity but do not command price premiums for identity preserved varieties. Representatives of the one of the largest organic grain buyers in the U.S. indicated that they prefer to purchase grain grown from hybrid seed because of its uniformity. Hybrids would also be their choice for seed provided to farmers growing grain on a contractual basis. A buyer suggested that farmers should "go after yellow", or #2 yellow dent, because it is the most used corn commodity type in organic markets.

Despite interest in agronomic performance that included competitiveness with weeds and tolerance for tillage, and, despite breeders' expressed interest, growers in our network were not very interested in collecting phenotypic data. Farmers expressed some interest in plant allometric traits including harvest index and root mass but had little experience with them because these data are rarely reported (**Table 1**). They were, however, interested in, and aware that, root traits may be essential for agronomic and environmental performance of organic maize (Dechorgnat et al., 2018). Even though allometric traits may have potential as indirect proxies for services like carbon sequestration, nutrient capture, or pollution protection, they were not priorities for participants. This is likely because farmers and buyers assume consumers accept organic certification as a proxy for environmental services due to the standards requirement for

TABLE 1 | Traits that are widely, frequently and rarely reported of relevance to Farmers (F), Grain Buyers or Processors (B), and/or Consumers (C) within the organic supply chain.

Plant attribute	Entity	Agronomic	Environment	Grain
	Commonly			
Yield	F			
Emergence (%)	F			
Day to harvest	F			
	Frequently			
Lodging resistance	F			
Disease resistance	F,C			
Weed competitiveness	F,C			
Gametophytic incompatibility	B,C			
	Rarely			
Harvest index, shoot/root ratios	F			
Nutrient use efficiency	F,C			
Rhizosphere functions (plant-soil associations, C sequestration)	F,C			
Nutrient uptake - removed from field	F			
Seed attribute	**Entity**	**Agronomic**	**Environment**	**Grain**
	Commonly			
GMO-free	F, B, C			
Color	F, B, C			
Size, shape	F, B, C			
Condition (cracked, cleanliness)	F, B, C			
Heat damage	F, B			
Endosperm	F, B			
Crude protein	F, B, C			
100 kernel / test weight	F, B			
Moisture content	F, B			
	Frequently			
Methionine content	F, B			
Cysteine content	B			
Lysine content	B			
Starch content	B			
Amylopectin (waxy) content	B			
Amylose content	B			
	Rarely			
Nutrient composition of grain	F, B, C			
Flavor profile	B, C			
Whole corn and starch pasting behavior	B, C			
Pesticide residue testing	C			

Shaded cells indicate traits of interest for focus group participants.

use of diversified rotations, reliance on natural methods for pest suppression, and commitment to the basic principles of Ecology, Health, Fairness and Care (IFOAM, 2005; Kremen and Miles, 2012). When asked about whether participatory data-collection and sharing were valuable, farmers in both focus groups were unsure. Farmers in Wisconsin expressed much more interest in regional breeding, but they have limited time and resources, and suggested that it would "take years and years to identify the ones (varieties) that respond well to local conditions. There was a consensus that even though participatory research networks can help gather information about crop attributes and ecosystem services to provide value to industry and society, this needs to be done without asking farmers to foot the bill (Hoffmann et al., 2007; Ugarte et al., 2018).

Interest in grain attributes other than yield differed with the market or consumer value that participants aimed to satisfy. Grain buyers routinely grade seed quality and uniformity. Moisture content, which is critical for seed hygiene, as wet seed supports growth of pathogens and the production of mycotoxins, was not mentioned even though it is the most routinely measured and reported seed attribute (**Table 1**). Farmers supplying smaller markets or feeding grain to livestock expressed more interest in specialty grain-traits like color and protein content in open-pollinated varieties. These specialty traits or other traits such as enhanced starch profiles for brewers that were of interest to a subset of network members, are frequently sourced through niche markets (Elbehri, 2007; Scott et al., 2019). Buyers in our network found "Niche products like open-pollinated varieties of certain color and quality are very susceptible to supply!" Organic livestock producers were quite interested in the quality of feed from corn grain and silage; for this, corn high in protein and the essential amino acids methionine and lysine was desirable. This is a growing concern because synthetic methionine will soon be phased out of use for organic producers by the USDA (Goldstein et al., 2019). While methionine and carotenoid contents are rarely reported for grain, grain color is and can provide a useful proxy for these desirable quality traits (Chandler et al., 2013) (**Table 1**). Even though there was limited discussion of traits desirable for baking, nixtamalizing, and cereal production during focus groups, a 2019 network meeting demonstrating how properties in unprocessed grain, e.g., aroma, are altered by preparation piqued their interest. Breeders and food scientists were most interested in properties like hardness known to influence nixtamalization (Billeb de Sinibaldi and Bressani, 2001). Small breeders were more interested in starch composition and its influence on baking.

Concern was expressed about seed purity and damage from pollen drift with emphasis placed on cross incompatibility with GMOs. Wisconsin farmers noted "cross incompatibility is a critical part of growing for organic markets" and, "there is not any place in the Midwest where you can get full isolation". While the wording of the U.S. organic standard is vague, it places responsibility on the grower to implement practices, such as buffers that exclude GMO pollen and avoid contamination with prohibited substances or excluded methods (Devos et al., 2009; Coleman, 2012). Despite the importance of seed purity, organic farmers are not required to test for the presence of GMOs for certification. Buyers frequently require or conduct tests themselves prior to purchasing grain (**Table 1**) (Benbrook and Baker, 2014). These tests serve as a proxy for a broader suite of services as typically, both purity of seed and protection of the environment are assumed to result from prohibition of synthetic inputs in organically certified fields (Ditlevsen et al., 2019).

Workshop and Seed Improvement

Building on observations from the focus groups, we organized a workshop at the 2019 American Seed Trade Association annual meeting, where 20 participants, including 5 seed growers and suppliers, 5 breeders, 2 lawyers with expertise in IP and seed patent law, 4 university experts working on organic systems and 4 students discussed how to improve the supply and quality of organic seed. We asked participants to rank their top priorities for maize improvement for organic applications from 1, lowest priority, to 5, highest priority. Participants' rankings were seed emergence (4.8), yield (4.7), disease resistance (4.2), competitiveness with weeds (4.2), GMO incompatibility (3.8), and soil conservation (3.8). When queried about the greatest concerns for organic maize seed supply, participants' responses were ranked: seed price (4), use of conventional non-treated seed (3.8), seed quality (3.8), seed imports (3.5), and dicamba drift (3.5). This list and its rankings closely mirror the focus group priorities. Despite this agreement, the vision for how to go about improving seed quality varied widely among participants. For example, representatives of larger seed houses catering to conventional markets assume "the best genetics are held in big germplasm collections" and, "we are still being paid for bushels produced so can't get around yield". Seeing organic seed as a niche, they argued "we just need to screen performance under appropriate conditions." While acknowledging "seed selection under organic conditions will lead to better performing varieties for the organic context", most agreed little information exists for hybrid seed producers on the suitability of conventionally developed inbreeds for producing hybrid seed under organic conditions.

Participants noted that seed emergence, yield, and GMO incompatibility are equally valuable characteristics for conventional and organic markets and can flow easily into organic production pipelines as untreated seed. Breeding efforts to protect non-GMO seed, including seed produced for organic systems, have increasingly turned to the use of gametophytic factors that prevent cross pollination. Some public and private breeding programs already produce hybrids that block cross pollination with GM-corn, but some are concerned that incorporation of some factors will undermine existing protective barriers like the Ga1-s allele that maintains purity of specialty endosperm and white dent varieties (Jones et al., 2015). Organic hybrids can be produced in a single year using organic practices by crossing parental inbreeds that were produced conventionally. Although this approach sounds relatively simple, participants found hybrid seed production using conventional non-GMO inbreds under organic management was a bottleneck with seed producers stating that "organic seed production is the main problem" and, "control of weeds is beyond master class level of difficult". These are challenges facing any organic seed production effort but seem to be exacerbated when producing hybrids. Agronomic tactics to enable organic seed production, including adjusting row spacing, mats or plastics to control weeds, were discussed. The potential value of doubled haploids and genomic selection to related efforts was raised. One breeder suggested the use of proxies for organic environments that might permit some non-organic 'crutches' to allow reasonable success in production. Seed producers' emphasized high costs of labor and material with one participant asserting costs of organic seed production from inbred parent lines were more than three times greater than costs to produce conventional non-treated seed.

Some participants thought the use of seed sourced through the loophole as seed corn or, even as parent lines for organic production, is problematic for both ethical and biological reasons. This assumes organic consumers share concerns about technology and consolidation in the industry contributing to loss of seed quality and diversity (Hubbard, 2019; McCluskey and Tracy, 2021). Participants also worried that conventional field conditions with high levels of nutrient inputs, optimized weed control, and water management, would not provide the selection pressures useful for identifying cultivars adapted to organic systems. This reflects evidence that conventional maize breeding programs have unintentionally selected against root physiological and morphological traits that could enhance N absorption and utilization capabilities by focusing on plant performance in high yielding environments (Schmidt et al., 2016; Favela et al., 2021). Carrying out crop improvement efforts and selection with soil conservation, participants' fifth ranked priority, in pursuit of environmental services, may produce more effective results under organic conditions. Organic goals are consistent with interest in managing the rhizosphere to achieve environmental goals that have grown with our understanding of biochemical networks connecting plant hosts and microbial associates (Bordenstein and Theis, 2015). Participants discussed how the assumption that the genetic background of parent lines influences N efficiency is already being exploited by organic breeding programs that apply a 'co-evolutionary' approach to cultivar development (Goldstein et al., 2019). Breeding targets include robust growth under N-limited organic conditions that foster rhizophagy, a seed-borne partnership between corn plant roots and a plant-tailored set of microbes (White et al., 2018, 2019) that assist in nutrient acquisition. This kind of 'partnership breeding', can draw upon the genetics of elite parent lines in interaction with microbial partners to engender desirable agronomic traits for more heterogenous systems including those under low-input conditions. Plant-modulated interactions have been shown to favor association with beneficial microbes to a greater degree when grown under stressful conditions (Rosier et al., 2016). However, some workshop participants challenged the idea that breeding programs should assume organic systems are nutrient, disease, and pest challenged, pointing out that this notion is fundamentally at odds with the soil health paradigm that assumes the use of crop rotation and balanced fertilization generate resilience and naturally pest suppressive systems (Wander, 2021). Members of our research team agreed that a useful goal for soil health assessment might be to inform breeding efforts such as those outlined by Peiffer et al. (2013) and Mueller and Sachs (2015) that employ basic principles of quantitative genetics and community ecology to facilitate coadaptation between plants and microbes to enhance functional utility (i.e., nutrient use efficiency, carbon sequestration, water use efficiency) along with agronomic and sensory dimensions of quality.

Loophole or Bottleneck?

To determine whether the loophole or the cost of organic seed production were more likely to be constraining innovation in the organic seed sector, we contacted 14 of a total of 15 seed vendors listed by the NOP's published list as sellers of certified organic seed between June and November 2020 to estimate volume of sales and seed price (National Organic Standards Board, 2019). We estimated the number of acres planted with organic seed assuming 80,000 seeds could plant between 2.2 and 2.5 acres depending on planting density ranging from 32 to 36 thousand plants/acre. Based on this assumption, we estimate that enough organic seed was sold to plant between 300,000 and 345,000 acres. According to Mercaris, approximately 419,200 and 376,400 acres of organic corn were harvested in 2018 and 2019, respectively. This agrees with USDA's 2019 Organic Survey that reported 374,636 acres of organic corn (grown for grain, seed, silage, and green chop) were harvested in 2019. A comparison of these values with our estimate of organic seed supply suggests that 10-25% of certified organic corn is likely grown with untreated conventional seed. This estimate agrees with the 2016 State of Organic Seed Report by Organic Seed Alliance in which surveyed farmers reported that 78% of field crops were planted with organic seed. According to the seed companies we contacted, certified organic seed prices ranged from $45-$90 more per 80,000 kernel unit than conventional non-treated non-GMO seed prices. This is consistent with reports of a 20-50% premium paid for organic field crop seed (Hubbard and Zystro, 2016). The premium does not cover greater costs of seed production which were reported to be 40% to 100% by the companies we consulted. While less than the 3X premium reported by the seed producer participating in our workshop, a 2X greater cost is not being fully compensated by sale prices. Raising seed costs may not be a viable option. The greater cost of organic seed is already a concern for many and is a particular concern for organic feed corn because cheaper imports satisfy as much as 50% of domestic demand (Torres et al., 2020) while accounting for just one third of total dollar sales (Greene et al., 2017; Reaves et al., 2019). These imports exert significant downward price pressure on grain, and there is significant concern that fraud will undercut public confidence in the organic label (Reaves et al., 2019). Even though USDA has increased enforcement efforts and proposed a series of reforms to enhance fraud monitoring and import controls, competitive pricing will remain a priority for the U.S. organic corn sector (Torres et al., 2020; USDA-AMS, 2021).

DISCUSSION

With 75% of U.S. organic corn being produced using certified seed that is sold at prices that make that seed less profitable than that sourced through the loophole, we conclude that it is the higher costs and significant challenges associated with organic seed production that are the most likely barriers to seed improvement for the organic maize sector. Heightening certification demands to mirror EU requirements for documentation could further restrict eligibility for the organic seed loophole and stimulate demand for certified organic seed. Moreover, adding modest sunset dates to close the loophole could spur needed innovation and investment. But while added investment could defray some of the potential increased costs of seed production for the 25% of the market using non-treated non-GMO seed, eliminating the loophole would not necessarily change the fundamental economics of organic seed production or alter the fundamental genetics of organic seed unless seed selection and seed increase phases were intentionally modified to enhance performance under organic growing conditions. Further, it isn't clear that tightening or closing the loophole could overcome the labor and monetary costs that already impede organic maize seed production. Finally, rapid changes in NOP rules would likely be disruptive given the significant lead times for seed production and competitive pressures facing this sector (Mulvany, 2005; Kroma, 2006; Mascarenhas and Busch, 2006; Aoki, 2009; Mendum and Glenna, 2009; Witcombe and Yadavendra, 2014).

We found that in the current economic environment the cost of organic seed production and not the seed loophole, is more likely constraining organic maize seed quality in the U.S. and elsewhere where farmers rely on hybrids supplied by global seed suppliers. Even though perceptions of quality and interest in traits varied among farmers depending on market outlets, there was widespread agreement that agronomic traits, like yield, that are of importance to all markets may not need targeted breeding and testing efforts unless development efforts are carried out in organic farming systems. We also observed that organic certification is used as a proxy for environmental and social protection with GMO free status satisfying the demand for 'pure seed [which] is a cornerstone of true sustainability in an organic farming system' according to the National Organic Standards Board (2014). Finally, we found that even though participatory networks could contribute to discovery and development of organic corn seed using on-farm testing, success more likely depends on increased societal investment in farming-systems based breeding and research networks that develop and support use of traits to enhance compositional and phenotypic value and sustainability.

AUTHOR CONTRIBUTIONS

AE and MW participated in research, conceptualization, drafted original text, and consulted with the other authors. CU, MB, WG, and JA helped conceptualize the work, participated in research and network activities, and contributed to text. EM and AF participated in research and network activities and contributed to review and synthesis. All authors contributed to the article and approved the submitted version.

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