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RESEARCH ARTICLE

Wheat seed demand assessment assisted by genotyping in Ethiopia

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Summary
This study examines the extent to which wheat varieties supplied by the formal seed system align with the varieties demanded and used by farmers in Ethiopia. The framework of stated and revealed preferences drawn from the consumer preference theory is used to analyze farmer demand for different wheat varieties. We used official data from the formal seed sector and representative survey data from wheat farm households in Ethiopia. The survey data allow to contrast the farmer reported varietal use with genotyping by sequencing (also known as DNA fingerprinting). Farmers' reliance on informal seed sources and own saved seed, among others, contributes to the misidentification of the varieties they grow. Consequently, farmers are likely to misinform the formal seed demand assessment leading to either an over- or underestimation of actual seed demand for specific wheat varieties. Genotyping by sequencing, as opposed to farmer reports, established the persistence of old varieties. This also implies vulnerability of wheat production to disease dynamics depending on the longevity of disease resistance by the variety in use. Apart from narrowing the gap between the actual and stated demand and ensuring timely replacement of wheat varieties, genotyping-assisted estimates can save seed carry-over cost. Genotyping by sequencing is increasingly used as the new benchmark and gold standard for identifying and tracking the adoption of crop varieties. The technique has potential to enhance the performance of the seed sector through effective planning that can optimize resource commitments and accelerate the rate of varietal replacement.

Keywords: Ethiopia; Genotyping by sequencing; Seed demand; Varietal replacement; Wheat

Highlights

- Existing practice failed to predict the actual seed demand by farmers
- Farmers' extensive reliance on informal seed sources rendered their report less reliable due to varietal misidentification
- There is a marked differences of seed demand estimate between the farmers' reports and genotyping results
- Genotyping-assisted estimate can minimize varietal misidentification error, better approximate the actual demand, and boost performance of the seed system

Introduction

In Ethiopia, wheat and derived products are important staple foods. Population growth and a rise in wheat-based food preferences have driven the growth in wheat consumption (Minot *et al.*, 2015). Concurrently, wheat farming has more than doubled in acreage and quadrupled in production (FAOSTAT, 2015). Currently, after *tef (Eragrostis tef),* maize and sorghum, it is the fourth major cereal produced in the country, and between 2010 and 2020 the total production increased by over 80% (Central Statistical Agency, CSA, 2010, 2020). Nonetheless, domestic production has not yet been able to keep up with the wheat demand increase leading to growing reliance on imports (see Supplementary Figure S1).

Seeds of improved varieties are indispensable to increase production and yields. The national average wheat yield in Ethiopia is 3 tons ha^{-1}, which is half the attainable yield (MoA, 2020). Realizing the attainable yield requires, amongst others, a well-developed seed sector that can supply certified seeds with resistance to diseases such as wheat rust (Hei *et al.*, 2017). The formal seed sector directly reaches only 16% of the wheat farmers; most farmers rely on informal sources, which often provide seeds of uncertain quality (Alemu and Bishaw, 2015). A well-functioning seed sector is necessary to reduce the yield gap and increase production.

The Ethiopian wheat seed market is constrained by challenges associated with demand and supply. Seed supply by the formal sector is not always aligned with the demand, whereas the demand side is not well quantified to provide accurate signals for the supply side (Alemu and Bishaw, 2015; Alemu *et al.*, 2010; Spielman and Mekonnen, 2018). Diverging estimates on the adoption of improved or certified seed illustrate some of the challenges to predict the market size. For example, based on CSA[1] reports, the use of certified wheat seed was estimated at 7% of cultivated wheat area in 2015/2016 – while the corresponding estimate for improved wheat varieties was 52.8% of the area planted (Yirga *et al.*, 2013). Another estimate by the Diffusion and Impact of Improved Varieties in Africa project (DIIVA) indicated that the area planted to improved wheat varieties accounted for 62–78% depending on the number of times the seed is recycled to still be considered as improved (De Groote *et al.*, 2015).

The mechanisms used by the Ethiopian formal seed system to estimate the certified seed demand for different crops including wheat follows a bottom-up approach depend on farmer reports. It typically starts at *kebele* (village) where farmers are asked for the variety(ies) they plan to grow next season and the data are aggregated at *weredas* (districts), then at subsequent upper administrative tiers up to national level.[2] In the process of aggregating the demand, adjustment is made based on the government development plan as well as the extent of use of certified seed in the previous year (Alemu *et al.*, 2010; Lakew and Alemu, 2012). The main actors involved in estimating the seed demand are extension agents in the administrative hierarchy. Seed enterprises operating at regional states and national levels are responsible for producing seeds of the specific varieties as per the estimated demand.

Ethiopia's process of aggregating the seed demand assumes that farmers have correct and full information on various aspects (agronomic traits, market demand, and so on) of available wheat varieties. It also takes for granted that farmers are aware of the names of all existing (including recently released or new) wheat varieties. Accordingly, the variety-specific seed demand expressed by farmers is assumed to correctly predict the actual demand. The report from Lakew and Alemu (2012) using data from the national seed production and distribution committee, however, showed that this is not the case; despite increasing supply of the quantity of estimated seed demanded, every year there is a mismatch and considerable seed carryover. This indicates that the mechanisms followed to predict the demand for certified seed of specific varieties (based on names reported by farmers) are flawed. Self-pollinated crops such as wheat can be repeatedly

[1]CSA is an institution responsible for collecting official data in Ethiopia.

[2]*Kebele, wereda* (district), zone, regional state, and federal state (national) are administrative hierarchies, in Ethiopia, from the lowest to the highest level in that order.

planted without the need to change the seed every year, and this may compound estimating seed demand. Still, farmers' limitation to correctly identify the varieties by their formal names could also be one possible reason for the mismatch that again leads to seed carryover. Thus, in the absence of correct varietal identification, variety-specific seed demand estimate based on solely farmer reports is unlikely to be reliable.

Developments in modern technologies allow for the correct identification of varietal identity. Over the past decade, compared to conventional methods, genotyping by sequencing (also known as DNA fingerprinting) has been established as an objective and less error-prone approach in identifying crop varieties (Poets *et al.*, 2020). It provides a modern and robust alternative to the use of, e.g., grow-out tests where seed samples collected from farmers may be grown along authentic or reference sample of the same released variety and comparison is made over the entire growing period to see if the variety conforms to its true identity and purity. Genotyping by sequencing (hereafter simply referred to as genotyping) is increasingly used as the new benchmark and gold standard for identification and tracking adoption of crop varieties such as wheat (Gade *et al.*, 2021; Garapaty *et al.*, 2021; Dreisigacker *et al.*, 2019; Hodson *et al.*, 2020; Jaleta *et al.*, 2020) as well as sweet potato (Kosmowski *et al.*, 2019). The technique offers a potentially robust approach for the seed system to better assess varietal demand and supply in Ethiopia.

This study examines the extent of varietal mismatch between the demand and supply of wheat seeds in the case of Ethiopia. Specifically, we look at the relationship between wheat seed demand and supply based on official estimates, farmer reports (recall), and genotyping. Recommendations are drawn to improve the precision with which the actual demand for preferred wheat varieties is estimated.

Methodology

Conceptual framework

Seed sources can be predictors of seed quality – a limiting factor for crop productivity. Seed quality includes genetic and physical purity accompanied by physiological soundness and health (disease and pest free) status (IRRI (International Rice Research Institute), 2013). Such qualities can be affected by several factors including repeated planting. In contrast to hybrids, self- and open pollinated crop varieties potentially allow for seed recycling. Yet, over recycling can reduce genetic purity, thus breeders claim that farmers need to renew seed of self-pollinated crops like wheat, at least once every 5 years (growing seasons) to maintain its genetic purity and yield potential (De Groote *et al.*, 2015). While certain physical qualities of seed are more likely to be observed before planting, qualities such as varietal identity and purity can be verified by field inspection and through strict follow-up of seed production and maintenance. In this case, formal seed sources that involve certifications are relatively more reliable in terms of the seed quality they supply than informal sources which function mainly based on trust and accessibility. This underlines the importance of reliable seed sources in ensuring, maintaining, and supplying seeds of required quality and quantity.

In developing countries like Ethiopia where informal seed system is dominant, discrepancies between seed of the variety farmer demand and what is supplied by formal sources is quite common. There could be several possible explanations for a mismatch between the demand and supply. One could be failure of the seed suppliers to capture the actual demand in the procedure followed to estimate the quantity of seed/variety demanded. Another could be that the farmers who express the demand for seeds of a specific variety may not properly identify it by the actual name. The latter may arise from farmers' varietal misidentification where they report their preferred variety using the name of another (non-preferred one) thereby sending a wrong signal to the formal seed suppliers.

We draw our analytical framework from the consumer preference theory. Central to this is the concept of utility. Individual's preferences are dictated by the utility expected to be derived from the choices of a particular product and/or services. While utility and consequently individual choice is determined by several socioeconomic and other factors, our interest here is not to explore what these factors are. Rather, we are interested in understanding the divergence between the aggregate demand for preferred products (wheat varieties, in this case) by farmers and the aggregate supply by formal seed producers.

Based on consumer preference theory, as consumers of seed, farmers' preferences can be categorized into stated and revealed preferences. Stated preference refers to the preferences voiced by a respondent (a farmer, in this case) when asked. This is useful but people's stated preference may not necessarily match with their actions. Stated preference methods are, for instance, widely used in travel behavior research and practice to identify behavioral responses to choice situations which are not revealed in the market (Hensher, 1993). Revealed preference, on the other hand, is a way to infer the preferences of individuals given the observed choices. It contrasts with attempts to directly measure preferences or utility, for example, through stated preferences. It contends that individual preferences are expressed more in what individuals do (observed choice/decision after considering a set of alternatives) than what they say (unobserved).

Ethiopia's formal seed system relies more on the stated preferences of the farmers. The frequent mismatch between what is supplied and what is demanded by farmers inspires this analytical framework to examine the relationship between the preferences that are stated (by way of farmers reporting the variety and quantity of seed they need) and revealed (by way of what varieties farmers are growing on their plots).

The revealed preference has some limitations as it assumes that the variety observed in the farmer's field coincides with actual preference of the farmer who cultivated it. Nonetheless, farmers may plant a given variety not because they prefer it, but because it was the only available option. In addition, the variety farmers reported to have grown on their field could have been wrongly identified. Jaleta *et al.* (2020), using the same dataset we used for this study, showed that farmers are likely to misidentify a given variety by a wrong name, and several factors such as source of seed and age of the variety were highlighted as potential contributors to the misidentification. Observed varietal use, therefore, remains only a proxy for revealed demand. In our analysis, we will compare the varietal use as reported by farmers against the genotyping verified identity of collected seed samples as benchmark.

Accordingly, in this study, the demand for wheat varieties is assessed based on three different types of preferences:

1. **Stated demand based on official estimate**: Based on the existing practice where farmers are asked for the varieties they intend to grow in the next season and then aggregated in the administrative hierarchy to establish the official demand.
2. **Revealed demand based on farmer reported use**: Based on what farmers self-reported as to have grown in the last season. This is one imperfect proxy for revealed demand, given the difficulty for farmers to correctly report the variety they grew.
3. **Revealed demand based on genotyping verified use**: Based on the genotyping result of the grain samples collected from the same sample farmers. This provides the correct information on the true identity of varieties grown/reported by farmers and therefore is a better proxy for revealed demand, given that it at least objectively identifies the actual variety grown by the farmers.

The results from this study thus need to be understood with the following caveats. The particular varieties farmers grow are proxy for their revealed preference. One cannot simply assume that there were always ample varietal options in the market for farmers to decide with no limitation in availability and volume. Nonetheless, given the available alternatives, the varieties the farmers

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grew are taken as their preferred choices. To avoid exacerbating the gap between the stated and revealed preferences, we considered only those varieties which had been released at least five years earlier (the assumed minimum time before farmers get exposure and start to use a new variety) at the time of the survey.

Data

The data for the study were collected from two sources. The first is an aggregate demand for seeds of wheat varieties and the amount supplied in the *Meher*[3] season of 2016/2017 which was collected from official sources in the formal seed sector. The formal seed suppliers considered include the Ethiopian Seed Enterprise and the three regional seed enterprises of Amhara, Oromia, and SNNP[4] regional states. Farmers' cooperatives and unions are also involved in seed production and distribution.

The second source is based on a survey of farmers in wheat growing areas of Ethiopia – the data are collected by CSA as part of the annual Agricultural Sample Survey (AgSS[5]). Crop-cuts are taken for estimating yield as an integral part of the AgSS. The samples for genotyping were obtained from the crop-cuts. Attached to the AgSS is a farmer survey qustionnaire that was used to collect data like basic demographics, plot size, input usage, seed source, crop choice, and output marketing.

Sampling was undertaken in four major wheat producing regional states (Amhara, Oromia, SNNPR, Tigray – which collectively represent 92% of national wheat production) using the standard AgSS stratified two-stage cluster sampling design. Enumeration Areas (EA) in each *zone* (the third administrative tier) were randomly selected using a probability proportional to size sampling technique where size represents the number of agricultural households. For the genotyping, 432 EAs were selected from the four regional states in 2016/2017. Subsequently, 20 agricultural households within each sample EA were randomly selected from household lists. Crop-cuts were taken from ten out of the twenty wheat plots randomly identified per EA. The crop cuts were conducted on a randomized selection of a 4 m $\times$ 4 m subplot within a randomly selected field. For the DNA sample, grain from the 4 m $\times$ 4 m crop-cut was air dried to constant weight, mixed and a random 200–250 g sample of grain was collected for DNA extraction. DNA was extracted from ground flour samples using standardized techniques by the National Biotech Centre at Holeta under the Ethiopian Institute of Agricultural Research (EIAR). Extracted DNA samples were genotyped by Diversity Arrays Technology (DArT) in Canberra, Australia using standard DArT protocols. A total of 3771 wheat field samples with genotyping were available from the 2016/2017 *Meher* cropping season. For the details of the DArTseq protocols involved at DArT including the sampling process, DNA extraction, DArTseq genotyping, and genetic ID/purity determination, we refer to Hodson *et al.* (2020) who used the same dataset as this study and provided a comprehensive methodological account.

The genotyped samples ($n = 3771$) were compared against a comprehensive wheat reference library comprising 111 unique varieties out of 133 total wheat varieties released in Ethiopia till 2016 (inclusive). Breeder seed for all reference varieties was obtained directly from the research centers that released the varieties or the national wheat coordinating research center, i.e., Kulumsa Agricultural Research Center. It was not possible to obtain seed for the missing 22 varieties – all of which were old and considered to be out of production. In most cases, multiple sources or multiple collections of breeder seed were sampled for each variety and the genotypic data analyzed for consistent results across samples from the same variety.

This sampling and genotyping methodology permitted a large, representative sample of the main wheat growing areas in Ethiopia. Varieties are compared based on farmer reports (recall)

[3]*Meher:* any temporary crop harvested between the months of September and February is considered as *Meher* season crop
[4]SNNP: Southern Nations Nationalities and Peoples.
[5]AgSS is the largest survey undertaken in Ethiopia with approximately 45 000 rural households surveyed each year.

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and genotyping results; the extent of matching between these two identifiers is estimated based on percentage matches. Similar comparison is also made against the aggregate official demand and supply data collected from the formal seed sector. Accordingly, the interplay between the demand and supply of the seed of wheat varieties is explained.

Varietal replacement

We also examine the rate at which farmers replace old wheat varieties with new ones. The varietal replacement rate will have important implications for the seed system in planning and deciding when to supply new varieties. Varietal replacement rate (also known as variety turnover rate) is useful to understand the longevity of disease resistance in varieties and the vulnerability of a crop to disease epidemics. It also affects potential productivity and yield variability as well as returns to public investment in crop improvement (Alston *et al.*, 2000; Day-Rubenstein *et al.*, 2005; Walker and Alwang, 2015). In addition, varietal replacement rate serves as performance indicator of the seed system and the dominance (or not) of varieties developed by plant-breeding in a given cropping system (Spielman and Smale, 2017).

The characterization of a given variety as 'new' or 'old' can be arbitrary (Brennan, 1984; Johnson and Gustafson, 1962). For this reason, researchers have proposed several definitions that measure rates of varietal turnover based on the age parameter. In this study, we estimate varietal age in two ways. One approach is based on the number of years (times) the farmers reported as have been growing the variety being cultivated since the first time of receipt until the time of the survey. This is unweighted average age based on farmer report irrespective of the extent of their use. A second approach is based on area weighted varietal age which considers the time (from release to survey year) and space (area under use) dimensions of a given variety. The area weighted varietal age also potentially provides better disaggregated estimates at different level of units of analysis such as national, regional state, and district as geographical domain. The indicator is known as (area)-weighted average variety age (WA or WAVA) proposed by Brennan and Byerlee (1991). For a given year, the WAVA is computed as

$$WAVA_t = \sum\nolimits_i p_{it} R_{it}$$

where p_{it} is the proportion of the crop's area cultivated in variety i in year t, and R is the number of years at time t since the release of variety i. For comparison purpose, apart from farms at household level, we have used different geographical units including national (overall sample), regional states, and zone to compute the varietal turnover at different levels. Varietal replacement rate is also computed and compared based on farmer's report and the genotyping result. The difference between the two estimates would underline the significance of varietal identification for effectiveness of the seed system. It is important to note that WAVA is sensitive to the identity (name) of the variety which implies the year of release and determines the value of R as stated in the equation. For example, if farmer's report identifies the wheat variety known as *Kubsa* (released in 1994) as *Kakaba* (released in 2010), which is often the case as in Jaleta *et al.* (2020), the varietal age will be different when calculated based on farmer reports and genotyping. This is because the two varieties have different years of release and possibly different area coverage under the two estimates. The calculation of WAVA does not include local or unknown/unclassified varieties as they do not have data on the year of release.

There are alternative measures of varietal replacement. For instance, Johnson and Gustafson (1962) propose to construct an index of varietal newness by comparing the proportion of area covered by presently grown varieties with the proportion covered by the same varieties in earlier period. A limitation with this is related to its sensitivity to the choice of target period for turnover of varieties and requires long time-series data to construct the index for any given year.

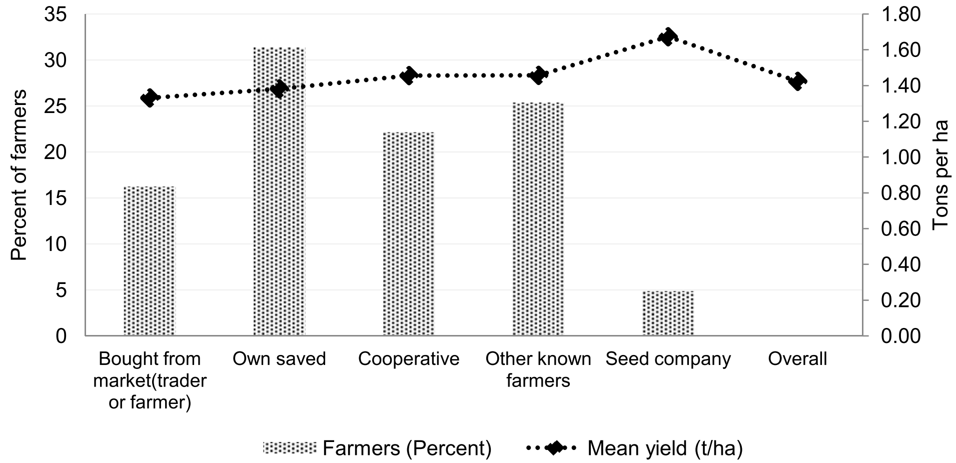

Figure 1. Seed sources used by sampled farmers and the mean yield by respective sources.
Source: CIMMYT/EIAR/CSA Survey, 2016/2017.

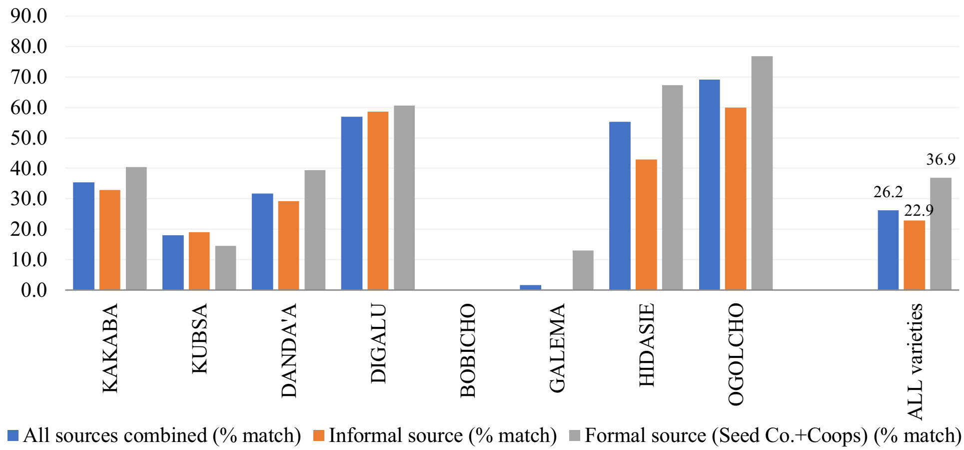

Figure 2. The relationship between seed sources and level of correct varietal identification (% correctly matched) for the top 8 varieties.

Results

Wheat seed sources

Most of our sampled wheat farmers used informal seed sources in the survey year. The dominant ones were seed from own (farmer) saved and other known farmers. From among the formal sector, cooperatives were the main seed source. Only less than 5% of sampled farmers used seed received from seed companies (Figure 1). Generally, the result showed that farmers who received seed from formal sources had higher yields (particularly, from seed companies) compared to those who used seed from informal sources.

We examined the association between seed source and farmers' ability to correctly identify the variety they grew. Accordingly, we observed that farmers who received certified seed from formal sources were able to correctly identify the varieties they grew in 37% of the cases compared to 23% by those who received seed from informal sources (Figure 2). Among the top ten varieties, none of the farmers were able to correctly identify *Bobicho* and *Arendato* – relatively old varieties

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(for detail see Supplementary Table S1). In addition, we made similar comparison between farmers who received certified seed from different formal sources, viz. seed company and cooperatives. Seed recipients from seed company were relatively better in correctly identifying the varieties they grow compared to those who received from cooperatives (43% vs 36%) (see Figure S2). Farmers who received wheat varieties such as *Kubsa*, *Bobicho*, and *Galema* from formal sources did not correctly identify them at all. This might be due to the fact that these varieties were mostly received from cooperatives (see Table S2) where correct identification was relatively an issue (as indicated in Figure S2) compared to those who got seed from seed companies.

Seed recycling and varietal age

Whereas recycling wheat seed is common, over recycled seed is likely to lose varietal purity and productivity. The extent of informal seed sources, however, makes it difficult to determine the number of times the seed was recycled before it reaches the respondent farmers. A farmer who receives seed from informal sources cannot correctly tell whether the seed was relatively fresh or not at the time of first acquisition. Thus, the farmer's response to the question 'how many times did you replant seed of this variety since you got it from other sources' needs to be taken with caution.

Our finding indicated that from the first acquisition of wheat seed until the time of our survey, the farmers reported to have refreshed their wheat seed stock only 2 times, on average. About 40% of the sample farmers refreshed the seed they used only once or twice. A quarter of our sample farmers had never changed their seed into a fresh one (See Figure S3). The average wheat growing experience of the sample farmers was about 16 years, which means for optimal performance, they should have refreshed their seed at least three times. Our data indicated that this is the case only for about 34% of the sample farmers. We estimated that it takes about six years, on average, for wheat farmers to refresh their seed stock (Figure S3, we used 16 years (the average wheat growing experience) for farmers who reported to have never refreshed their seed).

Following farmer reports, we computed an unweighted varietal age of currently grown wheat varieties based on the number of years from the first reported use of the current variety up to the survey time. While nearly a fifth of the sample farmers reported a varietal age of 5 or less years, about 12% reported a varietal age greater than 10 years (see Figure S4). The unweighted varietal age showed that farmers grew their current varieties for eight years, on average.

One may expect yield levels to decline when a given variety is over-recycled. The farmer reported data support this claim revealing a declining average as farmers continue to recycle the seed. For seeds recycled for 10 years or longer, the average yield remains around only one ton per hectare (see Figure S5). The lower yield observed for farmers who claimed to have used fresh seed could be an indication that they might have received from other farmers who already recycled it for some time. The average years to change the varieties (8 years) and refresh the seed stock (6 years) of currently grown varieties may generally reflect the extent of informal seed sources.

The area weighted average varietal age was estimated for various analytical levels (from national to farm household) based on farmer reports and genotyping (Table 1). The precision of estimates based on farmer reports depends on the farmers' ability to properly identify the name of the variety and the area cultivated to the variety in which case the genotyping based estimate is more robust.

Across levels of analysis, the farmer reported varietal age is in favor of newer varieties compared to the old ones they grow. The average varietal turnover rate based on genotyping is about five years longer than the one based on farmer reports. According to the farmer reports, the area weighted average age of varieties in use was about nine years at the national level and eight years at the regional state level. The corresponding figure from genotyping was fourteen and thirteen years, respectively. The genotyping results were consistent and comparable across specific

Table 1. Wheat varietal age based on farmer reports and genotyping

Level of analysis	Area weighted average varietal age (years)	
	Farmer reported	Genotyping based
National*	8.9	13.8
Regional states**	8.0	13.3
Tigray region	8.8	12.4
Amhara region	5.6	13.1
Oromia region	12.3	15.0
SNNP*** region	5.3	12.7
Zonal	6.4	15.1
Household (Farm)	6.7	12.6

*National refers to main wheat cultivating areas in the country that are in the sample.
**Average of the weighted averages for each of the four regional states.
***SNNP: Southern Nations Nationalities and Peoples regional state.

regional states except for Oromia where older varieties (15 years) prevail. Likewise, farmer reports showed that Oromia had markedly old varieties (12 years) compared to the other regional states. Of the 38 wheat varieties identified (via genotyping) as grown in Oromia, 36% of the total plots planted to wheat were allocated to *Kubsa* and *Digalu* varieties that were released in 1994 and 2005, respectively. Also we disaggregated the wheat varietal age by zones[6] (see Figure S6); the averages for genotyping were consistently higher than that of farmer reported ones. Based on farmer report, the area weighted varietal turnover at household level (6.7 years) was comparable with the unweighted varietal age reported earlier (8 years). The corresponding area-weighted varietal turnover based on genotyping, however, showed a contrasting figure of 12.6 years, on average, suggesting that households keep a given variety longer than they claim.

Stated demand of wheat varieties

Stated demand refers to the official demand which is collected from farmers by asking the variety of their preference which they plan to grow next season. Demand for a product is a function of knowledge and preferences, and we assume that farmers have made a choice from available options (varieties); and this choice is implicitly taken as a proxy of demand for that particular variety. From a total of 19 varieties in the stated wheat seed demand data, *Kakaba* (27% of stated demand) and *Danda'a* (25%) were the most demanded varieties (in that order) during the 2016/2017 cropping season followed by *Digalu* (13%) and *Hidasie* (9%) (Table 2). In terms of the quantity of seed supplied, however, *Hidasie* (24% of the supply) followed by *Ogolcho* (19%), *Kakaba* (18%), *Danda'a* (14%), and *Kubsa* (8%) were the top five varieties supplied from a total of 13 stated in the wheat seed supply data. Some of the varieties (mostly released in 2009 or later) were supplied 2–4 times the demand implying a possible seed carryover to the next year. Except the varieties known as *Kubsa* and *Tusie* which were released in the 1990s, almost all the other old varieties were under supplied. The formal sector is inclined to push seed of newer varieties whereas the demand is more focused on older ones.

Farmer reported use of wheat varieties

Based on farmer reports, as proxy for revealed demand, the wheat varieties used and their corresponding proportion of area as well as number of plots are presented in Table 3. The two proportions (area or plot) provided comparable estimates. Accordingly, *Kakaba* is by far the most widely cultivated variety (15% of the sampled wheat area) followed by *Digalu*,

[6]Zone is the next lower administrative tier after regional states (Provinces).

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Table 2. Official (stated) demand and formal supply (in metric ton) of different wheat varieties at national level

Name of varieties	Year of release	Stated demand (A)	Share (%) of stated demand (B)	Formal supply (C)	Share (%) of formal supply (D)	Proportion (%) of supply to demand (C/A)
Kubsa	1994	2,408.9	4.3	4,941.1	8.3	205
Galama	1995	42.4	0.1	–	–	–
Kakaba	2010	15,028.3	26.8	10,700.9	18.0	71
Danda'a	2010	13,782.5	24.5	8,249.7	13.8	60
Digalu	2005	7,439.1	13.2	984.2	1.7	13
Pavon-76	1982	2,023.5	3.6	771.1	1.3	38
Hawi	1999	2,320.5	4.1	–	–	–
Tusie	1997	613.9	1.1	977.0	1.6	159
ET-13	1981	477.0	0.8	–	–	–
Mangudo@	2012	132.5	0.2	58.35	0.1	44
Simba	1999	1,101.7	2.0	–	–	–
Sofumar	1999	23.8	0.0	24.5	0.0	103
Hidase	2012	4,876.0	8.7	14,045.2	23.6	288
Huluka	2012	1,673.2	3.0	4,414.2	7.4	264
Shorima	2011	977.1	1.7	2,780.4	4.7	285
Ogolcho	2012	2,674.8	4.8	11,524.5	19.3	431
Mada-Walabu	1999	442.2	0.8	–	–	–
Ejersa@	2005	94.5	0.2	–	–	–
Tate@	2009	29.4	0.1	131.9	0.2	449
Total		56,161.3	100	59,603.1	100	106

@Durum wheat varieties and all the rest are bread wheat varieties.
Source: Official document of the Ethiopian Seed Enterprise and the Regional state counterparts prepared for 2016/17 production season.

Danda'a, and *Kubsa* (6–9% each) and a range of other varieties for a total of more than 30 varietal names. This compares reasonably well with the stated demand (viz. *Kakaba*, *Danda'a*, *Digalu,* and *Hidasie* as top four). The name used by farmers to identify the variety could, however, still be incorrect. It takes the genotyping result to confirm if the varieties grown and reported by farmers are the same. Farmers report their perceived varietal identity which for whatever reason may not necessarily represent the actual variety.

Genotyping verified use of wheat varieties

A more robust proxy for revealed demand is the genotyping verified use of wheat varieties in the survey year. Based on genotyping, the wheat varieties used with their corresponding share of area/ proportion of plots are presented in Table 4, again area and plot indicators provided a comparable estimate. *Kakaba* is again by far the most widely cultivated variety (with 26% of sample wheat area), followed by *Kubsa* (12%), *Digalu* (10%), *Danda'a* (9%), and other five varieties each grown in over 2.5% and an array of less widely grown varieties (Table 4). The top four varieties together covered nearly 60% of the wheat area.

Consistent with the stated (official) demand and farmer reports, the genotyping verified use confirms that *Kakaba* is the most widely cultivated variety in Ethiopia at the time of the survey. Quantitatively, while the genotyping verified use (26% of area) largely coincides with stated demand (27%), the corresponding figure for farmer reported use (15%) was relatively lower. Likewise, genotyping verified use of *Kubsa* – a relatively popular yet older variety – was about double the area of farmer reported use (12% vs. 6%). The stated demand for *Kubsa* was even lower (4%), whereas the share from the formal supply was about 8%. The data, in general, suggest a moderate convergence in area-based ranking (but not the actual area covered) between farmer reports and genotyping verified wheat varietal use. And yet the rank convergence may not guarantee an exact varietal match between the two estimates because it is based on an aggregate figure, not a one-to-one matching on each plot. Thus, despite similarity in the ranking trend, there are differences in the size of area coverages of these varieties between the farmer report and genotyping result.

Table 3. Wheat varietal use indicators based on farmer reports

Wheat variety reported	Year of release	Share (%) of sample plots (*N* = 3666)	Share (%) of sample area (*N* = 703 ha)
Kakaba	2010	13.12	15.38
Digalu	2005	7.17	9.08
Danda'a	2010	5.62	7.79
Kubsa	1994	4.04	5.74
Dashen	1984	4.26	3.50
Hidasse	2012	3.08	2.99
Ogolcho	2012	2.54	2.49
Pavon-76	1982	1.01	1.56
Hawii	1999	0.49	1.54
Tusie	1997	0.87	1.51
Mada-Walabu	1999	0.87	1.47
Huluka	2012	0.57	1.09
Sofumar	1999	0.22	0.69
Galema	1995	0.55	0.54
Shorima	2011	0.68	0.53
Dereselign	1974	0.22	0.49
Batu	1984	0.41	0.49
Tate	2009	0.05	0.43
Enkoy	1974	0.57	0.34
HAR-407	1987	0.35	0.29
Arsi-Robe	1996	0.44	0.26
CI-14393	1975	0.25	0.26
Lakech	1967	0.49	0.22
Tay	2005	0.19	0.20
Mamba	1973	0.25	0.20
Ejersa	2005	0.05	0.18
Simba	1999	0.25	0.18
K6294A	1980	0.11	0.16
Other varieties*	–	2.19	1.59
Improved but names unknown**	–	16.75	12.08
Local**	–	32.35	26.77
Total	–	100.00	100.00

*Includes 30 more varieties specifically named by farmers
**'Improved unknown' and 'local' are generic labels (no specific variety name provided by farmer). N refers to total sample plots/area based on farmer report
Source: CIMMYT/EIAR/CSA Survey 2016/2017.

Comparison between farmer reported and genotyping verified use

The level of match between farmer reported and genotyping verified use of wheat varieties is compared based on aggregate area covered by each one of the varieties. Accordingly, the proportion of farmer-reported area to that of genotyping verified report was 59% for *Kakaba* and 47% for *Kubsa* – the two widely cultivated varieties (see Table S3). The area-based varietal match was relatively larger for *Digalu* (83%) and *Danda'a* (92%) and some other less widely used varieties. Among the top ten wheat varieties, the genotyping result showed that *Bobicho* and *Arendato* covered some area, but these varieties were not reported at all by farmers.

The plot-based comparison (Table 5) is more accurate in the sense it can match the farmer reported and genotyping verified varietal use for each plot. This matching confirms the stark difference between the two estimates. For example, out of all plots planted to *Kakaba* (based on genotyping result), farmers correctly reported as such for only 35% of their plots, a large under-reporting of *Kakaba* by farmers. Conversely, out of all the plots farmers reported as planted to *Kakaba*, about 75% of them correctly matched with the genotyping result. For *Kubsa* – the second most popular variety – farmers correctly identified only 18% of their plots. Although the number of plots were relatively small, farmer-reported use had a better match with genotyping verified use for the recently released varieties – *Ogolcho* (matched for 69% of the plot), *Digalu* (57%), and

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Table 4. Wheat varietal use indicators based on genotyping

Wheat variety identified	Year of release	Share (%) of sample plots ($N = 3771$)	Share (%) of sample area ($N = 710$ ha)
Kakaba	2010	27.02	25.80
Kubsa	1994	12.94	12.20
Digalu	2005	8.01	9.82
Danda'a	2010	9.94	9.26
Galema	1995	4.96	5.53
Bobicho	2002	5.78	4.57
Pavon-76	1982	2.44	3.39
Hidasie	2012	3.02	2.83
Ogolcho	2012	2.57	2.64
Arendato	1966	2.49	2.12
Hawi	1999	1.64	1.91
Simba	1999	1.83	1.85
Tusie	1997	0.93	1.60
Hulluka	2012	0.88	1.10
Sirbo	2001	0.80	1.04
Mada walabu	1999	0.72	0.98
Lasta	2002	0.16	0.82
Bolo	2009	0.61	0.79
Shorima	2011	1.19	0.72
Gambo	2011	0.58	0.65
Dereselign	1974	0.80	0.64
Katar	1998	0.37	0.61
ET-13	1981	0.64	0.57
Enkoy	1974	0.48	0.55
K6294A	1980	0.80	0.55
Sofumar	1999	0.21	0.48
Other varieties*		2.17	2.12
Unclassified		6.05	4.88
Total		100.00	100.00

*Includes 20 more varieties identified by DNA fingerprinting. 'Unclassified' includes varieties that could not be mapped against the reference library. N refers to sample plots/area based on DNA results.
Source: CIMMYT/EIAR/CSA Survey 2016/17.

Hidasie (55%). Among the old varieties, *Mada-Walabu* (70%) and *Tusie* (69%) had higher matches between the two estimates even if these varieties constitute only small number of plots.

For both plot- and area-based indicators, the dominant varieties are similar. For the top four varieties, Figure 3 shows the farmer-reported variety names against the genotyping verified results. Generally, farmers show a tendency to report these widely cultivated wheat varieties either as local or as unknown improved variety. They also misreport them using the name of other wheat varieties. Of the four varieties, farmers correctly identified *Digalu* markedly better, followed by *Kakaba* and *Danda'a* and trailed by *Kubsa*; *Kakaba* is misreported using the name of many different other wheat varieties (including as *Kubsa*, *Danda'a*, and *Digalu*).

The evidence thus shows marked differences between the farmers' reports and genotyping verified use. Typically, farmer reports underestimate the coverage of specific wheat varieties, in part linked to their common use of generic labels as 'improved varieties' and misidentifying as 'local'. For example, the genotyping verified use estimate of the top four wheat varieties taken together (57% of wheat area) was markedly higher than the farmer reports (38%). Farmers did not only have difficulty in identifying the wheat varieties with names but also often confuse them with other varieties. This is an important indication that seed demand assessment based only on farmer reports cannot be reliable enough to guide the supply (production and/or distribution) of required wheat varieties.

Comparison of demand and supply of wheat varieties

Table 6 presents the various demand and supply indicators of wheat varieties based on official, farmer-reported, and genotyping verified data. The quantity supplied by formal sources did not

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Table 5. Comparison of plot indicators for wheat varietal use based on farmer reports and genotyping

Wheat varieties	Year of release	Number of plots: Genotyping verified (A)	Number of plots: Farmer reported (B)	Number of correctly matched plots (C)	Correctly matched plots (%): As share of genotyping verified plots (C/A)	Correctly matched plots (%): As share of farmer reported plots (C/B)
Kakaba	2010	1019	481	361	35.4	75.1
Kubsa	1994	488	148	88	18.0	59.5
Danda'aa	2010	375	206	119	31.7	57.8
Digalu	2005	302	263	172	57.0	65.4
Bobicho	2002	218	0	0	0.0	–
Galema	1995	187	20	3	1.6	15.0
Hidasie	2012	114	113	63	55.3	55.8
Ogolcho	2012	97	93	67	69.1	72.0
Arendato	1966	94	0	0	0.0	–
Pavon-76	1982	92	37	30	32.6	81.1
Simba	1999	69	9	3	4.4	33.3
Hawi	1999	62	18	6	9.7	33.3
Shorima	2011	45	25	14	31.1	56.0
Tusie	1997	35	32	24	68.6	75.0
Hulluka	2012	33	21	9	27.3	42.9
Sirbo	2001	30	0	0	0.0	–
Dereselign	1974	30	0	0	0.0	–
K6294A	1980	30	4	2	6.7	50.0
Mada-Walabu	1999	27	32	19	70.4	59.4
ET-13	1981	24	1	1	4.2	100.0
Bolo	2009	23	0	0	0.0	–
Gambo	2011	22	0	0	0.0	–
Enkoy	1974	18	21	2	11.1	9.5
Other*	–	109	2142	6	5.5	5.5
Unclassified	–	228	–	–	–	–
Total		3771	3666	989	26.2	27.0

*"Other" includes less common varieties, and for farmer reported it also includes unknown improved and local varieties.
Source: CIMMYT/EIAR/CSA Survey 2016/17.

match well with the stated demand. *Kakaba* (27% of stated demand), *Danda'a* (25%), *Digalu* (13%), and *Hidasie* (9%) were the top four varieties which represented 74% of stated seed demand. Except for *Digalu* (released in 2005), the remaining three were new varieties released in 2010 or later. Farmer demand for relatively recent varieties is encouraging given the dynamics in wheat disease. In contrast, the top four wheat varieties formally supplied were *Hidase* (25% of the stated demand), *Ogolcho* (21%), *Kakaba* (19%), and *Danda'a* (15%) which together make up 80% of the total quantity of stated demand (Table 6). Correspondingly, these varieties cover 75% of the total amount supplied formally, and most of the varieties supplied well above the stated demand were the most recent ones on offer at the time of the study (refer to Table 2). Among the four most demanded varieties (stated demand), the only recent variety that was oversupplied was *Hidasie* reinforcing the argument that there is a supply-push toward the newly released wheat varieties.

If we consider the top varieties in terms of stated demand, their position in the farmer-reported use - *Kakaba* (15% of area), *Digalu* (9%), *Danda'a* (8%), and *Hidasie* (3%) – broadly ranked similarly albeit with marked differences in actual use. In all cases, the stated demand was well above farmer-reported use. The genotyping results follow a similar pattern except that farmer-reported use underestimated the use of *Kakaba* and *Kubsa* varieties. Genotyping results put *Kubsa* as the second most important variety in terms of use (12% of area), which contrasts with the corresponding lower stated demand (4%) and farmer reported use (6%).

The difference between the stated demand and genotyping verified use of the top wheat varieties is not consistent across varieties. For instance, for *Danda'a*, the genotyping verified use (9%) is

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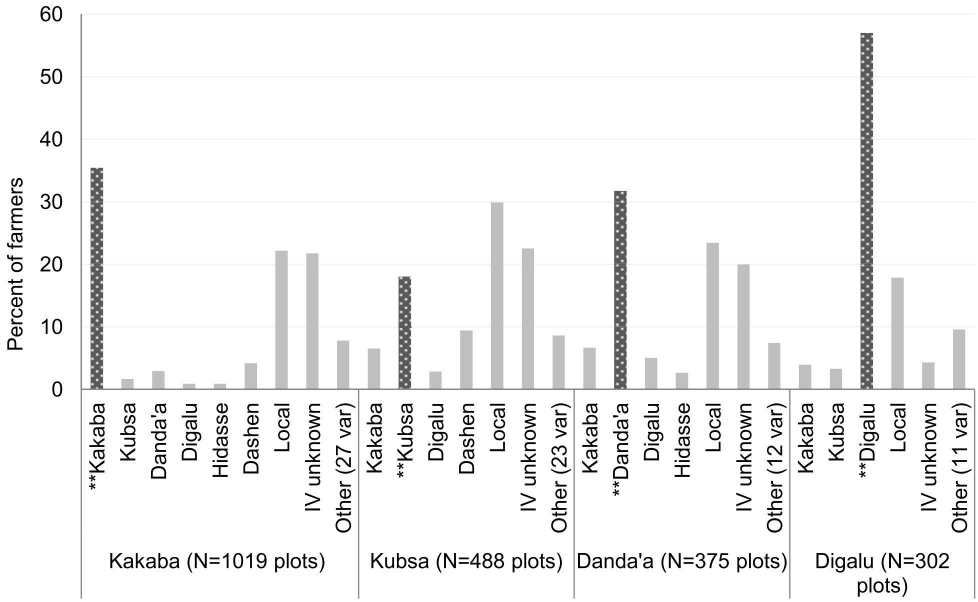

IV: Improved variety; *** The entries correctly reported/identified by farmers;*
Number of plots in parenthesis next to the four varieties refers to observations based on genotyping verified use

Figure 3. Share of farmers who correctly (dark bar) or incorrectly (light bar) reported the four dominant wheat varieties (Kakaba, Kubsa, Danda'a, Digalu) identified by genotyping.
Source: CIMMYT/EIAR/CSA Survey 2016/17.

much below stated demand (25%) suggesting this recent variety may expand further. *Hidasie* was another new variety which had stated demand (9%) well above verified use (3%). In contrast, *Kubsa* had a low stated demand compared to its verified use (4% vs. 12%) suggesting it is on a declining path. Varieties such as *Kakaba* (27% vs. 26%) and *Digalu* (13% vs. 10%) had relatively comparable stated demand and actual use suggesting the stated demand predicted the actual use well and probably indicative of varietal plateauing.

Discussion

Availability and access to quality certified seed of new improved wheat varieties is key to enhance and stabilize wheat productivity and production in Ethiopia. The country's annual demand for certified seed of improved wheat varieties (like for other crops) is estimated from official projections aggregated along the administrative hierarchies. The main suppliers of certified seed are seed parastatals (regional/national seed enterprises), farmer union/cooperatives, and private enterprises (mainly for hybrid maize). The proportion of farmers receiving wheat seed from the formal sources is about 27% (cf. 16% according to Alemu and Bishaw (2015)). Most wheat farmers used informal seed sources in the survey year, with farmer saved seed being most common. This has important implications for seed quality, stress tolerance, yield performance, as well as replacement of old varieties with new ones. For example, we found that farmers using wheat seed from formal sources (esp. seed companies) are more likely to correctly identify the variety they grow and achieve higher yields.

Varietal age and seed quality are important for the resilience of the wheat production system. Farmers may continue to recycle the seed of their preferred variety until fresh seed is available.

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Table 6. Demand and supply indicators of wheat varieties based on official data, farmer reports and genotyping (national level, Ethiopia)

		Of the total stated demand (56,161.3 metric tons)				Difference between stated demand vs.		
Name of varieties	Year of release	Share (%) of stated demand	Share (%) of formal supply	Share (%) of farmer reported sample area (703 ha)	Share (%) of genotyping verified sample area (710 ha)	Farmer Reported use (%)	Genotyping Verified use (%)	Formal supply (%)
A	B	C	D	E	F	G (C-E)	H (C-F)	I (C-D)
Danda'a	2010	24.5	14.7	7.8	9.3	16.8	15.3	9.9
Digalu	2005	13.3	1.8	9.1	9.8	4.2	3.4	11.5
Ejersa	2005	0.2	0.0	0.2	0.1	0.0	0.1	0.2
Enkoy	1974	0.0	0.0	0.3	0.6	−0.3	−0.6	0.0
ET-13	1981	0.9	0.0	0.02	0.6	0.8	0.3	0.8
Galama	1995	0.1	0.0	0.5	5.5	−0.5	−5.5	0.1
Hawi	1999	4.1	0.0	1.54	1.9	2.6	2.2	4.1
Hidase	2012	8.7	25.0	3.0	2.8	5.7	5.9	−16.3
Huluka	2012	3.0	7.9	1.1	1.1	1.9	1.9	−4.9
K6294A	1980	0.0	0.0	0.2	0.4	−0.2	−0.4	0.0
Kakaba	2010	26.8	19.1	15.4	25.8	11.4	1.0	7.7
Kubsa	1994	4.3	8.8	5.7	12.2	−1.5	−7.9	−4.5
Mangudo	2012	0.2	0.1	0.1	0.1	0.2	0.2	0.1
Mada-Walabu	1999	0.8	0.0	1.5	1.0	−0.7	−0.2	0.8
Ogolcho	2012	4.8	20.5	2.5	2.6	2.3	2.1	−15.8
Pavon-76	1982	3.6	1.4	1.6	3.4	2.0	0.2	2.2
Shorima	2011	1.7	5.0	0.5	0.7	1.2	1.0	−3.2
Simba	1999	2.0	0.0	0.2	1.9	1.8	0.1	2.0
Sofumar	1999	0.04	0.04	0.7	0.5	−0.6	−0.4	0.0
Tate	2009	0.05	0.2	0.4	0.2	−0.4	−0.1	−0.2
Tusie	1997	1.1	1.7	1.5	1.6	−0.4	−0.5	−0.6
		100	106.24	53.78	82.0	46.2	18.0	−6.1

Source: Compiled from data of Ethiopian and regional state seed enterprises and CIMMYT/EIAR/CSA Survey 2016/17.

The frequency with which farmers refresh their seed stock and the rate at which they replace their old varieties is also an important indicator for the performance of the seed system. Although most farmers claim to refresh their seed stock within six years' time since first use (cf. breeders recommend not to recycle wheat seed more than 5 times), it is difficult to rely on this figure as their main source of seed is informal. Varietal replacement data also show a stark difference between farmer reports (9 years) and the genotyping result (14 years). This difference emanated from, among others, the accuracy of the variety name as the measure of varietal turnover is sensitive to varietal misidentification (Spielman and Smale, 2017). Extended recycling of the same seed and persistence of old varieties are likely to affect productivity due to possible loss of genetic purity and potential/mechanical contamination (physical admixtures) and build-up of seed borne disease. The persistence of old varieties implies vulnerability to the dynamics of wheat diseases such as rust depending on the longevity of disease resistance by the variety in use. The seed system needs to devise mechanisms to ensure timely replacement of the old varieties with new ones and refreshment of the seed stock of currently grown varieties. In this case, accurate knowledge of varietal age and identity is helpful to plan appropriate interventions to promote varietal replacement and adjust seed supply both in space and time.

The performance of the Ethiopian wheat seed market can be enhanced if the demand is properly estimated. There is a mismatch between the stated demand and formal supply of certified seeds of improved wheat varieties. The formal seed sector calibrates seed production/distribution decisions based on incomplete data that do not reflect the real demand on the ground. The extent of mismatch between stated and revealed demand is worrisome indicating that farmers may not

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correctly identify the wheat variety of their interest. Farmers' stated or revealed demands not only incorrectly estimate the coverage of currently grown varieties but also fail to recognize some of the varieties grown. Farmers' report, thus, may not be robust enough to guide the seed production and/or distribution decisions by the formal seed sector. In fact, if farmers do not know the new varieties, they may not request them and the demand for these varieties will be limited. This can limit the rate of varietal replacement and often results in some varieties being undersupplied while others are oversupplied with huge and costly seed stock carryovers. Moreover, given the widespread use of farmer saved seed, fresh seed of old varieties may have limited demand, and the formal seed sector mainly supplies more of the new wheat varieties than the old ones in favor of speeding up varietal replacement. Nonetheless, the discrepancy between demand and supply of wheat seed has a lot to do with the way demand for the different wheat varieties is aggregated. The estimation based on farmer stated demand is thus constrained by misidentification, as also reported by Jaleta *et al.* (2020), rendering it less reliable.

Apart from varietal misidentification by farmers, another possible reason for the discrepancy between seed demand and supply of wheat varieties could be that the aggregated demand is established for the seed which is already produced, and the estimated demand will only serve to inform the distribution of seeds of available varieties, not the production of those in demand. In any case, poor demand assessment resulting from varietal misidentification by farmers is an important source of mismatch between what the farmers need and what is formally supplied. The tendency on the part of the formal seed system to supply more of the recent varieties than the old ones further contributes to the difference. Carryover seed implies substantial opportunity costs to formal seed suppliers. Efforts by the formal seed sector to supply more of the new varieties, despite farmer demand for the old ones, will serve the purpose of hedging farmers against wheat disease dynamics and climate change only if it is preceded by a more proactive and aggressive promotion of the new varieties. Such promotion, beyond raising awareness and demand, should also increase farmers' ability to correctly identify the new varieties they want to grow. In this regard, much care needs to be given in the naming of the new varieties – names should be easy to remember and able to transcend language barriers – to reduce identification errors and consequently minimize the demand and supply mismatch.

Farmers' varietal misidentification, hence, remains an important challenge associated with assessing demand for specific wheat varieties based on farmer reports (stated or revealed). Often farmers misidentify their wheat varieties, either giving a wrong name (by interchanging names) or failing to identify a specific name. For instance, *Kakaba* is the most preferred variety, but many farmers still report it using the names of other varieties or do not identify it at all with a name, whereas other farmers misuse the name of this variety to identify other varieties. Although there is consistency in terms of the order of importance of the dominant varieties between the stated and actual demand, there still can be large differences in their magnitude (size of the demand). The genotyping-based estimate indicates that farmers tend to underestimate the coverage of dominant varieties. This is an important indication that seed demand assessment based only on farmer reports cannot be reliable enough to guide the supply (production and/or distribution) of required wheat varieties. Thus, given the limitations of the centralized seed demand projection which depends on past land allocation and/or farmer report, genotyping can stand as a better option to potentially predict effective seed demand for certified seeds of specific improved wheat varieties.

Genotyping can as well facilitate quicker varietal turnover and enhance the sustainability and resilience of wheat production systems in Ethiopia in light of the wheat disease dynamics and climate change. As such, the need to ensure rust resistance is the major driver for the release and replacement of wheat varieties in Ethiopia. In this context, proper identification of the varieties being cultivated, demanded, and supplied, using genotyping, can present a greater leverage to take important measures that can hedge the smallholder wheat growing farmers against persistent rust pressure and climate change.

Conclusions

Ethiopia promotes wheat production to become self-sufficient and potentially export the surplus. Seeds of improved wheat varieties play an important role therein and can help contain disease risks such as wheat rust associated with widespread production. Reliable information on the demand and use dynamics of wheat varieties is necessary to guide seed production/distribution decisions, optimize resource commitments by seed suppliers, and make appropriate seed available to the farmers. This study indicated that the conventional assessment of the demand for wheat varieties in Ethiopia does not fully align with formal seed supply or varietal use by farmers. Stated or revealed demand based on farmers' reports does not predict the actual demand due to challenges associated with varietal identification. Farmers' reliance on informal seed sources and own saved seed, among others, contributes to the misidentification of the varieties they grow. Consequently, they are likely to misinform the formal seed demand assessment leading to either an over- or underestimation of actual seed demand for specific wheat varieties. Genotyping verified use, as opposed to farmers' report, established the persistence of old varieties. This also implies vulnerability of wheat production to disease dynamics depending on the longevity of disease resistance by the variety in use. Apart from narrowing the gap between the actual and stated demand and ensuring timely replacement of wheat varieties, genotyping-based estimates can save seed carry-over cost.

Genotyping can be a useful technique to provide accurate estimates of the actual demand and thereby help improve the performance of the seed system. Given that wheat seed can be recycled for up to five times with minimum loss of varietal purity, it is advisable to genotype wheat varieties in use through representative sample surveys at least every four years, and such data through genotyping can also shed light on the freshness of existing seed stock and/or varietal replacement rate as one possible measure of the performance of the seed system. Genotyping of seed samples collected at certain interval may not predict annual demand, but can provide a robust regular varietal update for the seed system. It can also indicate varietal coverage by defined geographical location which can be used as an important guide for production and distribution of existing and new wheat varieties. Genotyping is increasingly used as the new benchmark and gold standard for identifying and tracking the adoption of crop varieties. The technique has the potential to enhance the performance of the seed sector by supporting an effective planning that can optimize resource commitments and accelerate the rate of varietal replacement. It is time to expedite the effort to mainstream the application of this technique in agricultural data generating institutions in Ethiopia such as CSA in a way to correctly estimate the spread and demand size of wheat varieties as well as measure/boost the performance of the seed system.

Supplementary material. For supplementary material for this article, please visit https://doi.org/10.1017/S0014479723000042

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References

Alemu D. and Bishaw Z. (2015). Commercial behaviours of smallholder farmers in wheat seed use and its implication for demand assessment in Ethiopia. *Development in Practice* **25**, 798–814. https://doi.org/10.1080/09614524.2015.1062469.

Alemu D., Rashid S. and Tripp R. (2010). *Seed System Potential in Ethiopia: Constraints and Opportunities for Enhancing the Seed Sector*. Washington, DC: International Food Policy Research Institute (IFPRI), 62pp.

Alston J.M., Chan-Kang C., Marra M.C., Pardey P.G. and Wyatt T.J. (2000). *A Meta-Analysis of Rates of Return to Agricultural Ex Pede Herculem?* Washington, DC: International Food Policy Research Institute.

Brennan J.P. (1984). Measuring the contribution of new varieties to increasing wheat yields. *Review of Marketing and Agricultural Economics* **52**, 175–195.

Brennan J.P. and Byerlee D. (1991). The rate of crop varietal replacement on farms: measures and empirical resu1ts for wheat. *Plant Varieties and Seeds* **4**, 99–10.

Central Statistical Agency (CSA) (2010). *Area and Production of Major Crops*. Agricultural Sample Survey, 2010/2011. Addis Ababa: The Federal Democratic Republic of Ethiopia, Central Statistical Agency (CSA).

Central Statistical Agency (CSA) (2020). *Area and Production of Major Crops*. Agricultural Sample Survey, 2010/2011. Addis Ababa: The Federal Democratic Republic of Ethiopia, Central Statistical Agency (CSA).

Day-Rubenstein K., Heisey P., Shoemaker R., Sullivan J. and Frisvold G. (2005). *Crop Genetic Resources: An Economic Appraisal*. USDA Economic Research Service (ERS) Economic Information Bulletin 2. Washington, DC: ERS.

De Groote H., Gitonga Z., Mungo S. and Walker T.S. (2015). Assessing the effectiveness of maize and wheat improvement from the perspective of varietal output and adoption in East and South Africa. In Walker T.S. and Alwang J. (eds), *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*. Wallingford, UK: CABI, pp. 206–227.

Dreisigacker S., Sharma R.K., Huttner E., Karimov A., Obaidi M.Q., Singh P.K., Sansaloni C., Shrestha R., Sonder K. and Braun H.J. (2019). Tracking the adoption of bread wheat varieties in Afghanistan using DNA fingerprinting. *BMC Genomics* **20**, 660. https://doi.org/10.1186/s12864-019-6015-4

FAOSTAT (2015). *FAOSTAT Statistical Database*. Rome: FAO, Food and Agriculture Organization of the United Nations.

Gade P., Alam M.A., Barma N.C.D., Majumder R., Garapaty R., Paranjape V.D., Killian A., Vijayaraghavan V.K., Kabir M.R., Hakim M.A., Islam M.Z., Hossain M.M., Rahman M.M., Rahman M., Khan A.A., Islam M.R., Hasan M.M., Amin M.F. and Acevedo M. (2021). Assessment of wheat variety adoption in Bangladesh through DNA fingerprinting. *Crop Science* **61**, 3564–3577. https://doi.org/10.1002/csc2.20579

Garapaty R., Majumder R., Thapa D., Upadhyay S.R., Baidya S., Basnet R., Bhandari D., Gade P., Paranjape V., Killian A., Vijayaraghavan K. and Acevedo M. (2021). DNA fingerprinting at farm level to map wheat variety adoption across Nepal. *Crop Science* **61**, 3275–3287. https://doi.org/10.1002/csc2.20497

Hei N., Shimelis H.A. and Laing M. (2017). Appraisal of farmers' wheat production constraints and breeding priorities in rust prone agro-ecologies of Ethiopia. *African Journal of Agricultural Research* **12**, 944–952. https://doi.org/10.5897/AJAR2016.11518.

Hensher D.A. (1993). *Stated Preference Analysis of Travel Choices: The State of Practice*. Working Paper ITS-WP-93-6. Institute of Transport Studies Graduate School of Business, The University of Sydney NSW 2006.

Hodson D.P., Jaleta M., Tesfaye K., Yirga C., Beyene H., Kilian A., Carling J., Disasa T., Alemu S.K., Daba T., Alemayehu Y., Badebo A., Abeyo B. and Erenstein O. (2020). Ethiopia's transforming wheat landscape: tracking variety use through DNA fingerprinting. *Scientific Reports* **10**, 18532. https://doi.org/10.1038/s41598-020-75181-8

IRRI (International Rice Research Institute) (2013). *Seed Quality Training Manual*: Postharvest Unit, CESD, International Rice Research Institute (IRRI).

Jaleta M., Tesfaye K., Kilian A., Yirga C., Habte E., Beyene H., Abeyo B., Badebo A. and Erenstein O. (2020). Misidentification by farmers of the crop varieties they grow: lessons from DNA fingerprinting of wheat in Ethiopia. *PLoS ONE* **15**, e0235484. https://doi.org/10.1371/journal.pone.0235484.

Johnson D.G. and Gustafson R.L. (1962). *Grain Yields and the American Food Supply: An Analysis of Yield Changes and Possibilities*. Chicago, III: University of Chicago Press.

Kosmowski F., Aragaw A., Kilian A., Ambel A., Ilukor J., Yigezu B. and Stevenson J. (2019). Varietal identification in household surveys: results from three household-based methods against the benchmark of DNA fingerprinting in southern Ethiopia. *Experimental Agriculture* **55**, 371–385. https://doi.org/10.1017/S0014479718000030

Lakew T. and Alemu D. (2012). Approaches and procedures of seed demand assessment in the formal seed sector. In Teklewold A., Alemu D., Kiyoshi S. and Kirub A. (eds), *Proceedings of Seed Demand Assessment: Practices, Challenges, and Options*. Addis Ababa: Ethiopian Institute of Agricultural Research/Farmer Research Group II, pp. 1–8. Empowering farmers' innovation series no.5. https://doi.org/10.13140/RG.2.2.27447.62888.

Minot N.W., Warner J., Lemma S., Kasa L., Gashaw A. and Rashid S. (2015). *The Wheat Supply Chain in Ethiopia: Patterns, Trends, and Policy Options*. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.13140/RG.2.1.3408.7285.

MoA (2020). *Crop Variety Register. Issue No.23. Plant Variety Release, Protection and Seed Quality Control Directorate*. Addis Ababa, Ethiopia: Ministry of Agriculture.

https://doi.org/10.1017/S0014479723000042 Published online by Cambridge University Press

Poets A., Silverstein K., Pardey P., Hearne S. and Stevenson J. (2020). *DNA Fingerprinting for Crop Varietal Identification: Fit-for-Purpose Protocols, their Costs and Analytical Implications*. Rome: Standing Panel on Impact Assessment (SPIA).

Spielman D.J. and Mekonnen D.K. (2018). Seed demand and supply responses. In Minten B., Taffesse A.S. and Brown P. (eds), *The Economics of Teff: Exploring Ethiopia's Biggest Cash Crop*. Washington, DC, pp. 71–96. https://doi.org/10.2499/9780896292833.

Spielman D.J. and Smale M. (2017). Policy Options to Accelerate Variety Change among Smallholder Farmers in South Asia and Africa South of the Sahara. IFPRI, Discussion Paper 01666. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131364.

Walker T.S. and Alwang J. (2015). The importance of generating and documenting varietal change in Sub-Saharan Africa. In Walker T.S. and Alwang J. (eds), *Crop Improvement, Adoption, and Impact of Improved Varieties in Food Crops in Sub-Saharan Africa*. Wallingford, UK: CABI, pp. 1–6.

Yirga C., Jaleta M., Shiferaw B., de Groote H., Kassie M., Mebratu T. and Mohammad A. (2013). *Analysis of Adoption and Diffusion of Improved Wheat Technologies in Ethiopia*. Research Report 101. Addis Ababa, Ethiopia: Ethiopian Institute of Agricultural Research and the International Maize and Wheat Improvement Center.

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