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Varietal Adoption, Turnover, and Concentration for Major Crops in Ethiopia

Evidence from Household Surveys and Field Sample Genotyping

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Abstract

Although continuous genetic improvement of crops cultivated by smallholder farmers is a well-known route to increasing agricultural productivity, our understanding of varietal adoption, turnover, and concentration in farmers' fields is limited. Often, the greatest challenge to our understanding lies in the measurement approach (farmer self-reports versus DNA fingerprinting), as well as in the analysis and interpretation of the available data. To address this issue, we explore variety-level data on four main crops (wheat, maize, teff, and common bean) in Ethiopia. We estimate the area-weighted average varietal age (AWAVA) of each crop using data from a nationally representative sample survey of farm households and a unique genotyping dataset based on seed samples collected from the fields of sampled farm households. We also calculate indices to explore the concentration of varieties in farmers' fields, which serves to substantiate the varietal age analysis. Overall, results show considerable variation in average varietal age across crops, ranging from 12.5 years for wheat to 28.2 years for common bean. Analysis of area shares of individual varieties for each crop indicates that slower varietal turnover (i.e., higher varietal age) is driven by the continued dominance of older varieties, despite the presence of newer varieties in the market. Slow varietal turnover in the presence of new varieties suggests the need for greater investment in the systems and markets through which seed is distributed to farmers. This includes stronger coordination of research and extension activities, improvement of variety-specific popularization and marketing efforts, and continued experimentation in seed sector development in Ethiopia.

Keywords: Varietal turnover, genotyping, DNA fingerprinting, cereal crops, food security, Ethiopia

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1. Introduction

Crop genetic improvement and farmer adoption of improved crop varieties is an historically important pathway to increasing agricultural productivity, enhancing food security, and improving livelihoods in the Global South (Evenson and Gollin, 2003; Alwang et al., 2019; Avana-Tientcheu and Tiambo, 2019). The continuous improvement of cultivated varieties can provide farmers—especially small-scale, resource-poor farmers—with an effective means of increasing crop yields, reducing production costs, increasing the efficiency of land, water, and other natural resources, and mitigating damage caused by biotic and abiotic stressors. Varietal improvement can also introduce new traits that address micronutrient deficiencies in human diets or cater to consumer preferences and industry needs. In turn, these genetic improvements can enhance smallholders' capacity to generate viable livelihoods from farming and navigate weather and market risks, with the added benefit of reducing food prices for both urban and rural consumers (Singh et al., 2020; Henry, 2020; Gaikwad et al., 2020).

A rich body of empirical evidence demonstrates the importance of these multiple impact pathways leading from genetic improvement to productivity, welfare, and environmental outcomes (Matova et al., 2022; Abro et al., 2017). An equally rich body of empirical evidence highlights the challenges to improving the delivery of new varieties and related information to smallholders, with increasing attention given to incorporating context-specific agroecological conditions, farming systems, household food consumption patterns, and market demands (De Groote et al., 2025; Chivasa et al., 2022). Potential solutions to these challenges abound, with particular emphasis on improving the genetic and physical quality of seed supplied to farmers, improving the relevance and timeliness of information provision, and encouraging more effective marketing of new varieties (de Boef et al., 2024; Westengen et al., 2023; Gafney et al., 2016).

Yet it is often the very measurement, analysis, and interpretation of data on these topics that poses the most significant challenge to designing feasible solutions to these challenges. Seemingly simple indicators such as "adoption" are challenging to measure when the target population of interest is insufficiently defined, or when the intensity and duration of adoption are more relevant than a binary and static measurement (Diagne and Demont, 2007; Spielman and Kennedy, 2016). By the same token, varietal turnover rates are not simple to interpret: while most scientists and policymakers argue that productivity growth is increasing in the number of new varieties released to the market and supplied to farmers (e.g., Abate et al., 2017; Gisselquist et al., 2013), other researchers suggest that too many varieties and rapid turnover may be indicators of poorly targeted breeding priorities, insufficient information about each variety, or other systemic and market imperfections (e.g., Ramaswami et al., 2009). These issues have motivated prior studies on improving the measurement and analysis of varietal turnover, varietal concentration, and adoption patterns and trends (Brennan and Byerlee, 1991; Walker and Alwang, 2015; Spielman and Kennedy, 2016; Spielman and Smale, 2017).

To study these issues of measurement, analysis, and interpretation, we turn to Ethiopia. Since at least the 1970s, Ethiopia has invested in crop genetic improvement in support of its agricultural development agenda. The country has consistently allocated public resources to its national agricultural research system and crop improvement programs (see, e.g., Beintema and

Haregewoin, 2018), while collaborating closely with the international agricultural research system to obtain germplasm, scientific expertise, funding, and other resources (Alemu et al., 2024; Kosmowski et al., 2020).

Ethiopia also hosts a large-scale extension program and a formal seed system with considerable reach across the country's vast agricultural sector (Mengistu, 2016). Over the past five decades, successive efforts to strengthen coordination between and among crop improvement programs, seed producers, government extension services, and seed supply systems have played a role in delivering genetic gain to farmers' fields (e.g., Alemu et al., 2023, 2019; Haug et al., 2023; Hodson et al., 2020; Sisay et al., 2017; Alemu, 2011; Spielman et al., 2010).

Partly as a result of these investments, a substantial number of new varieties have been developed and delivered to farmers over successive periods (EAA, 2021). In the last decade, 67 new wheat varieties 39 maize varieties, 19 teff varieties, and 51 common bean varieties have been released (EAA, 2021) (see Figure 1 in the appendix).

During the past several decades, there have been changes in the organizations and infrastructure underlying Ethiopia's research, extension, and seed systems that are responsible for delivering these varieties to farmers' fields. However, the essential farmer-facing approach has remained fairly consistent. New varieties are developed by Ethiopia's national or subnational breeding programs with scientific and technical support from international agricultural research centers. After a series of national performance trials, newly released varieties are handed over to extension agents for promotion to farmers through on-farm field trials, field days, and other popularization strategies. The seed system—primarily driven by state-owned enterprises, smaller commercial seed producers, and cooperatives—then scales up production and delivery of new varieties to farmers (Habte et al., 2023).[1]

Yet despite Ethiopia's continuous investment in the development and delivery of new varieties, considerable variation remains across crops in terms of genetic gain. Notably, for certain crops, there is considerable evidence that farmers continue to cultivate older, less productive, or more stress-susceptible varieties (Walker et al., 2015; Jaleta et al., 2020). While there may be obvious reasons for why farmers choose to cultivate older varieties (Spielman and Smale, 2017), persistently low rates of genetic gain tend to highlight a potential mismatch between the supply and demand for improved varieties. Given Ethiopia's long-standing investments in genetic improvement, low rates of genetic gain on farmers' fields should be an important concern for policymakers in the country.

Key indicators that help characterize the nature of the problem can be captured by measuring varietal turnover and varietal concentration rates for a given crop (Spielman and Smale, 2017; Spielman and Kennedy, 2018). Varietal concentration rates can potentially indicate whether a few dominant (or several/diverse) varieties are covering the majority of a cropping landscape, and whether that landscape (and its cropping systems) are vulnerable to (or insulated from) variety-

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[1] For the most part, foreign or multinational seed companies are only present and active in Ethiopia's maize seed sector. See Abate et al. (2015) for a commentary on the marginal contribution of these companies to the sector.

specific production shocks. This is particularly relevant in the context of variety-specific susceptibility to pests, diseases, and adverse weather conditions, such as drought, heat, or cold.

Conventional practice has been to measure variety-specific quantities of seed produced by public and private seed producers, calculate each variety's age based on the number of years since its official release, and then calculate an average age that is weighted by the seed production quantities (Brennan and Byerlee, 1991). However, this approach requires that seed producers be willing and able to provide variety-specific seed production figures, while it overlooks the prevalence of seed saving practices and farmer-to-farmer seed exchanges. For certain open-pollinating, self-pollinating, and vegetatively propagated crops, seed saving and farmer exchanges may actually be the main source of seed for farmers, implying that seed production quantities from more formal producers are possibly irrelevant in analyzing the problem.

More recent practice has attempted to calculate average varietal age using data from farm-household surveys, and by deriving weights based on variety-specific areas under cultivation, seed quantities purchased for cultivation, or administrative data on seed distribution and crop cultivation (Naher and Spielman, 2021; Abate et al., 2017; Krishna et al., 2016; Smale et al., 2008). Unfortunately, these approaches are fraught with challenges. Farmers may not know what variety they cultivated; they may not be able to accurately recall the name of the variety they cultivated; they may provide local names of a variety that are unknown to the investigator; or they may provide responses that are too generic to be meaningful. To address this issue, considerable investment has been made in identifying varieties cultivated in farmers' fields through more objective and scientific genotyping approaches (Euler et al., 2022; Poets et al., 2020).

Recent studies that explore genotyping point out that farmer-reported data on variety adoption tend to contain a high rate of reporting errors, and estimate the consequences of incorrect varietal identification for input use and yield outcomes (e.g., Euler et al., 2022; Opata et al., 2021; Jaleta et al., 2020; Wineman et al., 2020; Wossen et al., 2019 Yigezu et al., 2019; Floro et al. 2018; Kosmowski et al., 2018; Maredia et al., 2016). Several such studies focus specifically on crop varieties in Ethiopia (Alemu et al., 2024; Bohr et al., 2024; Jaleta et al., 2020; Hodson et al., 2020; Kosmowski et al., 2019).

In this paper, we estimate the area-weighted average varietal age and the concentration of varieties in the field for four main crops (wheat, maize, teff, and common bean) in Ethiopia using data from a nationally representative farm household sample survey and a unique genotyping dataset based on seed samples collected from the fields of sampled farm households. The analysis aims to provide a more reliable estimate of varietal age for these four crops, improve the accuracy of varietal turnover rates, and highlight varietal concentration rates. This analysis is then meant to inform policy and investment.

2. Data and methods

The data used in this study were produced through a partnership among the Ethiopian Institute of Agricultural Research (EIAR) and its National Agricultural Biotechnology Research Center (NABRC), the Ethiopian Statistical Services (ESS) (previously known as the Central Statistical

Agency [CSA]), the International Maize and Wheat Improvement Center (CIMMYT), and Diversity Arrays Technology (DArT), with additional analytical support provided by the International Food Policy Research Institute (IFPRI).

The data were collected as part of the ESS's regular Agricultural Sample Survey (AgSS) program, in which crop cuts for major crops are regularly collected to estimate yield and output. The AgSS collects crop-cut harvest data from a random 4x4 meter area on randomly selected plots in randomly selected enumeration areas each year. We added an annex questionnaire to the AgSS with questions on farmers' knowledge about the crop varieties they had cultivated on the crop-cut plot, their seed sources, their seed management practices viz purchasing and saving/recycling, and other related questions. Additional questions on plot and farm characteristics, household demographics, intrahousehold decision-making in choosing varieties and purchasing seed, and other questions were also captured.

The genotyping work was piggybacked onto the AgSS in order to obtain grain samples from the crop-cut plots. Crop-specific grain samples of 200–250 grams were collected from each crop-cut plot and placed in a barcoded sample bag prepared for the study. The collected field samples were transferred to ESS's headquarters in Addis Ababa and then to NABRC in Holeta for DNA extraction. Barcoded DNA samples were then sent to DArT in Bruce, Australia, for DNA sequencing and marker identification using its DArTseq approach with an established reference library developed from variety-specific breeder seed of almost all released and registered crop varieties in Ethiopia for all four crops covered by this study.

For this study, the varietal identification results from DArT's sequencing analysis and the farm-household survey data were merged using the unique identifiers that matched grain sample barcodes with survey questionnaires. We analyze three rounds of data for wheat (2015, 2017, and 2019), two rounds for maize (2015 and 2017), and one round for teff and common bean (2021). Because our research on maize and wheat began some 10 years earlier, we are able to explore changes in varietal age and concentration across several points in time, whereas our research on teff and common bean provides a baseline for future studies in this same vein. The number of samples that were genotyped were as follows: 5,611 for wheat; 3,640 maize; 500 for teff; and 130 for common beans. In the teff and bean data, clusters of varieties with highly similar genetic profiles are observed. These clusters pose a challenge for assigning varietal age, as individual varieties within a cluster are typically associated with different release years. Using either the maximum age (oldest variety) or the minimum age (more recently released variety) may introduce bias, given that these varieties differ in their yield potential at the time of release. To address this issue, the analysis employs the average age of varieties within each cluster. Our key indicator of interest—area-weighted average varietal age (AWAVA)—is calculated as:

$$AWAVA_{ct} = \sum_{i=1}^{I} P_{cit} R_{cit}$$

Where $AWAVA_{ct}$ denotes the area-weighted average varietal age of crop c at time t, P_{cit} denotes the proportion of area sown to variety i in year t, and R_{cit} indicates the number of years (at time t) since the release of variety i.

AWAVAs were calculated using variety release dates provided in the Ethiopian Agricultural Authority (EAA) Crop Variety Register (EAA, 2021). Although the AWAVA can be interpreted in several ways, we use it primarily as an inverse indicator of the speed of varietal turnover, such that a high AWAVA indicates a low turnover rate. When interpreting AWAVAs—especially those for which we can make calculations for multiple time periods—we interpret the rate as "high" or "low" by exploring information on varietal releases in the EAA Crop Variety Register during the preceding periods, including the varieties' key traits and attributes.

Several measures of market structure and concentration are also used to better understand the role of dominant varieties for a given crop. In our study, we calculate concentration ratios for these dominant varieties as the share of area under cultivation by the top *n* varieties divided by total area under cultivation in the sample. Concentration ratios are calculated for each crop and year, and their values falls between 0 (indicating a competitive market) and 1 (indicating a concentrated market), following the formula:

$$CRn_t = \left(\sum_{i=1}^{n} s_{it} \right) \frac{1}{S_t}$$

where S_t denotes the total market size by volume or value at time *t*.

An additional indicator used in this study is the Herfindahl-Hirschmann Index (HHI). The HHI is a concentration measure that is calculated as the sum of squared percentage shares of each variety in the market (by area, i.e., $0 < a_{it} \leq 100$), with values falling between 0 (highly competitive) and 10,000 (highly concentrated). HHI accounts for relative size and distribution of varieties in a market and is thus more comprehensive than CRn indicators. HHI is calculated as

$$HHI_t = \sum_{i=1}^{n} a_{it}^2$$

where a_{it} denotes the percentage area share of the i^{th} variety of *N* varieties in at time *t.*

3. Results and discussions

Varietal age

Table 1 presents AWAVAs by crop and year based on our dataset that combines AgSS's farm, plot, and household data with the DArT genotyping data. We begin our analysis with wheat, followed by maize, teff, and common bean.

For wheat, the AWAVA decreased substantially by about 9 years between 2015 and 2019, from 21.2 years to 12.5 years. Despite this, we note that in the five years preceding 2019, more than 30 new wheat varieties were released (EAA, 2021). This suggests that the AWAVA for wheat warrants further analysis.

We find that the relatively high AWAVA for wheat in 2019 may be partly explained by the continuously expanding dominance of two varieties (*Kakaba* and *Danda'a*, both released in 2010) that are resistant to stem rust, and one variety (*Bobicho,* released in 2002) with substantially less resistance (Denbel et al., 2013). Our data indicate that *Kakaba* cultivation has expanded over time from 13.7 percent of area under improved wheat cultivation in 2015, to 27.0 percent in 2017, and to 32.2 percent in 2019 (Table 2). In 2019, *Kakaba* had become the most frequently identified variety in the genotyping data, and thus the dominant variety under cultivation. *Bobicho* was the second most widely grown variety, covering 28.2 percent of area under improved wheat cultivation in 2019, followed by *Danda'a,* accounting for 12.8 percent of area (Table 2).

To fully appreciate the relevance of these varietal turnover and concentration trends, it helps to explore events that shaped Ethiopia's wheat sector during this five-year period. In 2015, *Kubsa* accounted for the largest share of improved wheat-cultivated area in the country (33.2 percent) and the second largest share in 2017 (12.9 percent). However, *Kubsa* is susceptible to several rusts, including yellow rust and new variants of stripe rust, and Ethiopia is host not only to occasional rust epidemics but also constant rust pressures in its wheat-producing areas (Meyer et al., 2021). As such, following the 2010/11 yellow rust epidemic that devastated one-third of the wheat area in the country (Jaleta et al., 2020), *Kubsa* was taken out of seed production due to its susceptibility and eventually fell out of use by 2019, according to our data. However, *Bobicho* remains popular, and has certain susceptibility to rust that may also suggest the need to remove it from production. Such strategies are referred to as "planned obsolescence" (Spielman and Smale, 2017).

Interestingly, the average varietal age of wheat differs across regions. Wheat varietal age is relatively lower, implying better access to and/or use of more recently released wheat varieties, in the Southern Nations, Nationalities, and Peoples (SNNP)[2] and Tigray regional states (as compared to Amhara and Oromia regional states). This may relate to the fact that neither SNNP nor Tigray are major wheat-growing areas in Ethiopia, and farmers in these regions may rely more on wheat seed distributed through research centers and humanitarian assistance channels than through established channels involving extension services and cooperatives.

A disaggregated analysis of the 2017 data by bread and durum wheat also showed a substantial difference, with average varietal age of 12.8 and 39.1 years, respectively (Hodson et al., 2020). This disparity may be partly due to the focus of Ethiopia's breeding program on bread wheat, mainly due to productivity and marketing considerations. The program released 22 new bread wheat varieties in the five years preceding 2019, compared to just 8 new durum wheat varieties (EAA, 2021). Based on seed demand in the market, the wheat seed production and marketing system in Ethiopia is dominated by bread wheat varieties.

Finally, though not surprisingly, varietal age is lower among households that source their seed from formal sources compared to informal sources, which implies better varietal turnover for farmers relying on formal seed sources. Typically, improved varieties in Ethiopia—as in most countries—are first made available through the formal seed system and subsequently disseminated among farmers via market and nonmarket channels.

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[2] In 2023, the Southern Nations, Nationalities, and Peoples' Region (SNNPR) in Ethiopia was replaced by two new regional states: the South Ethiopia Regional State and the Central Ethiopia Regional State.

Table 1. Area-weighted varietal age estimates based on DNA fingerprinting for wheat, maize, teff, and common bean in Ethiopia, various years

Indicator	Wheat			Maize		Teff	Common bean
	2015	2017	2019	2015	2017	2021	2021
Varietal age, full sample							
	21.2	13.8	12.5	16.4	16.5	14.4	28.2
Varietal age, by region							
Amhara	26.0	13.3	13.6	17.4	18.8	11.8	40.6
Oromia	19.6	14.9	12.5	16.3	15.5	13.6	30.4
"SNNP"	16.1	12.7	10.8	15.0	16.4	17.4	16.5
Tigray	15.9	12.3	11.8	16.0	15.6	–	–
Varietal age, by seed source							
Formal	17.4	10.7	10.6	16.2	16.7	14.4	–
Informal	22.2	14.9	13.2	16.5	16.4	14.8	–

Source: Authors calculation based on data from ESS Agricultural Sample Survey (AgSS), household survey data, and DNA fingerprinting data from 2015, 2017, 2019, and 2021.
Note: Each sample is based on 200–250 grams of the crop's grain/seed collected from farmers' fields. For wheat, sample size = 5,611 samples; maize = 3,640; teff = 500; and common bean = 130.

The results for maize show no change in the varietal turnover rate between 2015 and 2017, with an area-weighted average varietal age remaining at 16.4–16.5 years (Table 1). This result may be surprising given the number of new varieties released, the active participation of private seed companies in the sector, and the supportive policy environment that emerged during this period, including the direct seed marketing approach (Mekonnen et al., 2026). For instance, data from the varietal release registry shows that 19 new maize varieties were released in 2015, followed by 23 in 2017 (EAA, 2021). Yet varieties released between 2010 and 2015 accounted for only about 17.6 percent of maize area in 2017. *Limmu*, which was released in 2012 by Pioneer Hi-Bred Seeds Ethiopia, a private company,[3] was the most prominent among these recently released varieties, accounting for 12.1 percent of maize area in 2017 (Table 2).

The slow rate of varietal turnover for maize may be explained by the continued dominance of BH-660 and the use of "*Admix*" (mixed) varieties. BH-660, a high-yielding and late-maturing hybrid that was released in 1993, accounted for 37.8 percent of the improved maize area in 2015 and 20.1 percent in 2017. While its area coverage decreased by about 18 percentage points (47 percent) during this period, it still accounted for a fifth of Ethiopia's total improved maize area in 2017 (Table 2).

Several factors may have contributed to the sustained dominance of BH-660 through this period.[4] Demand-side factors include its broad adaptability and suitability for high rainfall areas, as well as farmers' familiarity with the hybrid, BH-660 being Ethiopia's very first maize hybrid. Supply-side factors include the strategy for slow replacement of BH-660 by BH-661 (Ertiro et al., 2019), resulting in continuous production by both public seed enterprises and private seed companies.

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[3] Pioneer Hi-Bred Seeds Ethiopia PLC is a private firm and subsidiary of Pioneer Hi-Bred International, Inc., which is owned by Corteva Agriscience. See Kalsa et al. (2024).

[4] Note that in subsequent years, BH-660's dominance in Ethiopia decreased significantly (Ertiro, et al., 2019).

Despite the slow rate of varietal turnover at the national level, there are slight differences in this rate between regional states (Table 1). Varietal turnover was relatively slow in Amhara region (with average varietal age of 18.8 years in 2017) compared to SNNP (16.4 years), Tigray (15.6 years), and Oromia (15.5 years) regions. Similarly, there are only slight differences in varietal age by seed source.

Results for teff are less straightforward than those for wheat and maize. Genotyped field samples were matched to a cluster of teff varieties released in multiple years, rather than to single varieties with single release years. This resulted partly from the fact that some teff varieties had extremely similar genetic makeups due to the limited genetic variation in landraces used for crossing, resulting in indistinguishable varieties. For instance, *Tsedey*, *Amarach*, and *Simada* varieties were found to have similar genotypes even though they were released in 1984, 2006, and 2009, respectively.

In order to calculate area-weighted varietal age for teff, we reported the *average* age of clustered varieties with a similar genetic makeup, recognizing that this simplifying assumption could introduce an unavoidable level of inaccuracy in the results. Continuing with *Tsedey* (1984), *Amarach* (2006), and *Simada* (2009), we calculated a simple average varietal age of 21.3 years for these three varieties before calculating the area-weighted average varietal age.

Results indicate that the area-weighted average varietal age for teff was 14.4 years in 2021 (Table 1). The genotyping analysis shows that two clusters of varieties, each with their own similar genetic makeup, accounted for 81.2 percent of the teff area under improved varieties identified using DNA fingerprinting in 2021. The cluster that includes *Tsedey* (1984), *Amarach* (2006), and *Simada* (2009) accounted for 42.7 percent of the area, while *Gemechis* (2007) and *Abay* (2018) accounted for 38.5 percent. *Boset*, released in 2012, was the third most frequently identified teff variety by genotyping and covered 9.4 percent of the teff area under improved varieties identified using DNA fingerprinting in 2021 (Table 3).

Results also show notable differences in teff varietal turnover across regions, with a relatively fast turnover rate in Amhara (11.8 years) compared to Oromia (13.6 years) and SNNP (17.4 years). There was not much difference in area-weighted average varietal age of teff by seed source.

For common bean, results are notably distinct from those of the cereal crops discussed above. Again, we employed a clustering approach for several similar varieties that were released during the period 2003–2005. The area-weighted average varietal age of common bean was 28.2 years in 2021 (Table 1). The slow common bean varietal turnover may be primarily explained by the continued dominance of *Mexican-142*, which was released in 1973. *Mexican-142* was the most widely grown variety in 2021, accounting for 40.7 percent of the common bean area under improved varieties identified using DNA fingerprinting. The second and third most frequent groups of common bean varieties identified through genotyping were released more recently: the 2003–2005 variety cluster that includes *Anger*, *Tibe*, *Omo 95*, *Nasir*, and *Dimtu*; and *Hawassa Dume* (2008). Further, while the variety registry indicates the introduction of 19 new common bean varieties in the five years preceding 2021 (EAA, 2021), none of these varieties were identified in the genotyped samples from farmers' fields.

The results show substantial differences in common bean varietal turnover rate across regions, with a relatively fast varietal turnover in SNNP (16.5 years) compared with Oromia (30.4 years) and Amhara (40.6 years) regions (Table 1).

Varietal concentration

Table 2 provides indicators of genetic concentration of varieties cultivated in farmers' fields for wheat in 2015, 2017, and 2019, and maize in 2015 and 2017. Table 3 provides the same indicators for teff and common bean, both in 2021. A key observation is that the varietal concentration ratio (CR4) for maize shows a reduction from 0.71 to 0.65 between 2015 and 2017 due to reduction in the share of *BH-660* and *Kulani* (both from public seed enterprises) and the increase of *Shone* and *Limmu* varieties (both from a private seed company).In wheat, however, varietal concentration shows a reduction between 2015 and 2017 but an increase between 2017 and 2019. In 2019, three rust resistant varieties (*Kakaba*, *Bobicho,* and *Danda'a*) took the lion's share in terms of wheat area coverage.

Importantly, these results should be interpreted with caution. Taken at face value, it would seem that the varietal concentration rates of wheat and maize are lower than the rates for teff and common bean varieties. However, these observed differences may be partly due to differences in sample size, with the concentration rates for maize and wheat based on a relatively larger number of samples compared with teff and common bean. The high concentration rates for teff and common bean may also be related to the clustering of similar genotypes (Table 3), such that strong assumption that allows us to treat each variety as distinct would result in a much lower concentration ratio.

There is also a product pipeline effect that needs to be accounted for. A relatively small number of teff varieties were released by the breeding program over the period preceding the survey: a total of 54 teff varieties as of 2021, compared to 143 wheat varieties, 77 maize varieties, and 81 common bean varieties (EAA, 2021). Arguably, a relatively small number of releases could contribute to higher concentration rates simply because there are fewer varieties for farmers to choose from in the seed system. However, this explanation obscures other explanations, such as the possibility that many released varieties simply did not fully advance to production and distribution in the seed system. To this end, note that although a total of 81 common bean varieties were released in Ethiopia as of 2021, only a handful of varieties were actually identified through the genotyping of field samples. Clearly, for any number of reasons, most of these released varieties have not found their way into the seed system or into farmers' fields.

Table 2. Varietal ages and concentration rates for wheat and maize in Ethiopia, selected years

Wheat Variety	Release year	Share of area (%)			Maize variety	Release year	Share of area (%)	
		2015	**2017**	**2019**			**2015**	**2017**
Arendeto	1967	3.1	2.1	3.1	*BH-140*	1988	1.2	4.3
Dereselign	1974	0.5	0.7	0.0	*BH-660*	1993	**37.8**	**20.1**
ET-13	1981	0.3	0.6	0.3	*Jabi*	1995	1.2	0.5
Pavon-76 Tossa	1982	6.1	3.9	0.0	*Kulani*	1995	**17.4**	3.7
Kubsa	1994	**33.2**	**12.9**	0.0	*BH-540*	1995	4.6	9.4
Galema	1995	**11.0**	6.0	0.6	*Melkassa-1*	2000	5.4	0.1
Tusie	1997	0.4	1.4	0.5	*Gibe1*	2001	4.6	4.5
Hawi	1999	1.7	2.0	1.5	*Melkassa-2*	2004	1.7	2.8
Simba	1999	1.3	2.3	1.8	*Argane*	2005	**8.7**	0.0
Mada Walabu	1999	0.5	0.9	0.4	*Shone*	2006	8.1	**11.4**
Sirbo	2001	0.0	0.9	0.0	*Melkassa-4*	2006	0.1	0.2
Lasta	2002	1.8	0.2	1.2	*Melkassa-7*	2008	0.8	1.4
Bobicho	2002	1.1	4.5	**28.2**	*Jibat*	2009	1.2	0.1
Digalu	2005	1.7	**10.4**	2.1	*BH-661*	2011	0.9	4.6
Digalu-Bolo	2005	0.0	0.9	0.0	*Limmu*	2012	0.9	**12.1**
Bolo	2009	8.8	1.0	0.0	*Damote*	2015	0.0	0.9
Kakaba	2010	**13.7**	**27.0**	**32.2**	*Admix*	Various	0.0	22.0
Danda'a	2010	5.0	10.1	**12.8**	Others	Various	5.5	2.0
Gambo	2011	0.9	0.6	1.1				
Shorima	2011	0.0	0.0	0.3				
Ogolcho	2012	0.3	2.9	2.6				
Hulluka	2012	0.0	0.7	0.1				
Hidasie	2012	0.0	3.2	6.5				
Others	Various	8.7	4.0	4.8				
Concentration indices								
CR4		0.65	0.57	0.77			0.71	0.65
Herfindahl-Hirschman Index (HHI)		1528	1127	1926			1905	1334

Source: Authors calculation based on data from ESS Agricultural Sample Survey (AgSS), household survey data, and DNA fingerprinting data from 2015, 2017, and 2019.

Note: The maize and wheat results are based on data pooled across rounds. Aggregate wheat sample area = 1,095 ha; aggregate maize sample area = 473 ha; *s*ample size for wheat = 5611; sample size for maize = 3,640.

Table 3. Varietal concentration rates for teff and common bean in Ethiopia, 2021

Teff Variety	Release year	Share of area* (%) 2021	Common bean variety	Release year	Share of area* (%) 2021
Kena	2008	1.9	*Mexican-142*	1973	40.7
Boset	2012	9.4	*Dimtu +*	2003	22.7
Kora	2014	3.3	*Nasir +*	2003	
Tsedey +	1984	42.7	*Omo-95 +*	2003	
Amarach + Simada	2006		*Tibe +*	2004	
	2009		*Anger*	2005	
Dukem +	1995	3.4	*Hawassa Dume*	2008	19.8
Gola +	2003		*SER-119*	2014	11.3
Genete +	2005		Others	Various	5.6
Etsub +	2008				
Heber-1	2017				
Gemechis +	2007	38.5			
Abay	2018				
Others	Various	0.8			
Concentration indices					
CR4		0.94			0.94
Herfindahl-Hirschman Index (HHI)		3418			2708

Source: Authors calculation based on data from ESS Agricultural Sample Survey (AgSS), household survey data, and DNA fingerprinting data from 2021.
Note: Aggregate teff sample area = 111 ha; common bean sample area = 20 ha; sample size for teff = 500; sample size for common bean = 130. *Share of area under varieties identified using genotyping.

Correlates of varietal age

Next, we explore the correlates of varietal age using an ordinary least squares (OLS) regression and generalized linear model (GLM) estimates. For varietal age/turnover, the dependent variable, area-weighted average varietal age, is measured as a continuous variable that captures the number of years since the variety's initial release. Our explanatory variables are farm-household characteristics, including demographic attributes, land and other assets, and distance or access to agricultural input and service providers (including seed sources). These explanatory variables are consistent with both theory and practice in the study of technology adoption correlates in smallholder agriculture.[5] Summary statistics are provided in Table A1 in the appendix, and estimation results from the OLS regression in Table 4 (the results from GLM estimates are reported in Table A2 in the appendix).

Estimation results indicate the following. First, the results demonstrate that after controlling for time–variant factors that might otherwise affect the age of varieties cultivated by a household, varietal age decreased over time for wheat, with the average age decreasing by 4.7 years between 2015 and 2017, and by 6.1 years between 2017 and 2019. However, opposite results are obtained for maize, with a positive and statistically significant increase in varietal age of 1.0 years between 2015 and 2017.

Second, there is clear regional variation in the average age of varieties cultivated by farm households. Specifically, households in Tigray grew more recently released wheat and maize varieties than farmers in Amhara region, while similar effects were found for teff in Amhara region as compared to SNNP. For common bean, households in SNNP cultivate more recently released varieties than in Amhara region.

Third, formal seed source is negatively associated with varietal age for wheat. Wheat farmers who sourced seed from formal sources grew varieties that, on average, were three years younger than those used by farmers who obtained seed from informal sources. Relatedly, distance from the farm-household's dwelling to the seed source is positively and significantly associated with varietal age, at least for wheat and common bean.

Fourth, farm-household characteristics—age, sex, and education of the household head, household size, and whether the household included a model farmer—were generally not associated with varietal age across crops. Only for maize did the education of the household head have a positive and statistically significant association with varietal age, and only for teff did household size (a proxy for household labor supply) have a similar association.

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[5] See reviews and syntheses by Feder et al. (1985), Sunding and Zilberman (2001), Foster and Rosenzweig (2010), Pannell and Zilberman (2020), and Arslan et al. (2022).

Table 4. Correlates of varietal age for wheat, maize, teff, and common bean in Ethiopia

Explanatory variables	**Wheat**	**Maize**	**Teff**	**Bean**
Household characteristics				
Age of the head	0.002	0.001	– 0.014	0.052
	(0.008)	(0.011)	(0.020)	(0.092)
Sex of the head (male=1)	0.136	– 0.046	– 0.749	4.430
	(0.347)	(0.205)	(0.852)	(4.064)
Education of the head	– 0.060	**0.110****	0.007	**– 0.899****
	(0.040)	(0.045)	(0.076)	(0.449)
Household size	–	–	**0.380*****	– 0.378
	–	–	(0.116)	(0.666)
Model farmer (yes=1)	0.410	– 0.293	0.391	–
	(0.339)	(0.305)	(0.514)	–
Land/asset				
Total operated land	0.225	0.074	**– 0.395*****	0.227
	(0.154)	(0.118)	(0.149)	(1.007)
Share of crop area	– 0.007	– 0.003	– 0.001	0.055
	(0.006)	(0.005)	(0.010)	(0.034)
Asset index	– 0.114	– 0.140	0.087	0.978
	(0.087)	(0.102)	(0.191)	(0.989)
Tropical livestock units (TLU)	0.039	0.016	– 0.048	0.400
	(0.040)	(0.040)	(0.064)	(0.475)
Access/location				
Minutes of walking to seed source	**0.005*****	– 0.002	– 0.007	**0.070****
	(0.002)	(0.002)	(0.005)	(0.033)
Seed from formal sources (yes=1)	**– 3.038*****	– 0.008	1.391	–
	(0.273)	(0.227)	(0.978)	–
Survey round dummies (base year=2015)				
2017	**– 4.703*****	**0.924*****	–	–
	(0.400)	(0.286)	–	–
2019	**– 6.106*****	–	–	–
	(0.373)	–		–
Regional dummies (base: Tigray, Amhara, or Oromia) [#]				
Amhara	**0.934***	**2.656*****	–	–
	(0.494)	(0.337)	–	–
Oromia	0.529	0.435	– 0.272	–
	(0.447)	(0.407)	(1.136)	–
SNNP	**– 1.997*****	**1.685*****	**4.370*****	**– 10.970*****
	(0.427)	(0.410)	(1.210)	(2.809)
Constant	20.324***	6.878	16.673***	17.823**
	(0.707)	(4.283)	(1.869)	(7.390)
Observations	5579	3477	470	119
R^2	0.108	0.066	0.381	0.339
Woreda fixed effect	Yes	Yes	Yes	No

Source: Authors calculation based on the ESS Agricultural Sample Survey (AgSS), household survey data, and DNA fingerprinting data from 2015, 2017, 2019, and 2021.

Note: Dependent variable in the model is varietal age in years. Dashes (–) indicate variables that were difficult to derive from the existing data (household size for the wheat and maize estimations), lacked variation (model farmer in the bean estimation), data were not collected in the survey round (2021 for wheat; 2019 and 2021 for maize; 2015, 2017, and 2019 for teff and beans), or data were not collected in a region (teff and beans in Tigray region). Hashtags (#) indicates that the base region is Tigray for wheat and maize estimations, Amhara for teff, and Oromia for beans. Asterisks (*) indicate statistical significance levels at p < 0.10, ** p < 0.05, *** p < 0.01.

4. Conclusions and policy implications

There are clearly significant challenges in measuring, analyzing, and interpreting data on the adoption, turnover, and concentration of improved crop varieties. This paper illustrates these challenges through an exploration of data from four major crops in Ethiopia that are drawn from both genotyping and household survey data.

The findings indicate that Ethiopia is continuously developing and delivering new varieties to farmers, consistent with its broader national strategy to increase agricultural productivity and national food security. At a very basic level, this question matters because the translation of breeding for genetic gain into on-farm productivity growth requires widespread adoption of these new varieties by farmers.

Analysis results also show slow varietal turnover rates, albeit with substantial variation across crops. This is expected as the four crops considered in this study have unique features in terms of their seed systems and their drivers of varietal turnover. Analysis of the wheat data indicates significant reductions over time that have resulted in the lowest area-weighted average varietal age (12.5 years in 2019) among our four focal crops. This happened in response to rust challenges where older and susceptible wheat varieties were replaced by recently released and rust resistant varieties both at seed production and field levels. The analysis of teff indicates a low area-weighted varietal age of 14.4 years in 2021, suggesting limited varietal turnover. However, robust trend analysis is not possible due to the nature of the available data. Maize results provide something of a surprise: a relatively high and constant area-weighted average of 6.4–16.5 years during the 2015–2017 period despite considerable public and private participation in the maize seed sector. Finally, common bean is an outlier in our analysis, with a much higher varietal age (28.2 years in 2021) compared to the other three crops.

Our analysis of concentration rates generally indicates continuous dominance of older varieties, which not surprisingly, may explain the relatively slow rates of varietal turnover for several of our focal crops. For wheat, *Bobicho* (released in 2002) accounted for 28 percent of area under wheat cultivation in 2019; for maize, BH-660 (1993) accounted for 20 percent in 2017; for teff, a cluster of genetically similar varieties (*Tsedey* (1984), *Amarach* (2006), and *Simada* (2009)) accounted for 43 percent of area; and for beans, *Mexican-142* (1973) covered 41 percent of area.

Beyond the various well-known supply- and demand-side factors (e.g., accessibility, risk or uncertainty, trait preference), emphasis on the adoption of improved varietals rather than varietal turnover by the extension system is the main reason for the observed lasting dominance of older varieties and slow varietal turnover rate.

Slow varietal turnover in the presence of new varieties clearly indicates certain weaknesses in the seed system. Exactly where those weaknesses lie is beyond the scope of this paper, although the problem has attracted considerable attention in the past and is likely to do so in the future. Instead, we pivot to the question of where genotyping can be used to accelerate varietal turnover and productivity growth—a question that has been raised recently by other researchers exploring the practical applications of genotyping data in seed markets and systems (see, e.g., Melesse et al., 2025; Michelson et al., 2023). We consider three areas: (1) public investment prioritization; (2) policy and program experimentation; and (3) seed sector governance.

In Ethiopia, as in many low-income countries across sub-Saharan Africa, the development and delivery of improved varieties still depend substantially on public investment. This is particularly the case for self-pollinating crops such as wheat, teff, and common bean, open-pollinating varieties of maize, and even maize hybrids. Genotyping can play a role in validating the reach of such public investments, as demonstrated here with evidence on the collective capacity of Ethiopia's research organizations, extension services, and seed systems to influence what is grown on farmers' fields.

The same approach can be used to work backward to begin identifying where the key bottlenecks in the seed supply chain occur, at least with respect to preserving the genetic attributes of a variety. For example, if supply chain issues result in poor varietal performance, there is a role for genotyping in monitoring genetic quality at each point along the seed supply chain, beginning with maintenance breeding and nucleus (pre-basic/breeder) seed all the way through to seed that is distributed to farmers via cooperatives and retailers. By identifying where genetic quality breaks down in the supply chain, government agencies can allocate scarce public resources to fixing the problems where they occur.

Relatedly, genotyping may have a role to play in aligning the promotion of improved management practices by extension agents, on the one hand, and the varieties that farmers are cultivating, on the other hand. For example, it makes sense for extension agents to promote inorganic fertilizer use based on recommendations for hybrid maize cultivation if (and only if) farmers receiving such advice know that they are indeed planting fresh seed of a specific hybrid, rather than recycled hybrid seed that has lost its vigor or an openly pollinated variety. While providing genotyping services for each and every farmer may be prohibitively costly and time-consuming, genotyping at points of sale as a market monitoring and surveillance mechanism can help reduce risks and uncertainty facing farmers.

To this end, considerable study has gone into the efficiency outcomes of variety misidentification and misallocation of complementary inputs for the farmer (Bohr et al., 2024; Wossen et al., 2019; Euler et al., 2022). From a policy perspective, these efficiency outcomes also shape the evaluation of an allocation of public funding to research and extension systems.

But market monitoring and surveillance are only one possible use of genotyping that effectively augments existing seed quality assurance systems, regulations, and guidelines. A more innovative use of genotyping is direct use as an incentive for seed providers to improve the quality of their product offerings to farmers. For example, Miehe et al. (2023) develop a digitally crowdsourced platform that aggregates ratings from farmers for agro-dealers selling maize seed in Uganda.[6] With the addition of genotyping of random samples obtained by a mystery shopper (and assuming a more rapid turnaround time than is currently available), it may be possible to provide farmers with valuable information on the quality of seed being sold in individual shops. This could go a long way to addressing persistent concerns about the quality of seed sold by the private sector in Ethiopia, while also supporting efforts to increase the confidence in market-based arrangements, in which seed is directly marketed and sold to farmers (see, e.g., Mekonnen et al., 2026).

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[6] Also see work by Ashour et al. (2015) in Uganda that explores DNA fingerprinting of maize hybrids to address asymmetric information in seed markets.

Next, there is a role for genotyping in seed sector governance. Scientific and technical tools associated with genetics and molecular biology are fast becoming standard practice in crop improvement programs to identify individual genotypes, often complementing but also improving on more conventional tools that rely on morphological/phenotypic identification. Genotyping introduces a more objective set of tools that can be leveraged to encourage or improve effective seed sector governance and management. Specifically, genotyping can provide a means to monitor performance at each point along the seed supply chain, allowing for greater accountability and transparency among and between seed sector actors, and to support more informed decision-making on available policy and investment choices for seed sector development. These are key topics in the narrative on Ethiopia's own seed sector development journey (Kifle et al., 2022; Borman et al., 2022; Mulessa, 2021; Hassena et al., 2016) and likely deserve continued attention.

But even with effective genotyping to guide seed sector governance, questions remain about whether improved varieties are reaching farmers' fields at a rate that can help accelerate productivity growth in Ethiopia. We recognize that self-reported data from farmers regarding which varieties they are cultivating are an insufficient means of estimating varietal turnover due to both non-identification and misidentification of varieties, as demonstrated by several prior studies on Ethiopia (e.g., Alemu et al., 2024; Bohr et al., 2024; Jaleta et al., 2020; Hodson et al., 2020; Kosmowski et al., 2019). But a need remains for continued investment in data quality improvement on improved variety adoption and turnover and in empirical testing of the relationship between genetic gain and agricultural productivity growth under farmers' real-world conditions. Moreover, further studies are required to explore the drivers of seed industry decision-making on developing and delivering new varieties, on farmer decision-making about adopting newly released varieties, and ultimately, the associated benefits for both farmers and firms.

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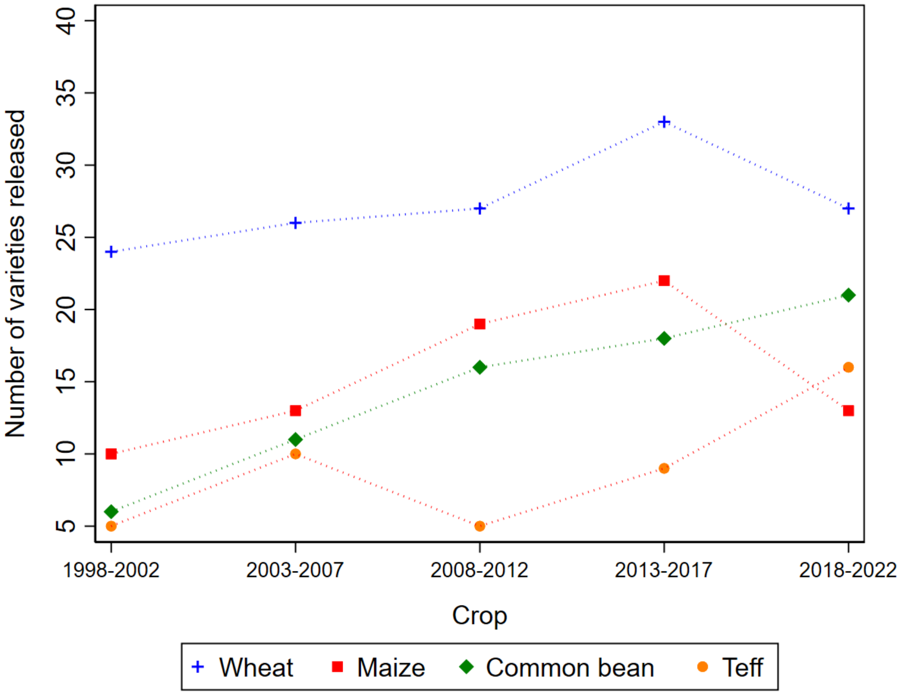
Appendix: Supplementary figures and tables

Figure A1. Number of varieties released in Ethiopia: Selected sources, crops, and periods



Source: Authors, based on data from the Ethiopian Agriculture Authority (EAA) Crop Variety Register Report (EEA, 2021).

Table A1. Summary statistics of covariates used in the regressions

Covariates	Crop			
	Wheat (n=5,579)	**Maize (n=3,477)**	**Teff (n=470)**	**Beans (n=119)**
Age of the head	41.58	42.84	44.83	43.08
Share of male household head (%)	77.50	71.99	88.08	85.71
Education of the household head	2.39	2.40	2.40	2.50
Household size	–	–	5.28	5.24
Share of model farmers (%)	22.90	17.40	26.00	–
Total operated land (ha)	1.48	1.45	1.76	1.37
Share of (wheat/maize/teff/beans) area (ha)	31.73	34.77	48.76	44.37
Asset index	0.04	0.05	0.00	0.07
Tropical livestock units (TLU)	5.87	5.19	5.87	4.06
Minutes of walking to nearest seed source	64.30	59.81	49.65	52.82
Share of seed from formal sources (%)	27.81	42.36	6.17	
Round				
2015	22.06	16.36	–	–
2017	50.13	83.64	–	–
2019	27.80	–		
2021	–	–	100.00	100.00
Region				
Tigray	12.88	9.58	–	–
Amhara	29.05	29.28	23.82	–
Oromia	30.47	37.78	30.42	57.14
SNNP	27.58	23.38	45.74	42.85

Source: Authors calculation based on ESS Agricultural Sample Survey (AgSS), household survey data, and DNA fingerprinting data from 2015, 2017, 2019, and 2021.

Table A2. Correlates of varietal age for wheat, maize, teff, and common bean in Ethiopia, Generalized Linear Model (GLM) regressions

Explanatory variables	Wheat	Maize	Teff	Bean
Household characteristics				
Age of the head	0.000	0.000	– 0.001	0.003
	(0.001)	(0.001)	(0.001)	(0.004)
Sex of the head (male=1)	– 0.001	– 0.009	– 0.050	0.193
	(0.020)	(0.019)	(0.053)	(0.160)
Education of the head	– 0.003	**0.007*****	0.000	**– 0.039****
	(0.003)	(0.003)	(0.005)	(0.018)
Household size	–	–	**0.027*****	– 0.015
	–	–	(0.009)	(0.026)
Model farmer (yes=1)	0.010	– 0.025	0.036	–
	(0.020)	(0.023)	(0.040)	–
Land/asset				
Total operated land	0.012	0.004	**– 0.027****	0.001
	(0.008)	(0.008)	(0.011)	(0.040)
Share of crop area	**– 0.001****	**– 0.001***	– 0.000	0.002
	(0.000)	(0.000)	(0.001)	(0.001)
Asset index	– 0.010	– 0.011	0.003	0.045
	(0.007)	(0.007)	(0.013)	(0.039)
Tropical livestock units (TLU)	0.002	– 0.001	– 0.002	0.007
	(0.002)	(0.002)	(0.004)	(0.019)
Access/location				
Minutes of walking to seed source	**0.000*****	– 0.000	– 0.000	**0.003****
	(0.000)	(0.000)	(0.000)	(0.001)
Seed from formal sources (yes=1)	**– 0.193*****	– 0.016	0.093	–
	(0.018)	(0.017)	(0.070)	–
Survey round dummies (base year=2015)				
2017	**– 0.309*****	**0.041***	–	–
	(0.025)	(0.023)	–	–
2019	**– 0.328*****	–	–	–
	(0.027)	–	–	–
Regional dummies (base: Tigray, Amhara, or Oromia) #				
Amhara	– 0.004	**0.135*****	–	–
	(0.028)	(0.032)	–	–
Oromia	0.041	**– 0.055***	0.015	–
	(0.029)	(0.032)	(0.060)	–
SNNP	**– 0.171*****	0.037	**0.308*****	**– 0.331*****
	(0.027)	(0.033)	(0.058)	(0.110)
Constant	2.985***	2.092***	2.769***	2.754***
	(0.043)	(0.345)	(0.117)	(0.291)
Observations	5579	3477	470	119
R2				
Woreda fixed effect	Yes	Yes	Yes	No

Source: Authors calculation based on the ESS Agricultural Sample Survey (AgSS), household survey data, and DNA fingerprinting data from 2015, 2017, 2019, and 2021.

Note: Dependent variable in the model is varietal age in years. Dashes (–) indicate variables that were difficult to derive from the existing data (household size for the wheat and maize estimations), lacked variation (model farmer in the bean estimation), data were not collected in the survey round (2021 for wheat; 2019 and 2021 for maize; 2015, 2017, and 2019 for teff and beans), or data were not collected in a region (teff and beans in Tigray region). Hashtags (#) indicates that the base region is Tigray for wheat and maize estimations, Amhara for teff, and Oromia for beans. Asterisks (*) indicate statistical significance levels at $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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