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Field pea diversity and its contribution to farmers' livelihoods in northern Ethiopia

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Abstract

Field pea is grown by smallholder farmers in Ethiopia as a source of food, fodder, income, and soil fertility. This study explores intraspecific diversity of field pea and its contribution to farmers' livelihoods in two agroecological zones of South Tigray and South Wollo, northeastern Ethiopia. Interviews were conducted with 168 farming households. The number of varieties and the Shannon Diversity Index (SDI) were higher in South Tigray (seven varieties, 0.35 SDI) than South Wollo (two varieties, 0.025 SDI). Farmers in South Tigray plant field pea during two growing seasons, allowing for integration of multiple varieties into their farming systems. The price of one field pea type from South Tigray known as “DEKOKO” was twice as high as other field pea varieties, most likely due to high demand and relatively low supply. Key informants reported “DEKOKO” has become less common in their communities, with diseases and pests reported as major production constraints. Multistakeholder collaboration is recommended to enhance the contribution of field pea to Ethiopian farming systems.

KEYWORDS

agrobiodiversity, crop rotation, farmers' varieties, *Pisum sativum*, production constraints

1 | INTRODUCTION

Field pea (*Pisum sativum* L.) is one of the oldest domesticated food legume crops, cultivated as early as the 9th millennia BC (Zohary & Hopf, 1973). The genus *Pisum* consists of both wild relatives (*P. fulvum* Sibth. & Sm. and *P. sativum* subsp. *elatius* (M.Bieb.) Asch. & Graebn.) and cultivated species (*Pisum sativum* L. and *Pisum abyssinicum* A. Braun¹), all originating in the Mediterranean region, primarily the Middle East (Ellis et al., 2011; Institute of Biodiversity

Conservation [IBC], 2012). As of 2019, field pea was the fourth most widely produced legume in the world (following common bean, cowpea, and chickpea), with cultivated areas covering 7.2 million hectares (Food and Agriculture Organization [FAO], 2020).

In Ethiopia, field pea is widely grown at middle to high altitudes (1800 to 3000 m a.s.l) in areas with average annual rainfall of 800 to 1100 mm (Central Statistical Agency [CSA], 2016; Hagedorn, 1984). Among the legumes produced in Ethiopia, field pea ranks second (following only faba bean) by volume of production and area coverage.

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During the 2016/17 growing season, field pea was cultivated on 216,786 ha, yielding 360,811 tons (CSA, 2016). Although field pea is an important export crop, garnering foreign currency for the national economy (Habtamu & Million, 2013), here we will examine its direct contributions to the livelihoods of smallholder farmers. In addition to its use as food and source of income, field pea residues are important feed for domesticated animals (including horses, cattle, and sheep) and it plays a significant role in maintaining and restoring soil fertility (Abberton, 2010).

The average yield of field pea in Ethiopia is only 1.66 t ha^{-1} (CSA, 2016), far below the 4 to 5 t ha^{-1} achieved in Europe (Netherlands, France and Belgium). Low productivity has been attributed to a lack of high-yielding varieties that are resistant to disease, insect pests and increasingly variable climate conditions (Smykal et al., 2012). Plant breeding led by the Ethiopian Institute for Agricultural Research has resulted in the development and distribution of numerous new field pea cultivars, most derived through hybridization with international sources (Jarso et al., 2006). However, despite the distribution of these cultivars, the productivity of field pea remains low. It is not clear if the limited impacts of so-called improved cultivars should be attributed to low rates of adoption or to lower than expected yields in the heterogeneous conditions found across Ethiopia.

It is generally believed that the Ethiopian field pea landraces include valuable genetic diversity based on farmers' selection for advantageous traits across highly heterogeneous landscapes (Kenehi et al., 2007; Singh & Singh, 2015). Although field pea was most likely domesticated in West Asia, the diversity of field pea varieties found by

Vavilov and others led them to identify Ethiopia as a secondary center of diversity (Harlan, 1969; Vavilov et al., 1997). Agromorphological characterization and genetic analyses have confirmed the presence of high genetic diversity among Ethiopia's field pea landraces (Kenehi et al., 2005, 2007; Teshome et al., 2015). Despite this evidence of their genetic significance, the status of field pea landraces has not been monitored, nor has their contribution to farmers' livelihoods been evaluated. Thus, the objectives of this study were as follows:

- To investigate the current status of field pea diversity by conducting an inventory of local landraces and introduced cultivars of field pea grown in different sociocultural and agroecological contexts.
- To assess the significance of field pea diversity to farming communities by comparing the area planted; planting and harvesting times; frequency of crop rotation; average yields; and gender roles in production and use.
- To identify constraints on field pea production and opportunities to enhance its contributions to farmers' livelihoods.

2 | MATERIALS AND METHODS

2.1 | Study area description

The research was conducted in August 2016 to January 2017 in the South Tigray administrative zone of the Tigray Region and

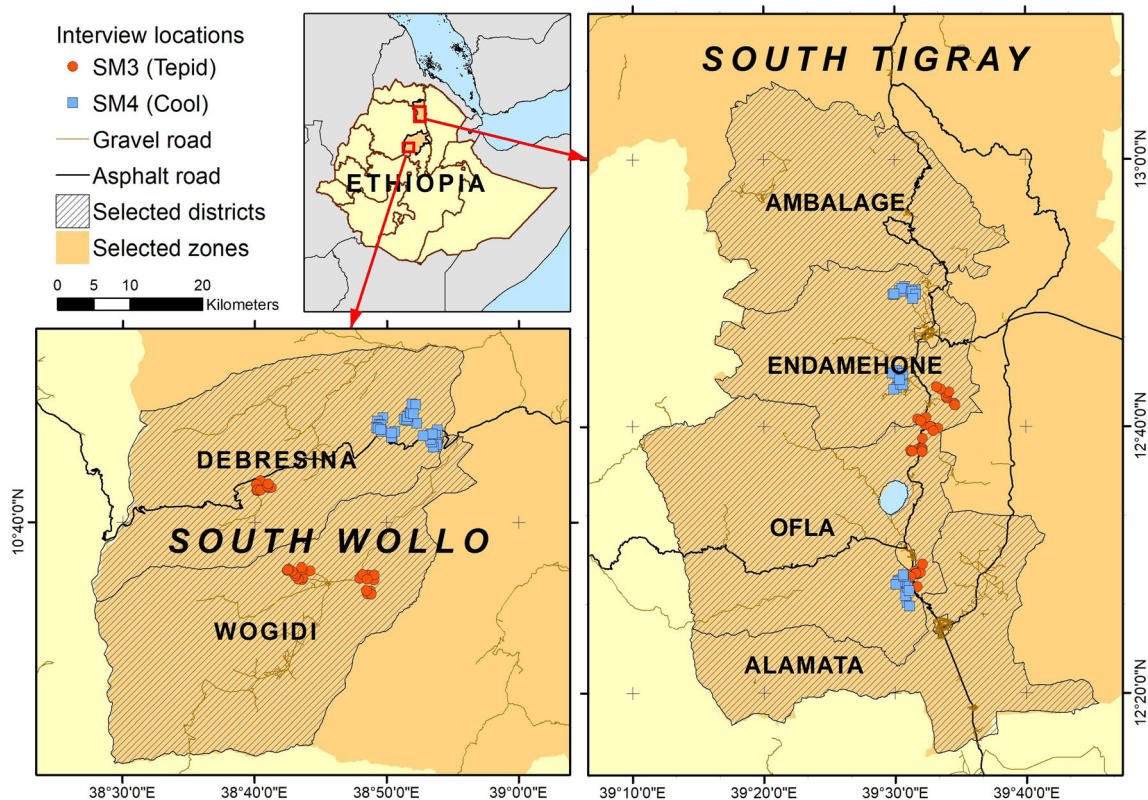


FIGURE 1 Map of interview locations in South Tigray and South Wollo, northern Ethiopia

neighboring South Wollo administrative zone in the Amhara Region (Figure 1). Although these zones belong to different regions with distinct cultural traditions, languages and identities, smallholder farmers in both areas practice mixed agriculture (production of crops and live-stock). The most common cereal crops grown in these zones are barley (*Hordeum vulgare*), wheat (*Triticum* sp.), teff (*Eragrostis tef*), and sorghum (*Sorghum bicolor*). As for pulses, field pea, lentil (*Lens culinaris*), and faba bean (*Vicia faba*) are most common (CSA, 2016).

2.2 | Study site selection

A multistage sampling method was used to select study communities and individual farmers. A review of the national agricultural census (CSA, 2016) revealed that a high percentage farmers in these two administrative zones produce field pea. Within each zone, districts known to produce field pea were identified through conversations with zonal administrators and extension officers. In South Tigray, four districts were selected: Raya Alamata, Ofla, Enda Mehoni, and Emba. In South Wollo, three districts were included: Were Illu, Borena, and Wogidi.

Stratified random sampling was conducted according to four factors: (i) agroecology, (ii) administrative zone (associated with culture), (iii) relative wealth, and (iv) gender. The stratification by agroecology and administrative zones was performed using GIS. Stratification by relative wealth and gender was conducted during field work based on the information from subdistrict administrators.

To compare the diversity of legumes according to agroecology and sociocultural differences, the study focused on two agroecological classes that are found in both administrative zones; tepid submoist mid-highlands (SM3) and cool submoist mid-highlands (SM4) were selected in both South Tigray and South Wollo, resulting in four strata (Table 1). These agroecological classes are based on a national classification system defined by thermal zones and length of the growing season (Ministry of Agriculture and Rural Development [MoARD], 2005). Using GIS, each subdistrict (known in Amhara as “kebele” and in Tigray as “tabia”) was assigned to one of the four strata based on the majority agroecology found within its boundaries. Three subdistricts were then selected at random from each stratum.

2.3 | Sample size determination and design

Sample size was determined using statistical power analysis based on the relationships between significance level, power, effect size, and sample size (Cohen, 1992). By estimating significance level

($\alpha = 0.05$), power (0.8), and effect size ($h = 0.5$), optimal sample size was estimated using the “pwr” package (Champely, 2020) in R (version 3.6). Optimum sample size (n) for a binomial distribution was estimated as 63 households but was increased to 72 per stratum to account for design effects. Therefore, the total number of sample households interviewed was 144, including 12 households from each of the 12 subdistricts.

A list of households growing field pea was obtained from each subdistrict administration. These lists were stratified by relative wealth based on participation in a federal safety net program; beneficiaries of that program were classified as low income, non-beneficiaries as mid- to high-income farmers. Six low income and six mid- to high-income households were selected at random from each list. Furthermore, within each relative wealth category, an equal number of men and women were interviewed by alternating the gender of the participant as the researchers moved from house to house. To gain more in-depth information from the most knowledgeable individuals participating in the study, two key informants were selected from each of the 12 subdistricts (24 key informants in total). These key informants were identified by subdistrict administrators as men and women who were particularly knowledgeable about field pea diversity.

2.4 | Data collection

Primary data were collected using structured and semistructured interviews. Free and informed oral consent was obtained from all participants prior to each interview. Interview questions focused on the name and defining characteristics of each variety, agroecological distribution, gender roles on the production and management of field pea, cropping practices, area planted with field pea, planting time, rotation frequency of the crop, market price, crop yield, and production constraints. Structured interviews were documented using Open Data Kit (ODK) on an Android smart phone, uploaded to Kobo Toolbox (www.kobotoolbox.org) and then downloaded for analysis in MS Excel and R (version 3.6) using R-Studio (version 1.0.136). Semistructured interviews were documented using field notes and compiled in MS Excel for coding and analysis.

2.5 | Data analysis

Descriptive statistical techniques were used to analyze interview data, to assess the number of varieties per household, market price, gender roles, rotation frequency, planting time of the crop variety, and use

TABLE 1 Agroecological classification, administrative zones, and subdistricts included in the study areas

Stratum	Agroecological class	Administrative zone	Subdistrict (three per stratum)
1	Tepid submoist mid-highlands (SM3)	South Tigray	Hayalo, Tahtay Haya, Higumburda
2		South Wollo	Wenberet, Tsibet, Simret
3	Cool submoist mid-highlands (SM4)	South Tigray	Sekashmbra, Tewa, Tungi
4		South Wollo	Endiras, Gelamot, Dilfere

values. Multiple factor analysis of variance (ANOVA) was conducted in R to determine whether (1) the number of field pea varieties per household differs according to agroecology and/or administrative zones; (2) the area planted with field pea differs according to agroecological zone and/or relative wealth of household; and (3) price and yield differ according to variety, agroecology, and/or administrative zones. Where ANOVA results were significant ($p < 0.05$), a post hoc Tukey test of honest significant differences (HSD) was undertaken to identify statistically significant pairwise differences.

To compare the varietal richness of field pea within and among households, we adopted Whittaker's system of alpha, beta, and gamma diversity (Ruelle, Kassam, et al., 2019; Whittaker, 1960). In this case, alpha diversity is the average number of field pea varieties per household and was calculated for each stratum. Gamma diversity was calculated as the total number of field pea varieties encountered in each stratum. Finally, beta diversity is the average turnover in varieties from one household to the next and is obtained by dividing gamma by alpha diversity for each stratum.

The Shannon Diversity Index (Shannon, 1948), which accounts for evenness as well as richness, was used to compare the diversity of field pea varieties on farms between administrative zones and agroecological zones, using the area planted as a measure of relative abundance. The Shannon Diversity Index (H') is calculated as follows:

$$H' = - \sum_{i=1}^s p_i \ln(p_i),$$

where s is the total number of field pea varieties documented on the farm and p_i is the relative abundance of the i th field pea variety based on the area planted by the interviewee during the 2015/2016 growing season. Although the Shannon Diversity Index is more frequently used to analyze ecological data, it is also applied to measure intraspecific diversity of crops among farming households (Abera et al., 2020; Ruelle, Asfaw, et al., 2019).

Participation rates used for gender analysis accounted for the age and gender groups available within each household. For example, to calculate the participation rate of female children in planting, one would divide the number of households reporting that their female children contribute to that activity by the number of households with female children.

Finally, analysis of qualitative data obtained from semistructured interviews with key informants, including the meaning of the name of the variety (e.g., its origin, colour, size, taste, and nutritious value), production management, and primary constraints was conducted by iterative coding of interview data in Excel and cross-tabulating for analysis.

3 | RESULTS AND DISCUSSION

3.1 | Farmers' varieties of field pea

A total of nine field pea varieties were documented within the study area, seven in South Tigray and two in South Wollo (Table 2). One of






the varieties encountered in South Tigray was identified as a mixture of multiple types but is planted, harvested, and used as a single variety and is therefore analyzed here as such. In both the SM3 and SM4 agroecologies, South Tigray had more varieties (six each) than the corresponding agroecologies in South Wollo (two and one, respectively). In South Tigray, five varieties (“gotate adi,” “dekik gotate,” “dekoko,” “tegegnech,” and “hiwshilshal”) were common to both agroecologies; a unique variety was found in each: “BIRKITU” was found only in SM3, whereas “CHEBEREYAY GOTATE” only in SM4. In South Wollo, one local variety (“DALICHA ATER”) was found in both SM3 and SM4 agroecologies, and “NECH ATER” (an improved variety) was limited to SM3. According to Elders interviewed as key informants in South Tigray, no varieties of field pea have been lost from their area. However, in one of the subdistricts in South Wollo (Sekashmbra) two Elders remembered a variety known as “GROTHMEN ATER” that they had not seen for 20 to 30 years.

General respondents and key informants classified their field pea varieties according to seed color, seed size, nutritional value, and maturity time. Some—but not all—of this information is encoded in the local names for varieties (Table 2). Most local names refer to seed color. Interestingly, farmers in South Tigray classify and name their varieties by their seed color, seed size, their locality, and maturity time, while the two varieties in South Wollo are classified based on seed color only.

A total of 32 germplasm accessions were collected from the study area, including 23 accessions of the seven varieties from South Tigray and nine accessions of the two varieties from South Wollo. Key informants in South Wollo suggested that the lower diversity of field pea varieties in their communities is due to the lack of “improved” varieties developed by plant breeders at the Ethiopian Institute of Agricultural Research, suggesting that they had not been distributed in the zone. Indeed, of the seven field pea varieties found in South Tigray, four were reported as improved types, and another was a mixture that includes local and improved types, suggesting that varietal diversity has been enhanced by the distribution of those new cultivars. In any case, the number of field pea varieties documented in both zones is relatively low. These results align with the observations of Keneni et al. (2007) that accessions of field pea from southern Ethiopia are generally more genetically diverse than those from northern parts of the country.





Four of the varieties found in South Tigray were planted by more than one third of farmers. The most popular was “TEGEGNECH” (planted by 61% of farmers), followed by “GOTATE ADI” (51% of farmers), “DEKOKO” (47% of farmers) and “DEKIK GOTATE” (38% of farmers). According to respondents, “TEGEGNECH” and “GOTATE ADI” have higher productivity and disease resistance than other varieties. “DEKIK GOTATE” and “DEKOKO” were more common in the SM3 than SM4 agroecology of South Tigray. Respondents explained that they grow these two varieties during the “BELGI” (short rains) because they mature faster than others and are relatively drought tolerant. By comparison, in South Wollo, one local variety (“DALICHA ATER”) is common throughout both SM3 and SM4 agroecologies and is planted by 89% of farmers. In both agroecologies, respondents reported that “DALICHA ATER” is preferred because it resists disease and tolerates waterlogging.

TABLE 2 Varieties (including local landraces and improved cultivars) of field pea identified by farmers in South Tigray and South Wollo zones of northeastern Ethiopia

No.	Local name	Language	Meaning of name	Zone	District(s)	AEZ	Status	Photograph
1	Nech ater	Amharic	White (color)	South Wollo	Borena, Wogidi	SM3	Improved	
2	Dalicha ater	Amharic	Cream (color)	South Wollo	Borena, Wogidi	SM3, SM4	Local	
3	Keyih gotate, gotate adi, abiyi gotate	Tigrigna	Red (color), local (origin), large (seed size), or long growing period	South Tigray	Ofla, Endamehoni	SM3, SM4	Local	
4	Dekik gotate	Tigrigna	Small (seed size)	South Tigray	Ofla, Endamehoni	SM3, SM4	Improved	
5	Dekoto	Tigrigna	Tiny (seed size)	South Tigray	Ofla, Endamehoni	SM3, SM4	Local	

(Continues)

TABLE 2 (Continued)

No.	Local name	Language	Meaning of name	Zone	District(s)	AEZ	Status	Photograph
6	Tegegnech	Amharic	Unknown	South Tigray	Ofla, Endamehoni	SM3, SM4	Improved	
7	Birkitu	Amharic	Unknown	South Tigray	Ofla	SM3	Improved	
8	Hiwshilshal	Tigrigna	Mixture (of varieties)	South Tigray	Endamehoni, Ofla	SM3, SM4	Mixture of local and improved	
9	Chebereyay gotate	Tigrigna	Gray (color)	South Tigray	Endamehoni	SM4	Local	

Note: SM3 refers to the tepid submoist mid-highlands and SM4 to the cool submoist mid-highlands.

3.2 | Varietal diversity within and among households

A majority of farmers in South Wollo reported planting only one variety of field pea, whereas more than two thirds of farmers in South Tigray planted more than one, and more than one-third planted three or four varieties (Figure 2). The average number of varieties cultivated per year (alpha diversity) was higher in SM3 and SM4 of South Tigray than in the corresponding agroecologies in South Wollo (Table 3). The results of a two-factor analysis of variance (ANOVA) confirm that the number of varieties grown per household is significantly different between the two zones ($p < 0.0001$) but not between agroecologies ($p = 0.84$). Furthermore, given the high number of varieties available within both strata in South Tigray, the varietal turnover of the crop among households (beta diversity) is higher than in South Wollo. In other words, farmers in South Wollo are limited to growing the same

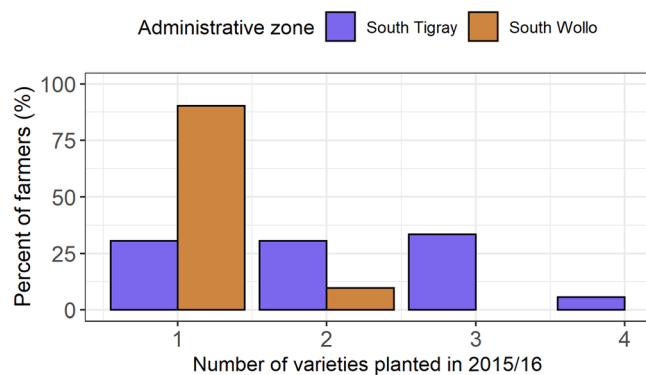


FIGURE 2 Number of varieties planted by farmers in select communities of South Tigray and South Wollo, Ethiopia ($n = 144$)

few varieties, while farmers in South Tigray have more than twice as many varieties available to them as the typical household grows.

The Shannon Diversity Index was calculated for each farmer based on the hectares planted to each variety. Similar to alpha diversity, a two-way ANOVA of the Shannon Diversity Indices found that the administrative zone was a significant factor ($p < 0.0001$), while agroecology was not ($p = 0.413$). The average diversity index per stratum in South Tigray is 0.37 in SM3 and 0.33 in SM4, whereas the average in South Wollo is 0.05 in SM3 and 0 in SM4. In South Wollo, almost all farmers planted only one variety, so their Shannon Diversity Index was equal to 0, whereas in South Tigray, many farmers planted more than one variety. Shannon Diversity Indices in South Tigray sometimes exceeded 1 if the household planted multiple varieties and relatively similar areas to each variety. Nonetheless, these results are relatively low. For example, in a comparable study of common bean varieties, Abera et al. (2020) reported higher Shannon Diversity Indices; even in one area where only two varieties were identified.

3.3 | Area planted to field pea according to relative wealth

Most farmers in Ethiopia measure their fields in “TIMAD,” which is equivalent to $\frac{1}{4}$ hectare, the area that can be ploughed by a pair of oxen in the course of 1 day. Farmers within the study area planted between one-half “TIMAD” and three “TIMAD” (0.125 to 0.75 ha) of field pea. On average, low-income farmers planted less (0.25 ha) than mid- to high-income farmers (0.36 ha). A multifactor ANOVA revealed significant differences in the area planted according to relative wealth ($p = 0.000349$), but not agroecology or administrative zone (Table 4).

TABLE 3 Alpha, gamma, and beta diversity of field pea varieties in the four strata

Stratum	AEZ	Zone	Number of households	Alpha diversity	Gamma diversity	Beta diversity
1	SM3	South Tigray	36	2.19	6	2.73
2	SM3	South Wollo	36	1.19	2	1.67
3	SM4	South Tigray	36	2.08	6	2.88
4	SM4	South Wollo	36	1	1	1

Note: SM3 refers to the tepid submoist mid-highlands and SM4 to the cool submoist mid-highlands.

TABLE 4 ANOVA of area planted to field pea according to administrative zone, agroecological zone, relative wealth, and year

	Df	Sum sq	Mean sq	F value	p value
Zone	1	0.004457	0.004457	0.2108	0.6466
Agroecology	1	0.01907	0.01907	0.9018	0.3433
Wealth	1	0.2791	0.2791	13.2	0.0003493***
Year	1	0.09018	0.09018	4.264	0.04011*
Residuals	218	4.611	0.02115	NA	NA

***0.001.

**0.01.

*0.05.

3.4 | Planting and harvesting time of field pea varieties

The main growing season for most crops in northern Ethiopia lasts from June to September. This rainy season is known as “KIREMTI” in Tigrigna and “KIREMT” or “MEHER” in Amharic. Field pea varieties grown during “KIREMTI” are typically planted near the end of June or beginning of July and harvested in late October to early December, regardless of zone or agroecology. One exception is “DEKOKO,” which is planted later than other varieties, from mid-July to early August, because it has a shorter maturity time. In South Wollo, almost all field pea varieties are planted during the main growing season, with one exception: in the SM3 agroecology, some respondents plant ‘NECH ATER’ in irrigated fields in late October to mid-November, after the end of the rainy season, to be harvested in March or April.

In South Tigray, in both SM3 and SM4 agroecologies, field pea is also planted during a second, shorter growing season known as “BELGI.” During “BELGI,” farmers plant field pea starting in late November up to early March, depending on rainfall. For example, farmers in Ofla and Endamehoni districts said that the onset of rain during “BELGI” is highly variable, sometimes coming immediately after they have finished harvesting crops planted for the main season. In that case, they will immediately start planting field pea. Otherwise, they will plant it whenever the rains begin, up until mid-March. Field pea planted during the “BELGI” are harvested from early-April to June, depending on the planting time and maturity time of varieties.

Based on planting and harvesting dates, it is clear that different varieties have different maturity times. “DEKOKO” has the shortest maturity times (60–80 days), whereas most other varieties take much longer to mature (120–160 days). Previous studies have documented similar maturity times for “DEKOKO,” between 71 and 80 days and confirm that it is typically harvested earlier than other varieties (Gebreegziabher & Tsegay, 2018; Yemane & Skjelvåg, 2003; Yirga & Tsegay, 2013). The maturity time of other varieties is longer but highly variable, ranging from 110 to 150 days, depending on the variety, planting date, and agroecological zone (Habtamu & Million, 2013; Tadesse et al., 2018).

Human-induced climate change is already requiring farmers to adapt their planting times and selection of varieties. Climate change

models predict that Ethiopia's short rains will become less reliable over time (Conway & Schipper, 2011), meaning that farmers in South Tigray may not be able to plant field pea during the “BELGI.” Furthermore, farmers throughout the country report that in recent years the main growing season has tended to start later and end earlier, thereby shortening the growing season. Varieties like “DEKOKO,” which has a considerably shorter maturity time, will likely fare better than some improved varieties (e.g., “TEGEGNECH” and “NECH ATER”) that require a long rainy season. Future plant breeding efforts should focus on developing varieties that come to maturity in the shortened growing season and can withstand intermittent drought.

3.5 | Crop rotation of field pea

As in other parts of eastern Africa (Julius, 2014), farmers in the study area cultivate field pea in upland areas and hilltops, often in light and stony soils that are unsuitable for other crops. They also grow field pea on land with low or medium fertility in rotation with cereal crops. The frequency of crop rotation varies between the two zones, with farmers in South Tigray tending to rotate field pea with cereals more frequently than those in South Wollo (Figure 3). In South Tigray, the majority of farmers (58% in SM3 and 61% in SM4) rotate field pea in a 2-year cycle, that is, plant it every 2 years in the same field. In addition, some farmers in South Tigray rotate their field pea with a cereal even faster, by double-cropping with a cereal in a seasonal rotation. There is some evidence that farmers in South Tigray are rotating field pea faster than they did in the past; earlier reports indicate that farmers typically planted the crop after 2 or 3 years of cereal crops (Ethiopian Institute for Agricultural Research [EIAR] & Tigray Agricultural Research Institute [TARI], 2011). By contrast, most farmers in South Wollo plant field pea in the same field every 3 years (86% in SM3 and 50% in SM4). On the other end of the spectrum, a few farmers in the SM4 agroecology of South Wollo plant cereals for 3 years before planting field pea (thus, every fourth year).

Farmers rotate field pea for different purposes but mainly to improve soil fertility and enhance production of the cereals while reducing the need for fertilizer. As a legume crop, field pea develops symbiotic relationships with *Rhizobia* bacteria that fix atmospheric

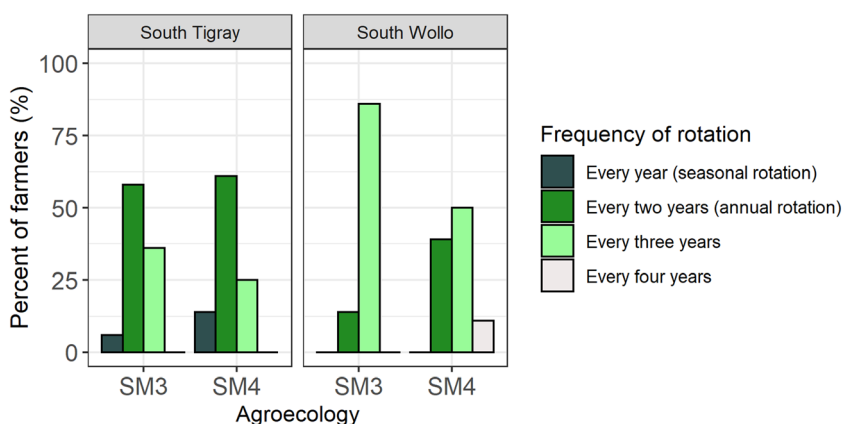


FIGURE 3 Frequency of field pea rotation within the crop sequence in South Tigray and South Wollo, Ethiopia. SM3 refers to the tepid submoist mid-highlands and SM4 to the cool submoist mid-highlands

nitrogen and make it available to plants through their root systems (Clark, 2012). Key informants described how field pea restores soil fertility not only for the current production year but also for the succeeding 2 to 3 years of production. Crop fields that have been sown with field pea and are therefore important for next year's cereal production are called "BESELA" in South Tigray and "IKIR" in South Wollo, names that refer to their high soil fertility. In addition, rotation with field pea is used to interrupt pest and diseases cycles. Key informants explained that rotating cereals with field pea reduces pests and diseases that affect cereals without chemical pesticides. In fact, 97% of the respondents said they forego use of external chemical inputs such as fertilizers, pesticides or herbicides, resulting in cost savings. Furthermore, as field pea requires minimum tillage, farmers typically plough their fields only once at the time of sowing, thereby saving labor for ploughing and weeding.

Farmers' knowledge of field pea is supported by scientific studies. Elzebroek and Wind (2008) agree that the crop is adapted to many soil types but grows best on light-textured and well-drained soils. A relatively shallow root system and high water use efficiency make field pea an excellent rotational crop with small grains, especially in arid areas where soil moisture conservation is critical (Clark, 2012). Studies by Chen et al. (2006) and Habtamu and Million (2013) support the notion that rotation with peas plays a significant role in soil fertility restoration and breaks diseases and pest cycles. In general, Drinkwater et al. (1998) found that without appropriate rotation with legume crops, soil fertility and biomass production decrease, while disease, weed and insect infestation increase.

3.6 | Yield of field pea

Farmers' reports of their own yields (converted from local units to kg ha^{-1}) were highly variable. A multiple factor ANOVA did not detect significant differences among the two zones ($p = 0.789$), agroecologies ($p = 0.673$) or among varieties ($p = 0.21$). However, there were statistically significant differences in yield between the 2014/15 and 2015/16 growing seasons ($p = 0.000113$). According to information from key informants, the main reason for yield reduction in the second year (2015/16) was a shortage of rain and a disease outbreak (identity of the disease is unknown) during the main growing season. While average yields were consistently lower in 2015/16 than in 2014/15, the post hoc Tukey test detected significant differences for only one variety, "DALICHA ATER," the most widely grown variety in South Wollo.

Given that farmers are producing field pea under a wide range of conditions, the analysis of yields was unlikely to detect consistent differences between varieties. Furthermore, because some varieties were planted by only one or two farmers, these had to be excluded from the analysis. Nonetheless, the reported yields for those rare varieties appear to differ from those that are more widely planted. The single farmer who planted "CHEBEREYAY GOTATE" (in the SM4 agroecology of South Tigray) reported very high yields in both the 2014/15 and 2015/2016 growing season (between 2300 and 2400 kg ha^{-1}). By contrast, the few farmers in South Tigray who

planted the varietal mixture "HIWSHILSHAL" reported very low yields (ranging from 200 to 800 kg ha^{-1}).

Overall, the yields reported by farmers in the study area, with averages less than 1 t ha^{-1} , were far below the national and global averages (1.66 t ha^{-1} and 1.7 t ha^{-1}) (CSA, 2016; Smýkal et al., 2012). In Europe, that is, in the Netherlands, France, and Belgium, field pea yields can reach 4 to 5 t ha^{-1} (Smýkal et al., 2012). Previous studies of field pea production in South Tigray have reported higher yields (1.25 t ha^{-1}) than the current study (1.1 t ha^{-1}) (EIAR & TARI, 2011). In any case, there is a significant gap between the potential yield of the crop and the actual yields (3.2–4 t ha^{-1}). One likely reason for lower yields is that few of the farmers interviewed apply fertilizers to their legumes. For example, the average yield reported for "DEKOKO" in South Tigray was 0.77 t ha^{-1} , whereas a study in which phosphorous fertilization was applied to "DEKOKO" yielded 1.95 t ha^{-1} (Yemane & Skjelvåg, 2003).

3.7 | Use of field pea

Field pea is a staple food as well as a major income earner for most smallholder farmers in Ethiopia. Farmers in both zones grow field pea for food, fodder, and income generation. Given that almost all respondents reported using the crop for all three of these purposes, there was no significant difference between the two cultural groups (Tigray and Amhara) nor between agroecologies included in the study. For the most part, Ethiopian farmers tend to prioritize household consumption, keeping what they need to feed their household before selling any surplus at the local market. Crop residues (leaves and stems) are used as animal fodder, especially for equines and cattle. As mentioned in the preceding section, farmers grow the crop not only for direct economic benefits but also to improve soil fertility and reduce diseases and pests.

Field pea has an important market value for rural households. At the time of data collection, the average prices of field pea varieties were similar except for "DEKOKO," which had a significantly higher market price (p value < 0.0001). As reported by others (Gebreegziabher & Tsegay, 2018; Yemane & Skjelvåg, 2003) the reported prices of "DEKOKO" in South Tigray averaged 30.7 Ethiopian Birr kg^{-1} , nearly twice that of all other varieties in the zone (16.4 Birr kg^{-1}) and three to four fold that of cereals (which ranged from 8 to 11 Birr kg^{-1}). The high price might be explained by relatively low supply and high demand, based on lower yields and higher nutritional value than other field pea varieties. In any case, more than 90% of the farmers who grow "DEKOKO" (all in South Tigray) primarily sell it at the market and therefore refer to it as a cash crop. The prices of field pea in South Wollo did not differ by variety; both varieties were similarly priced to those in South Tigray (16.5 Birr kg^{-1}). Nonetheless, previous reports have argued that field pea is a critical source of income for smallholders in Ethiopia, particularly in South Tigray, due to its relatively high market value and potential use in value added products that could be sold at local markets or prepared for export (EIAR & TARI, 2011; International Food Policy Research Institute [IFPRI], 2010).

The value of field pea in general and “DEKOKO” in particular can be attributed to its nutritional value and its contribution to food culture. In general, field pea is a nutritious legume, containing up to 35% protein, and high concentrations of the essential amino acids lysine and tryptophan (Elzebroek & Wind, 2008). Field pea is often cracked or ground and added to cereal grain rations; such preparations consist of approximately 18% to 20% protein (McKay et al., 2003). Due to their knowledge of its nutritional benefits, local people call “DEKOKO” the “DORO WET” (chicken stew) of the poor, as reported by the key informants in this as well as previous studies (Sentayehu, 2009). Furthermore, key informants in Higumburda, South Tigray, explained that their community uses “DEKOKO” to prepare a special food known as “GA’AT” (a kind of porridge), which is fed to underweight children and lactating women when they need to gain weight. While some previous studies suggest that “DEKOKO” is a suitable complementary source of protein for the rural poor (Yemane & Skjelvåg, 2003), further analyses are necessary to compare its nutritional benefits with those of other field pea varieties.

3.8 | Gender roles in production and use of field pea

In both South Tigray and South Wollo, agronomic activities for most field crops (including field pea) are said to be men's work. However, respondents in both zones reported that women are involved in many activities related to field pea (Figure 4). Ploughing and planting were said to be primarily conducted by men, whereas food preparation was the sole responsibility of women in both zones. Most of the other

activities are carried out by both genders, with slightly lower participation rates for women than men, including preparing the soil for planting (preplanting), weeding, harvesting, threshing, storing, and marketing. Children (defined as younger than 14 years old) also contribute to most activities, with the exception of marketing and seed selection. Some male children assist women with food preparation in both zones. Elders also participated in many activities, particularly male Elders.

There were a few differences in women's roles related to field pea between the two zones: women more often participated in hoeing and collecting fodder in South Wollo than in South Tigray, whereas they were more often involved in preplanting activities and seed selection in South Wollo. By comparison, most households reported that adult men participated in all activities related to field pea except for food preparation. Similar results were reported in a parallel survey of households conducted by Berhanu (2017) in Arsi and Keffa zones of southern Ethiopia, where women also participated in many of the activities related to field pea. While the current study documents the participation rate, a more detailed survey might be able to compare the time invested by different household members in the various activities and thereby provide a deeper understanding of the relative workload between male and female household members.

3.9 | Production constraints for field pea

Given the relatively low yields reported by respondents, it is important to consider constraints to field pea production, particularly those factors identified by farmers, to set priorities for research and

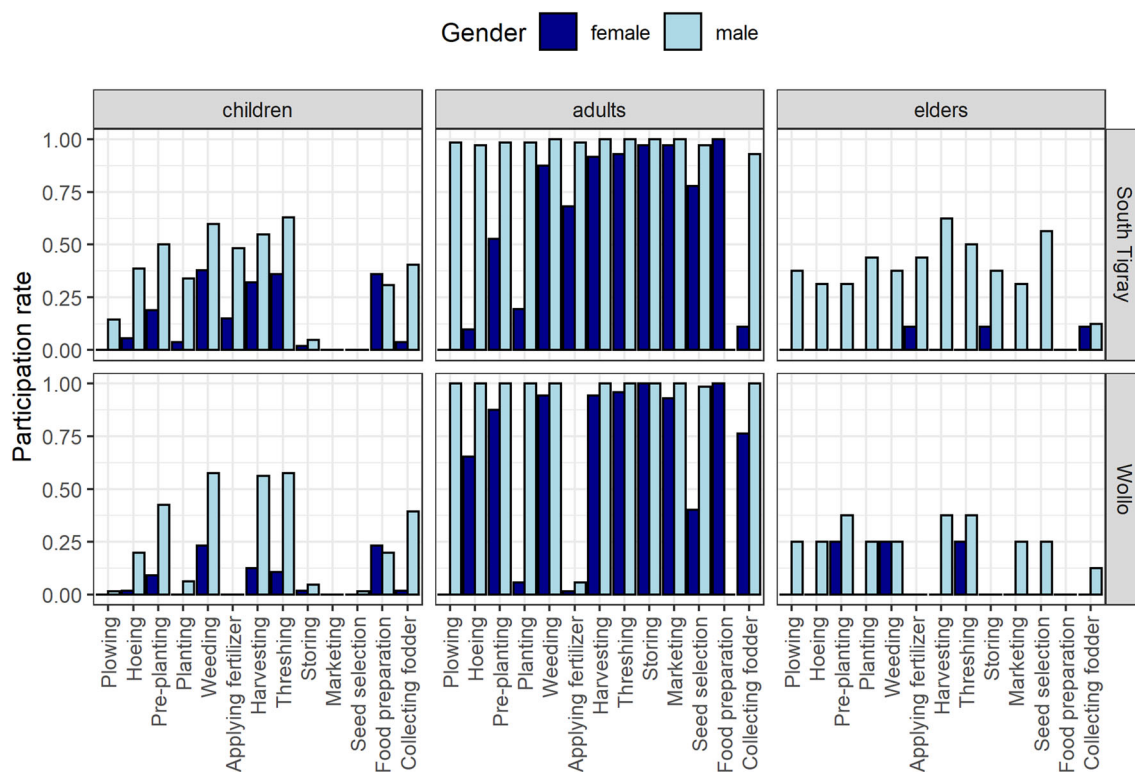


FIGURE 4 Gender roles in production and use of field pea in South Tigray and South Wollo, Ethiopia

development efforts. According to key informants, field pea has been less commonly planted within the last 5 years, though the explanations for this change vary. Across both agroecologies and cultural groups, 60% of respondents reported that a major constraint facing field pea production is disease, followed by 56% who mentioned insect pests. Other frequently mentioned constraints were low soil fertility (28%), frost (28%), lack of improved varieties (28%), drought (24%), and government programs that incentivize planting other crops (mainly cereals) (21%). The latter, which is administered by local extension agents, encourages farmers to adopt new cereal varieties following a 'cluster' development model; the cluster program in the study area in South Tigray focuses on wheat, whereas that of South Wollo focuses on teff. In some subdistricts (Sekashmbra, Tungi, and Tewa in South Wollo), farmers reported that they are losing their local varieties of field pea and other crops.

Two other constraints were mentioned by a small number of farmers. First, a few farmers reported that field pea production is limited by a shortage of land. Indeed, at a national scale, increased competition for land, particularly in subdistricts located close to market towns, has reduced household landholdings across the country; however, yields (in terms of tons per hectare) appear to be higher among farmers with smaller landholdings (Paul & wa Githinji, 2018). Nonetheless, having less land means that farmers must adapt their farming systems and cropping patterns, and may be less able to rotate their cereal crops with legumes (see also Ruelle, Asfaw, et al., 2019). Secondly other farmers said that they do not use fertilizer due to its high cost. Traditionally, field pea and other legumes are used as a source of soil fertility, and therefore applying fertilizers to them may be counterintuitive. However, while planting legumes' relationships with soil biota enhance soil nitrogen, addition of phosphorous, potassium and sulfur (PKS) may increase both yield and nutrient content (Yemane & Skjelvåg, 2003). Applying multiple strategies to enhance soil health (including organic and inorganic fertilizers) may enhance the productivity of field pea as an important protein source.

Many of the production constraints listed by farmers are long-standing concerns. A study conducted by Telaye et al. (1994) and CSA (2009) also found that field pea yields were limited by disease, insect pests, poor management practice, frost and low-yielding local varieties. A more recent study conducted in South Tigray zone and Raya Kobo District reported similar challenges, including drought, insect pests, diseases, weed infestation and lack of improved varieties (EIAR & TARI, 2011). As a result there was a yield reduction by 9.2% in 2009 as compared to 2008 cropping season (CSA, 2009). The future of field pea production will depend on the ability of research and development programs to prioritize and find solutions to these concerns.

4 | CONCLUSION

Interviews with field pea growers in South Tigray and South Wollo revealed the use of nine varieties, including four local landraces, four

improved cultivars, and one mixture that included both local and improved germplasm. Varietal diversity was higher in South Tigray, including a higher number of varieties present (7), a higher number per household, and a higher Shannon Diversity Index values based on the area planted to each variety. Differences in varietal richness may be attributed to the introduction of improved varieties to South Tigray where four of the seven varieties were developed by the Ethiopian Institute of Agricultural Research. Importantly, the introduction of new varieties has led to diversification, rather than loss of local landraces.

Field pea is an important source of food, fodder, and income in both South Tigray and South Wollo. However, higher varietal diversity in South Tigray enables farmers to plant field pea at different times of year. While most varieties are planted at the beginning of the main rainy season, "DEKOKO" is planted later due to its short maturity time. Furthermore, "DEKOKO" was twice as expensive as other field pea varieties, which farmers attributed to its taste and nutritional value. Further study is needed to enhance production of this highly adaptable and nutritious variety.

Field pea offers multiple benefits and can contribute to sustainable agricultural development in Ethiopia. However, the average yield reported here is far below the national average. Further studies in other areas may locate landraces with advantageous traits to overcome the production constraints described by farmers. Participatory breeding programs are recommended to develop new varieties based on farmers' diverse needs. Collaboration between farmers, extension workers, NGOs and research institutions are necessary to enhance the contribution of field pea to farmers' livelihoods.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

YG, MLR, STB, and AGP designed the research protocols; YG conducted all interviews with farmers; YG, MLR, AT, and KT analyzed the data; YG wrote the first draft of the manuscript; KT, AT, MLR, STB, and AGP revised and edited the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the Legume Diversity Project principal investigator, STB, upon reasonable request.

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ENDNOTE

¹ Until recently, *Pisum abyssinicum* was considered a subspecies of *Pisum sativum* known as var. *abyssinicum*; it is a unique species independently developed and cultivated in Ethiopia (IBC, 2012; Yemane & Skjelvåg, 2003).

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