

Integrated Ethnobotanical and Agroecological Valuation of *Pisum sativum* var. *abyssinicum* landraces in Ethiopia

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Additional Declarations:

No competing interests reported.

Statement of Ethics Approval This study involving human participants was conducted in accordance with the ethical principles for research involving human subjects and was reviewed and approved by North Wollo and South Tigray Agricultural Ethical Review Committees, Ethiopia. The study procedures complied with the ethical requirements of the approving institution. **Participant Consent** Prior to data collection, all participants were informed about the purpose and procedures of the study, the voluntary nature of their participation, and their right to decline participation or withdraw at any time without consequence. Written informed consent was obtained from each participant before the interviews and collection of ethnobotanical information. Participants also consented to the use of the information they provided for scientific research and publication in an anonymized form. No personally identifying information is reported in this manuscript.

Integrated Ethnobotanical and Agroecological Valuation of *Pisum sativum* var. *abyssinicum* landraces in Ethiopia

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Abstract

Pisum sativum var. *abyssinicum* A.Braun is an exceptional and challenging taxon demanding tangible valuation. It is cultivated as homegrown exchange and human consumption under the confined areas with poor management, old-fashioned cultivation methods and expertise. Integrated valuation of this native and continually adapted crop is pressing research problem. The overarching goal was appraising distribution thereby investigating the operative agronomic performance in different agro-ecology from germination up to harvesting time then valuing the productivity of the crop. The investigation includes ethnobotanic survey and experimentation in three different agroecologies. Cross-sectional design was employed to collect data from 444 respondents that were analyzed using SPSS software and ANOVA. To assess the effects of agroecology on morphological and yield traits of three selected landraces a completely randomized block design was used. Results showed the crop requires about two good rains, Nitisol soils and about 21-30 kg ha⁻¹ seeding rate. Flowering to maturity time ranges 1^{1/2} to 2^{1/2} months depending on the agroecology, with a yield of about 300-400 kg ha⁻¹. Major delaying factor was agro-ecology. Mid-altitude had the highest pH 7.71±0.07, cation exchange capacity 45.46±0.71, covenant with most soils (>40 CEC meq/100 g soil) around neutral pH. Mid-altitude agroecology was found best for overall performance of the landraces. Altitudinal gradients and soil quality factors brought a significant difference among the landraces. Even same landraces grown in different agroecologies have different phenotypic performances. Midland altitudes are good for vigirousity and overall yield of the crop's landraces and Gedober landraces perform best in harvest index.

Key Words: Ethnobotanical survey, landrace, seeding rate, soil type, yield, harvest index

Background of the study

Pisum sativum var. *abyssinicum* A.Braun, is one among the pulse field crops grown in Ethiopia [1]. Local farmers' inevitability expresses the crop's special taste, marketability, and earliness [2]. Researchers are critically investigating it but yet not fully attain factors and genes responsible for the delightful taste, the early flowering and maturity of the crop [3, 4, 5, 6, and 7]. Ethiopian farmers connoted the crop's deliciousness in different ways; "urban stew", "stew for recipient of hospitality" and "chicken stew of the poor" for its delightful taste. On the other way, it is named as "seed of the well-off", for its marketability and unavailability for the poor. Regarding to its earliness, *Pisum sativum* var. *abyssinicum* is considered as early maturing ("fetno-derash") referring to its short life cycle. Studies made so far about the crop indicated lack of local yield gap estimation method developed to maximize the *Pisum sativum* var. *abyssinicum* yields [8]. This is a major problem, particularly to the undeveloped countries like Ethiopia facing challenges to achieve potential yield [9], especially when viewed in the global climate change scenario.

The crop is less known outside of the tropical and subtropical belts of Africa [10 and 11]. It is a charming herbarium specimen for the scientific community and considered as a germplasm accession included in the 6096 pulse accessions of Ethiopia [1]. This requires valuation of the stakeholders' indigenous knowledge so as to re-establish the prospect of food legumes together with the ecological insight to the agricultural system [12]. Besides, loss of diversity in farmers' field crops is aggravating shortage of expected evidences of the threats in the available literatures [13]. Moreover, a study from [14] indicated the narrow distribution of *Pisum sativum* var. *abyssinicum* accompanying narrow genetic variation but long inherent tolerance abiotic stresses adaption like salt [15]. The overall goal of this research was to assess distribution thereby investigating the agronomic performance of the crop's landraces in different agro-ecological areas starting from germination establishment up to harvesting time subsequently the and productivity of the crop were evaluated. This would help to tackle food security, climate change and biodiversity conservation challenges.

Materials and methods

Description of the study areas

The study was conducted in Northeast Ethiopia in Amhara and Tigray regions (Figure 1). It was piloted in six districts that proportionated into three districts per region based on agro-ecology. Each district was well-adjusted into three kebeles (small administrative units of a district existing in table 2) which represent different agro-ecology. The districts have different geographical and climatic features (Table 1).

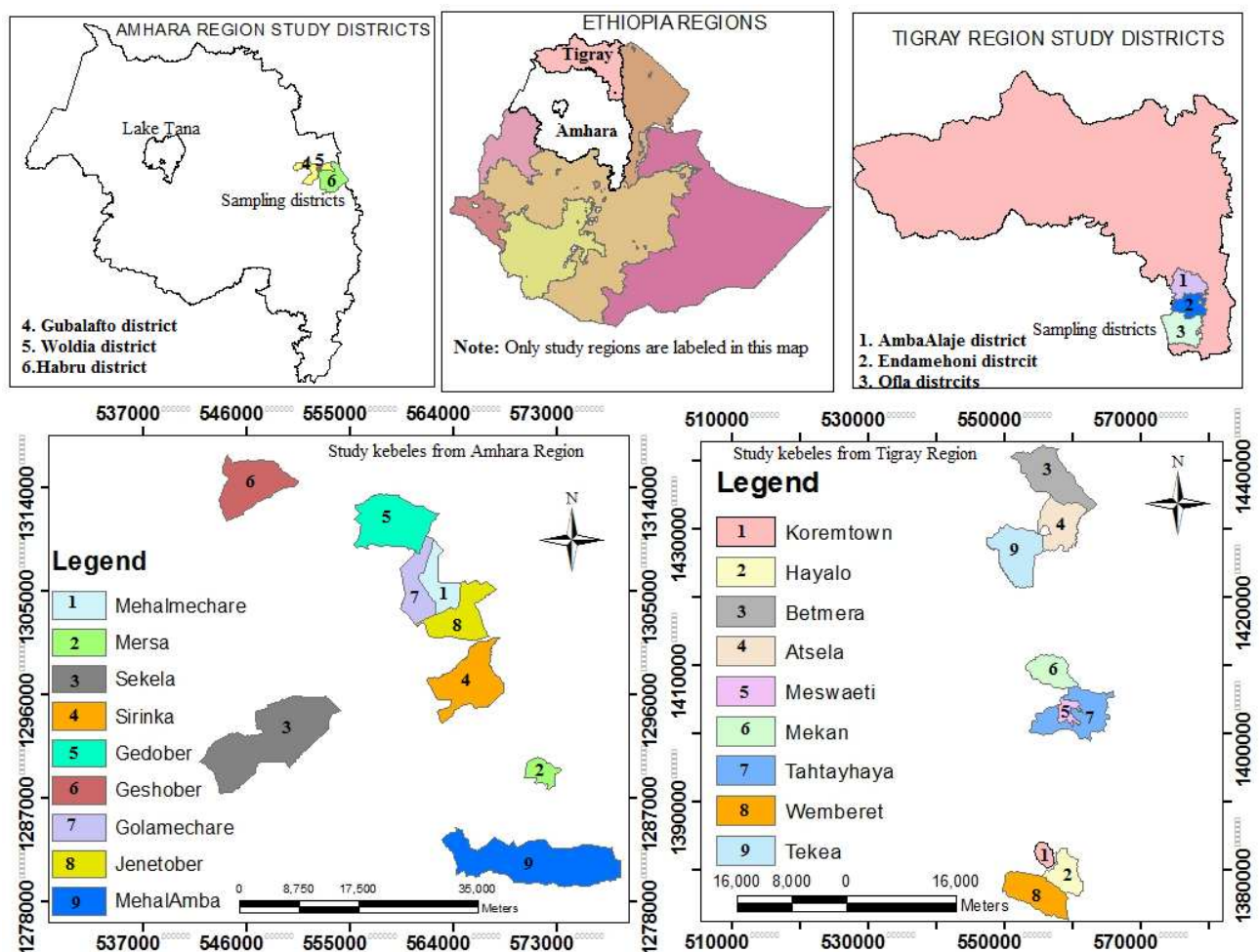


Figure 1. Map of Ethiopia showing location of the study areas within Amhara and Tigray regional states

Gubalafto and Habru are situated in east plain possessing high potential agricultural value chain and beneficial from the varying topography with suitable climate and agro-ecology for crop production [16]. In Woldia, the study was conducted in kebeles within a radius of 10-15km. Oflla

and Amba-Alaje districts are mostly highland agro-ecological districts [17]. They have normally sufficient rainfall and suitable temperatures for rainfed agriculture as indicated in Table 1.

Crop production areas in Ethiopia are shaped by the agro-ecological variability [18 and 19]. The study districts from north Wollo (Table 1) are mainly characterized by production of stable crops such as sorghum, maize, teff, chickpea, and coffee and the districts from south Tigray (Table 1) produce stable crops namely wheat, barely, teff, chickpea and maize [19]. All regions produce the present study crop at different rates.

Table 1. Geographical and climatic features of the study areas

Sampling regions	Districts	Altitude (masl.)	Mean annual rainfall (mm)	T(°C)
Amhara	Gubalafto	1379-3200	990-1030	21-25 [20]
	Woldia	2112-2218	600-820	10-20 [21]
	Habru	700-3500	300-876	21-32 [22, 23]
Tigray	Ofla	2432-2450	350-1200	20-26 [24]
	Endamehoni	1600-3960	600-1000	9-18 [25]
	Amba-Alaje	2445-2480	580-845	14-22 [25]

T^o (°C): temperature in degree Celsius.

Data collection design

Cross-sectional data collection design was employed as this is better and more effective for obtaining information about the current status or the immediate past [20, 26] of this icon crop (Abyssinian Pea). Personal interviews with oral verbal stimuli were presented and replied by way of oral verbal responses in the first steps of this study. This is in order to collect information that helps to understand the research topic better through information interchanged between the individuals. Pilot study tested questionnaires consisting of series of printed multiple choice questions; to be marked by the informants were distributed and collected. Observations (on residence, market and field) were ended for seed colors, pests and soil conservations (Figures 2 and 5), and focus group discussion with farmers who have the current growing experience of the crop for the last three years were used. Data were collected in 2017 using local language of informants that latter translated to English.

Sample size determination

Districts were selected purposely based on the current production potential of the crop and the climatic and geographic (altitudinal) differences of the districts (Table 1). Moreover, recommendations from agricultural and rural development experts were used.

A total of 6228 Abyssinian pea producer farmers of the six districts found from the pilot ethnobotanical survey were proportioned into the representative kebeles using the formula of [26]. Additionally, a total of 82 agricultural experts with crop specializations from two Agricultural Research Centers (ARCs) were proportioned into their respective districts. $n = \frac{N}{1+N(e)^2}$ [26]. Where n: the number of required samples of respondents for the districts and ARCs (sample size); N: total farmers of the districts (population size) and Agricultural Experts; e: confidence level (0.05 (95%) level of precision. Accordingly, 396 farmers and 48 agricultural experts respectively with a total of 444 sample respondents were taken.

On field experimental designs and methods description

Following the ethnobotanical survey study, the research work was proceeding with field based experimental observations at three experimental sites considering crop type and altitude as influencing factors. Therefore field experiments was conducted using seed of three *Pisum sativum* var. *abyssinicum* landraces from three different altitudes for agronomic studies on farm level at three farmers' fields. For better stand, seed bedded soil preparation was carried out through plowing as planters from other developing countries ensure good seed-soil contact encourage good establishment [27]. The fields were prepared well by ploughing and digging. The soil became less pulverised and fine. Additionally, the field was free from weeds and stubble of the kharif crop grown earlier. Seeds were soaked overnight to plump them up and give them head start toward germination. The soil samples nutrient content determination was carried out at Amhara Design and Supervision Works Enterprise and Laboratory Service. Detailed soil nutrient requirements and food value contents of the crop were assessed. Therefore, experimental methods involved soil characterizations plant features determination tasks that were used for the investigation of the agronomic performances, production of productivity of *Pisum sativum* var. *abyssinicum* in different agro-ecological areas. Field experiments of the three altitudinal landraces were approved to characterize the crops responses as clearly described in [25].

Data for the determination of the agronomic performances from six sample plants for each landrace randomly selected from each farm and pot were collected and analyzed. These includes, days to 50% flowering, grain filled period, days to 90% maturity, stand count, plant height, number of pods per plant, number of seeds per pod, number of seeds per plant, biomass yield, thousand seeds weight in gram, harvest index in percentage and seed yield per pot was measured and analyzed. The actual yield obtained on the farmers was considered as average farmers yield. Grain yield was calculated by converting plot grain yields to a hectare basis (kg ha^{-1}) and was considered as research yield. Moreover, *Pisum sativum* var. *abyssinicum* yields of dry pea, green pea in pod and shelled green peas was determined based the references for yield of field peas that varies enormously: for dried peas-2MT/ha is considered satisfactory and for a good average yield of green peas in the pod is 6.5-7 MT/ha, and 4.5 MT/ha of shelled green peas [28]. This was after growth periods 104 days for dry pea and 49 days for green seed or shelled pods respectively.

Six competitive plants were randomly select from each replication in a farmer's cultivar for recording morphological observation. The selected plants were tagged and data on individual plant was recorded for the following characters except for days to 50% flowering and days to maturity. The procedures that were adopted for recording observations on different characters are given below:

1. **Plant height (cm):** The plant height was measured in centimeters from the ground level to tip of the main stem at the time of harvest.
2. **Days to 50 percent flowering:** Days taken from the date of sowing to the initiation of flowering in 50% of the plants of a plot was recorded.
3. **Number of branches per plant:** The total numbers of branches directly arising from main stem of a plant were counted at physiological maturity stage.
4. **Days to maturity:** The number of days from sowing to the complete pod maturity of the plants of a plot was recorded (pods turned dark golden brown to yellow in colour).
5. **Number of pods per plant:** Total number of fully matured pods obtained from each plant were counted and averaged to obtain number of pods/plant.

6. **Number of seeds per pod:** 10 pods were randomly taken from the total pods of sampled plant and the seeds were counted and averaged.

7. **Seed yield per plant (g):** All the mature pods obtained from five randomly selected plants were threshed and weight of grains of individual selected plant was recorded on a top pan electric balance and the average taken to record seed yield per plant.

8. **Test weight (g):** From the produce of each plot, 1000 seeds were taken randomly and weighed in grams using electronic single pan balance.

9. **Biological yield per plant (g):** Five randomly selected plants from each plot were harvested.

These plants were sundried and weighed (including pods, excluding roots) and averaged to obtain biological yield per plant.

10. **Harvest index (%):** Harvest index is the ratio of seed yield to biological yield expressed in percentage and was calculated using the formula given by [29]:

$$\text{Harvest index (\%)} = \frac{\text{Seed yield/plant (g)}}{\text{Biological yield/plant (g)}} \times 100$$

Analysis of soil nutrients from the *Pisum sativum* var. *abyssinicum* landraces growing areas

The nutrient contents for the soils of the study fields were examined. This is irrespective of the management practices implement technologies, input application level, timing of application, and date of sowing of the farmers of the different altitudes for the landraces under study in different agro-ecologies.

Soil sample collection and processing

When collecting the soils, composite of samples were taken from different locations in the field as taking the soil only from one spot cannot represent the whole fields. Clean utensils were used to collect soil from four locations at the corner and one at the center for composite sampling within the proposed field sites. Soils were dig at a depth of 20 cm after removing surface litter and the top 1.0 cm of soil. If the soil is sufficiently dry, it was passed through a 2mm sieve in the field. Otherwise the soil was removed to a cool, shady place to air dry until it can be passed through the sieve as passing through a large mesh screen first speed up the drying process [30].

Soil samples chemical analysis

It is known that an agronomist has to identify the various types of nutrients required by the crops, particularly N₂, P and K for the pulses. Therefore, determinations of N, P, and K of the soil where the ecotypes grow were carried out on the ground dry material basis for the 6 core samples. Nitrogen concentration was determined by micro-kjeldhal method ($N \times 6.25$) according to [31]. The soil samples were first digested in strong sulfuric acid in the presence of a catalyst, which helps in the conversion of the amine nitrogen to ammonium ions. The ammonium ions were then converted into ammonia gas, heated and distilled. The ammonia gas was led into a trapping solution where it dissolves and becomes an ammonium ion once again. Finally the amount of the ammonia that has been trapped was determined by titration with a standard solution, and a calculation will be made.

Available phosphorus was estimated colorimetrically using [32, 33] for acidic soils. The soil was shaken with an extracting solution of 0.03 N NH₄F in 0.025 N HCl, which dissolves the fraction of Phosphorus roots. Ammonium Fluoride complexes with Al and Fe ions in the acid solution with the consequent release of phosphorus held by the soil, by these trivalent ions. Thus, the combination of HCl and NH₄F helps in removing easily acid soluble forms of phosphorus, largely calcium phosphates and a portion of aluminium and iron phosphates. In the filtered extract P was estimated calorimetrically by adding Ammonium Molybdate. To soils that are mildly acidic to alkaline pH the method developed by [36] was used. A 2.5 gram scoop of soil and 50 milliliters of 0.5 M sodium bicarbonate (pH 8.5) solution was shaken for 30 minutes. The mixture was then filtered through Whatman filter paper and the ortho-phosphate in the filtered extract was determined colorimetrically (at 630 nm in Technicon Auto Analyzer II) by reacting it with ammonium molybdate using ascorbic acid as the reducing agent. Results are reported as parts per million (ppm) of phosphorus (P) in the soil.

Potassium was determined using the flame emission spectrophotometer. A 5.0 g of an air-dried, ground and sieved sample was placed in an Erlenmeyer flask. Then a 20 mL of extracting solution (0.05N HCl + 0.025N H₂SO₄) was added. This was placed in a mechanical shaker for 15 minutes. Then filtration through Whatman number 2 filter paper into a 50-ml volumetric flask and dilute to 50 mL with extracting solution was followed.

Data analysis

Descriptive statistics, one way ANOVA, and Exhaustive CHAID growth method were used for socioeconomic data analysis, significance test of variance, and prediction of yield and yield related agronomic descriptors, respectively, based on agroecologies using SPSS v.24 software to evaluate indigenous knowledge on *Pisum sativum* var. *abyssinicum*. ANOVA was used for landraces growth performances and soil nutrient contents of the study areas with mean comparison at $P \leq 0.05$.

Results

Socioeconomic features of respondents

The impact of the different population sectors to the crop diversity, cultivation and production varies among the communal and agro-ecological areas. A great variation was observed on sex of respondents among districts and kebeles; in some of the areas, females take no part. This is particularly observed in Tigray region, Oflla district where 59(13.3%) of the respondents were men and Korem-suburb kebele where 22(100%) of them were men. Women living in Amhara region, Gubaltto and Woldia districts are equally concerned as men. Most of the respondents were within the age groups of 44-56, 137(30.8%) of the total participants (Table 2) followed by 31-43, 97(22%). The knowledge about the crop is less in the potential young respondents (age group 18-30) though the crop is said worth marketable, provide job seeking for trading and income source for local exchange. The informant household family size was 4-5, 145(32.7%) similar to average size of households by region of an atlas series of Ethiopia [34]. About 200 (45%) of them cannot read and write and about 64 (14.4%) have education below high school (Table 2).

Indigenous knowledge survey on *Pisum sativum* var. *abyssinicum* and factors affecting it

One way ANOVA between groups was used (Tables 3 and 5) to explore the knowledge of respondents based on districts of different agro-ecologies (Table 1). The results of the one-way between groups' analysis of variance with post-hoc tests, example for familiarity to the crop are presented as $[F(2, 424): 2.2, p: .002]$. Values are presented in percentages and leading questions are nominated as descriptors. Familiarity with the crop, duration, areas of distribution, and reasons for irregular occurrence and less knowledge about the crop and the likes were evaluated.

There was a statistically significant difference (at the $p < 0.05$) among districts and agro-ecologies for the descriptors [F (2, 424) : 2.2, $p = 0.002$; F (2, 424) : 1.8, $p = 0.019$; F (2, 424) : 4.8, $p = 0.000$; F (2, 424) : 2.4, $p = 0.001$, F (2, 424) : 1.8, $p = 0.026$; F (2, 424) : 3.0, $p = 0.000$; F (2, 424) : 3.4, $p = 0.000$; F (2, 424) : 1.46, $p = 0.054$; and F (2, 424) : 2.7, $P = 0.029$], respectively.

Respondents from highland areas of both regions knew *Pisum sativum* var. *abyssinicum* very well even their cultivation practice is not much as such as their familiarity (Table 4). Possibly due to less cultivation practice in the agro-ecologies, there are some respondents who do not know the crop in the midland and lowland areas of Amhara and lowlands of Tigray regions, respectively. Descriptors for duration of knowledge about *Pisum sativum* var. *abyssinicum* from the two regions are presented in table 4.

Table 2. Respondents' age group, family size, marital status, and educational background

Age group of respondents	Name of districts and Agricultural Institutes							Total
	Gubalafto	Habru	Ofla	Woldia	Endamehoni	Amba-alaje	ARARCs	
18-30	12(2.7)	17(3.8)	15(3.4)	11(2.5)	5(1.1)	8(1.8)	8(1.8)	76(17.1)
31-43	10(2.3)	21(4.7)	11(2.5)	11(2.5)	20(4.5)	18(4.1)	6(1.4)	97(22.0)
44-56	20(4.5)	15(3.4)	20(4.5)	17(3.8)	18(4.1)	25(5.6)	22(4.9)	137(30.8)
57-69	6(3.6)	8(1.8)	13(2.9)	15(3.4)	13(2.9)	6 (1.4)	6 (1.4)	77(17.3)
70 and >70	8(1.8)	5(1.1)	7(1.6)	12(2.7)	10(2.3)	9(2.0)	6 (1.4)	57(12.8)
Total	66 *	66*	66*	66*	66*	66*	48**	444(100)
Family size								
1	2(0.5)	1(0.2)	4(0.9)	0(0)	0(0)	0(0)	2(0.5)	9(2.0)
2-3	31(6.9)	19(4.3)	16(3.6)	16(3.6)	21(4.7)	12(2.7)	14(3.2)	129(29.0)
4-5	15(3.4)	30(6.7)	19(4.3)	25(5.6)	19(4.3)	23(5.2)	14(3.2)	145(32.7)
6-7	16(3.6)	9(2.0)	17(3.8)	18(4.1)	18(4.1)	22(4.9)	0(0)	100(22.5)
8-9	2(0.5)	6(1.4)	9(2.0)	5(1.1)	8(1.8)	4(0.9)	16(3.6)	50(11.3)
>9	0(0)	1(0.2)	1(0.2)	2(0.5)	1(0.2)	4(0.9)	0(0)	11(2.5)
Total	66*	66*	66*	66*	66*	66*	48**	444(100)
Marital status								
Married	51(11.4)	54(12.2)	52(11.7)	60(13.5)	60(13.5)	46(10.4)	38(8.6)	361(81.3)
Single	6(1.4)	3(0.6)	4(0.9)	3(0.6)	4(0.9)	18(4.1)	8(1.8)	46(10.4)
Divorced	6(1.4)	9(2.0)	4(0.9)	3(0.6)	1(0.2)	2(0.5)	2(0.5)	27(6.1)
Widowed	3(0.6)	0(0)	4(0.9)	0(0)	1(0.2)	0(0)	0(0)	8(1.8)
Others	0(0)	0(0)	2(0.5)	0(0)	0(0)	0(0)	0(0)	2(0.5)
Total	66*	66*	66*	66*	66*	66*	48**	444(100)
Education background of the respondents								
Cannot read & write	32(7.2)	33(7.4)	25(5.6)	35(7.8)	43(9.7)	32(7.2)	0(0)	200(45.0)
Read & write (1-4)	12(2.7)	10(2.3)	11(2.4)	15(3.4)	1(0.2)	15(3.4)	0(0)	64(14.4)
Elementary School (5-8)	6(1.4)	9(2.0)	4(0.9)	7(1.6)	11(2.4)	9(2.0)	0(0)	46(10.3)
Secondary School (9-10)	2(0.5)	1(0.2)	6(1.4)	2(0.5)	0(0)	1(0.2)	0(0)	12(2.7)
Certificate and above	8(1.8)	8(1.8)	13(2.9)	7(1.6)	7(1.6)	7(1.6)	48(10.8)	98(22.1)
Religious and adult	6(1.4)	5(1.1)	7(1.6)	0(0)	2(0.5)	2(0.5)	0(0)	22(5.0)
Science and religious	0(0)	0(0)	(0)	(0)	2(0.5)	0(0)	0(0)	2(0.5)
Total	66*	66*	66*	66*	66*	66*	48**	444(100)

Note: the values within parentheses are percentages. *Indicates the percentage (14.9%) of the total sixty six respondents per district. ** Indicates the percentage (10.8%) of the total forty eight agricultural experts from two ASARCs.

Table 3. ANOVA for knowledge about current distribution and reasons for limitation of the crop

Descriptors	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Knowledge about <i>Pisum sativum</i> var. <i>abyssinicum</i>	Between Groups	1.393	19	.073	2.216	.002
	Within Groups	14.030	424	.033		
	Total	15.423	443			
Duration of familiarity with <i>Pisum sativum</i> var. <i>abyssinicum</i>	Between Groups	91.023	19	4.791	1.815	.019
	Within Groups	1119.417	424	2.640		
	Total	1210.439	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> availability in the study districts	Between Groups	135.709	19	7.143	4.772	.000
	Within Groups	634.568	424	1.497		
	Total	770.277	443			
Reasons for <i>Pisum sativum</i> var. <i>abyssinicum</i> limitation in sporadic areas	Between Groups	157.372	19	8.283	2.399	.001
	Within Groups	1463.727	424	3.452		
	Total	1621.099	443			
Reasons for <i>Pisum sativum</i> var. <i>abyssinicum</i> 's less known	Between Groups	159.684	19	8.404	1.750	.026
	Within Groups	2036.091	424	4.802		
	Total	2195.775	443			
Production status of <i>Pisum sativum</i> var. <i>abyssinicum</i>	Between Groups	4.707	19	.248	2.983	.000
	Within Groups	35.212	424	.083		
	Total	39.919	443			
If the production of <i>Pisum sativum</i> var. <i>abyssinicum</i> decreasing, reasons for reduction	Between Groups	551.756	19	29.040	3.368	.000
	Within Groups	3656.053	424	8.623		
	Total	4207.809	443			
Intervention by agricultural extensions	Between Groups	1.696	19	.089	1.595	.054
	Within Groups	23.727	424	.056		
	Total	25.423	443			
Type/s of intervention	Between Groups	16.860	19	.887	1.731	.029
	Within Groups	217.417	424	.513		
	Total	234.277	443			

Respondents from highland areas of both regions recognized that *Pisum sativum* var. *abyssinicum* is currently available in about four districts of their neighborhoods. In the midland and lowland agro-ecologies, the crop availability is limited to three districts of the two regions (Table 4). The main reason for limitation in distribution of the crop is its agroecology preference particularly in the highlands (Table 4). Lack of intervention for expansion and preference of high yielding other pea varieties in Amhara region districts and the soil type and moisture requirements in the midland and lowland areas of Tigray districts affects the crops distribution (Table 4). The crops' inferiority in yield and pest susceptibility before people consume it is the main reason for less consideration of farmers about the crop cultivation in all agro-ecologies of Tigray region (Table 4). Now it is grown ordinarily as solitary planting. The crop production result showed that the crop is intensely decreasing and becoming rare. The main cause for reduction at small farmers' scale of the crop is expensive price to buy the seed and small land holding of farmers. According to this result, there is no noticeable intervention started (Table 4).

Farmers' agronomic descriptors and use value of *Pisum sativum* var. *abyssinicum*

A one-way ANOVA was conducted to explore the knowledge on agronomic performances and use values of *Pisum sativum* var. *abyssinicum*. There was a statistically significant difference (at $p < 0.05$) for the descriptors across the agro-ecologies as shown in table 6 [F (2, 424) :2.3, $p<.002$; F (2, 424) :3.9, $p<.000$; F (2, 424) :2.0, $p<.007$; F (2, 424) :11.7, $p<.000$; F (2, 424) :3.4, $p<.000$; F (2, 424) : 3.3, $p<.000$; F (2, 424) :10.1, $p<.000$; F (2, 424) :5.0, $p<.000$; F (2, 424) :6.0, $p<.000$; F (2, 424) :5.1, $p<.000$; F (2, 424) :1.8, $p<.025$; and F (2, 424) :2.2, $p<.003$; F (2, 424) :5.0, $p<.000$; F (2, 424) :6.0, $p<.000$; F (2, 424) :5.1, $p<.000$; F (2, 424) :1.8, $p<.025$; F (2, 424) :2.2, $p<.003$; F (2, 424) :3.0, $p<.000$; and F (2, 424) : 3.4, $p<.000$], respectively.

Table 4. Knowledge about current distribution and reasons for limitation of *Pisum sativum* var. *abyssinicum* in the study area

Descriptors	Tigray			Amhara		
	Highland (N:74)	Midland (N:82)	Lowland (N:66)	Highland (N:66)	Midland (N:90)	Lowland (N:66)
Do know <i>Pisum sativum</i> var. <i>abyssinicum</i>?						
Yes	100.0	100.0	92.7	100.0	91.1	97.0
No	0.0	0.0	7.3	0.0	8.9	3.0
%within districts	100	100	100	100	100	100
How long do you know the crop (Duration in years)						
<10yrs ago	2.7	0.0	2.4	0.0	0.0	3.0
10yrs ago	20.3	13.6	9.8	21.2	16.7	12.1
20 yrs ago	16.2	30.3	18.3	16.7	26.7	15.2
30 yrs ago	31.1	40.9	52.4	16.7	26.7	21.2
40 yrs ago	14.9	9.1	12.2	6.1	6.7	13.6
50 yrs ago	9.5	1.5	1.2	15.2	11.1	13.6
60 yrs ago	5.4	4.5	2.4	18.2	7.8	15.2
≥60 yrs ago	0.0	0.0	0.0	6.1	0.0	6.1
I don't know it	0.0	0.0	1.0	0.0	4.0	0.0
%within districts	100	100	100	100	100	100
In how many of the the study districts do you know <i>Pisum sativum</i> var. <i>abyssinicum</i> availability (Distribution knowledge)						
I don't know	0.0	0.0	1.2	0.0	4.0	16.2
1-2 districts	4.5	19.7	7.3	34.8	10.0	19.7
3 districts	14.9	27.3	29.3	25.8	34.4	33.3
4 districts	31.1	22.7	30.5	19.7	17.8	28.8
5 districts	25.7	18.2	15.9	10.6	11.1	12.1
≥6 districts	23.0	12.1	15.9	9.1	22.2	6.1
%within districts	100	100	100	100	100	100
Reasons for irregular pattern in distribution of the crop						
G1	8.1	3.0	2.4	6.1	8.9	4.5
G2	9.5	0.0	4.9	9.1	8.9	12.1
G3	0.0	0.0	7.3	6.1	10.0	15.2
G4	6.8	24.2	25.6	6.1	7.8	13.6
G5	10.8	9.1	12.2	10.6	20.0	21.2
G6	56.8	53.0	39.0	48.5	37.8	22.7
G7	0.0	3.0	0.0	3.0	0.0	0.0
G8	2.7	0.0	3.7	6.1	0.0	10.6
G9	4.7	7.6	3.7	4.5	2.2	0.0
G10	0.0	0.0	1.2	0.0	4.4	0.0
%within districts	100	100	100	100	100	100
Reasons for why the crop got slight attention by participants						
G1*	1.4	6.1	11.0	6.1	13.3	25.8
G2*	2.7	0.0	0.0	0.0	2.2	2.7
G3*	27.8	36.4	23.2	42.4	27.8	19.7

G4*	60.8	43.9	45.1	28.8	18.9	22.7
G5*	0.0	0.0	0.0	3.0	0.0	0.0
G6*	0.0	0.0	1.5	0.0	0.0	1.2
G7*	0.0	4.5	2.4	6.1	7.8	1.5
G8*	20.3	9.1	13.4	13.6	23.3	27.3
G9*	0.0	0.0	3.7	0.0	6.7	1.5
%within districts	100	100	100	100	100	100

Note: G1:soil type requirement, G2:moisture requirement, G3:cultural bias against peasant crops, G4:both soil type and moisture requirements, G5:lack of intervention for the crop expansion and preference of other high yielding varieties, G6:Agro-ecological preferences, G7:combined requirement of soil type, sunlight and moisture, G8:small landholding of farmers and climatic condition susceptibility, G9: susceptibility to pest and birds of the crop, G10:I don't know the reason. G1*:inferiority of this displaced crop by new pea varieties, G2*:misclassification of the crop, G3*: cultural bias against peasant crops and lack of expansion by extension experts to other areas of the crop, G4*:inferiority in yield and pest susceptibility of the crop, G5*:cost effectiveness of the crop, G6*:disappearing in the writing of travellers for scientific communication of the crop, G7*:both cultural bias and inferiority in yield, G8*:Agro-ecological requirements hindering further adaptation of the crop, and G9*:if other specify. N: Number of respondents

Farmers from Gubalafto highland areas grow *Pisum sativum* var. *abyssinicum* completely depending on the long rainy season. However, in Tigray region particularly in the lowlands of Endamehoni and midland areas of Amba-Alaje there are irrigation based *Pisum sativum* var. *abyssinicum* cultivation starting's (Table 6). *Pisum sativum* var. *abyssinicum* thrives better in Nitisols in all agro-ecologies in general and in Leptosols in the highland and midland areas of Tigray region in particular (Table 6), respectively. Majority of the respondents in lowland, midland and highland areas of Amhara sow *Pisum sativum* var. *abyssinicum* the in March and May months (during belg season) after other crops like teff are harvested followed by the long rainy season (Table 6). Farmers in the Ofla highland areas sow the crop starting from July the half up to August the first with a single plough. The sowing time of the crop in the midland and lowland areas of Tigray is both during belg season and the long rainy season, although very few respondents experienced different sowing times (Table 6).

Respondents were also enquired the seeding rate for *Pisum sativum* var. *abyssinicum* they used during sowing. Majority of the respondents use a seeding rate of 21-30 kg ha⁻¹ even it varies enormously within the agro-ecologies (Table 6). The crop start flowering one month after planting but florescence best in one month and fifteen days after planting in all the agro-ecologies (Table 6) viewing its early flowering phenotypic traits. According to the respondents data the crop matures at 2^{1/2} months in average. The maximum yield farmers obtain from the 21-30 kg ha⁻¹ is 300 kg ha⁻¹ that can be enhanced to 400 kg ha⁻¹ at the seeding rate of 41-50 kg ha⁻¹ (Figure 10).

Table 5. ANOVA for agronomic performances descriptors of *Pisum sativum* var. *abyssinicum*

Agronomic descriptors	Source of variation	Sum of ssquares	df	Mean Square	F	Sig.
<i>Pisum sativum</i> var. <i>abyssinicum</i> dependency on rain or using other means	Between Groups	6.858	19	.361	2.294	.002
	Within Groups	66.727	424	.157		
	Total	73.586	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> soil preference	Between Groups	345.896	19	18.205	3.900	.000
	Within Groups	1979.402	424	4.668		
	Total	2325.297	443			
Habit of using <i>Pisum sativum</i> var. <i>abyssinicum</i> in intercropping and crop rotation	Between Groups	3.488	19	.184	2.023	.007
	Within Groups	38.485	424	.091		
	Total	41.973	443			
Crops intercropped or rotated with <i>Pisum sativum</i> var. <i>abyssinicum</i>	Between Groups	807.477	19	42.499	11.650	.000
	Within Groups	1546.758	424	3.648		
	Total	2354.234	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> sowing time (seasons)	Between Groups	241.356	19	12.703	7.404	.000
	Within Groups	727.455	424	1.716		
	Total	968.811	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> 's land ploughing number including the final sowing time	Between Groups	23.634	19	1.244	3.307	.000
	Within Groups	159.508	424	.376		
	Total	183.142	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> rainfall requirement starting from sowing to maturity	Between Groups	52.100	19	2.742	10.060	.000
	Within Groups	115.576	424	.273		
	Total	167.676	443			
Seeding rate (Kg/ha)	Between Groups	128.927	19	6.786	4.943	.000
	Within Groups	582.053	424	1.373		
	Total	710.980	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> flowering time (Number of months)	Between Groups	170.863	19	8.993	5.984	.000
	Within Groups	637.144	424	1.503		
	Total	808.007	443			
Time of maturity (months)	Between Groups	70.312	19	3.701	5.138	.000
	Within Groups	305.364	424	.720		
	Total	375.676	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> yield (100 Kg/ha)	Between Groups	53.996	19	2.842	1.763	.025
	Within Groups	683.644	424	1.612		
	Total	737.640	443			
<i>Pisum sativum</i> var. <i>Abyssinicum</i> conservation practice started	Between Groups	1.039	19	.055	2.181	.003
	Within Groups	10.636	424	.025		
	Total	11.676	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> use related traits	Between Groups	105.837	19	5.570	2.764	.000
	Within Groups	854.386	424	2.015		
	Total	960.223	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> part/s used for forage	Between Groups	505.395	19	26.600	25.353	.000
	Within Groups	444.848	424	1.049		
	Total	950.243	443			
Animals <i>Pisum sativum</i> var. <i>abyssinicum</i> straw preference compared to other peas	Between Groups	144.698	19	7.616	7.624	.000
	Within Groups	423.545	424	.999		
	Total	568.243	443			
Browser animals prefer <i>Pisum sativum</i> var. <i>abyssinicum</i> straw better	Between Groups	709.775	19	37.357	11.234	.000
	Within Groups	1409.871	424	3.325		
	Total	2119.646	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> medicinal values	Between Groups	71.770	19	3.777	7.991	.000
	Within Groups	200.417	424	.473		
	Total	272.187	443			
Parts used for disease cure	Between Groups	693.293	19	36.489	6.100	.000
	Within Groups	2536.455	424	5.982		
	Total	3229.748	443			
Rate of <i>Pisum sativum</i> var. <i>abyssinicum</i> usability	Between Groups	64.973	19	3.420	7.436	.000
	Within Groups	195.000	424	.460		
	Total	259.973	443			
Way of using <i>Pisum sativum</i> var. <i>abyssinicum</i>	Between Groups	39.873	19	2.099	2.843	.000
	Within Groups	312.962	424	.738		
	Total	352.836	443			
<i>Pisum sativum</i> var. <i>abyssinicum</i> storage mechanism	Between Groups	241.724	19	12.722	5.559	.000
	Within Groups	970.303	424	2.288		

	Total	1212.027	443			
Table 6. Knowledge about agronomic performances descriptors of <i>Pisum sativum</i> var. <i>abyssinicum</i>						
Descriptors	Highland (N:74)	Tigray Midland (N:82)	Lowland (N:66)	Highland (N:66)	Amhara Midland (N:90)	Lowland (N:66)
Is cultivation of the crop dependent on seasonal rain?						
Yes	79.7	80.3	79.3	100	85.6	97.0
No	17.6	19.7	19.5	0.0	8.9	3.0
I don't know	2.7	0.0	1.2	0.0	5.6	0.0
%within districts	100	100	100	100	100	100
Soil type preference of the crop						
Vertisol	18.9	19.7	14.6	4.5	21.1	9.1
Nitisols	25.7	36.4	36.6	65.2	32.2	42.4
Lithic leptosols	5.4	0.0	4.9	0.0	2.2	10.6
Cambisols	8.1	1.5	4.9	1.5	2.2	3.0
Leptosols	31.1	40.9	36.6	16.7	25.6	25.8
Regosols	5.4	1.5	1.2	0.0	13.3	4.5
all soil types	5.4	0.0	1.2	12.1	0.0	4.5
I don't know	0.0	0.0	0.0	0.0	3.3	0.0
%within districts	100	100	100	100	100	100
Sowing time of the crop						
Long rainy season (June-August)	28.4	28.8	12.2	40.9	30.0	25.8
After crops harvest (belg) e.g Teff	16.2	0.0	9.8	54.5	37.8	57.6
Both during belg and June-August	2.7	48.5	58.5	0.0	15.6	13.6
Late (July half-first August)	52.7	22.7	18.3	4.5	12.2	3.0
If other specify	0.0	0.0	1.2	0.0	4.4	0.0
%within districts	100	100	100	100	100	100
The numbers of plough of land for the crop cultivation						
I don't know	0.0	0.0	1.1	0.0	4.4	0.0
One time	70.3	72.7	59.8	65.1	70.0	63.6
Two times	25.7	21.2	29.3	25.8	15.6	30.3
Three to four times	4.1	6.1	9.8	9.1	10.0	6.1
%within districts	100	100	100	100	100	100
Seeding rate respondents experiencing						
10-15 kg ha ⁻¹	9.5	25.8	3.7	3.0	3.3	0.0
15-20 kg ha ⁻¹	12.2	3.0	17.1	9.1	13.3	6.1
21-30 kg ha ⁻¹	41.9	19.7	39.0	40.9	33.3	40.9
31-40 kg ha ⁻¹	25.7	18.2	13.4	37.9	21.1	28.8
41-50 kg ha ⁻¹	10.8	25.8	23.2	9.1	21.1	19.7
60-70 kg ha ⁻¹	0.0	7.6	2.4	0.0	3.3	1.5
I don't know	0.0	0.0	1.2	0.0	4.4	3.0
%within districts	100	100	100	100	100	100
The time required for flowering						
1 month	24.3	24.2	11.0	0.0	4.4	4.5
1 month & 15 days	59.5	56.1	52.4	83.3	73.3	45.5
2 months&15 days	2.7	7.6	20.7	0.0	7.8	18.2
2 months	13.5	6.1	11.0	15.2	10.0	25.8
40 days	0.0	6.1	3.7	1.5	0.0	6.1
If other specify	0.0	0.0	1.2	0.0	4.4	0.0
% within districts	100	100	100	100	100	100
<i>Pisum sativum</i> var. <i>abyssinicum</i> maturity time						
2 months	23.0	21.2	20.7	48.5	22.2	51.5
2 months&15 days	31.5	56.1	34.1	48.5	57.8	27.3
3 months	39.2	19.7	39.0	3.0	13.3	21.2
3months &15 days	0.0	3.0	4.9	0.0	0.0	0.0
≤49 days	2.7	0.0	0.0	0.0	2.2	0.0
If other specify	0.0	0.0	1.2	0.0	4.4	0.0
%within districts	100	100	100	100	100	100
Yield in (100 kg ha⁻¹)						
200 kg ha ⁻¹	16.2	6.1	8.5	9.1	7.8	3.0
300 kg ha ⁻¹	43.2	48.5	41.5	45.5	37.8	47.0
400 kg ha ⁻¹	25.7	27.3	29.3	30.3	35.6	31.8
500 kg ha ⁻¹	12.2	18.2	15.9	12.1	17.8	12.1
600 kg ha ⁻¹	2.7	0.0	3.7	3.0	0.0	6.1
If other specify	0.0	0.0	1.2	0.0	0.0	0.0
I don't know	0.0	0.0	0.0	0.0	1.1	0.0
%within districts	100	100	100	100	100	100



Figure 2. Seed size, color (A-F), and resistance (D-F) to pea weevil (*Bruchus Pisorum* L.) differences of *Pisum sativum* var. *abyssinicum* landraces where creamy seeds are bored more by pea weevil larvae feed on the seed during storage (F)

The price of *Pisum sativum* var. *abyssinicum* (53 Ethiopian birr per kilogram) was more than twice better than the price of common pea (24 birr) during the market survey time in all the agro-ecologies. Besides, delicious tastes followed by expensive seed price are the best use value related descriptors that come to the mind of Ethiopian farmers when asked about *Pisum sativum* var. *abyssinicum* landraces. Beyond the forage value for donkeys and horses > cattle > sheep and goats), respectively (Table S1), 90.9% of the interviewed farmers from Tahtay-haya (Figure 1), the lowland area from Endamehoni districts claimed the medicinal value of the crop straw as the best cure of their animals' neck wounding by bat during the rainy season. It is also given as food for patients prescribed not eating some foods because of stomach ulcer in the highland areas of Tigray and all the agro-ecologies of Amhara region. The crop is currently fairly usable and mainly for earning income for local exchange of other staple crops, the very type well-suited to feeding the hungriest vulnerable farmers as it grows earlier. From the different storage mechanisms, the most common respondents practicing is dressing seeds using chemicals particularly of malathion after harvest and before storage in all the agro-ecologies to protect from

pea weevil (Figure 2.D and 2.F). During consumption the chemically dressed seeds are washed very well.

Morphological and physiological variations among the crop's landraces

Differences in seed's size, seed coat color and resistance to the pea seed weevil of the crop farmers' landraces were observed during the study time (Figure 2). The *Pisum sativum* var. *abyssinicum* locally named Abyssinian pea (English), Dekoko (Tigrigna), Agerie Ater (Amharic) correspondingly. The English and Amharic terms describe its origin and the Tigrigna term defines its seeds smallness. The first ranked morphological descriptors most farmers used for selection of Abyssinian pea from other local peas were earliness > grain coverage (germination rate) > seedling vigor > leaf greenness > plant height (short and vigorous) > pods per plant > branches per plant > seeds per pod (Figure 3).

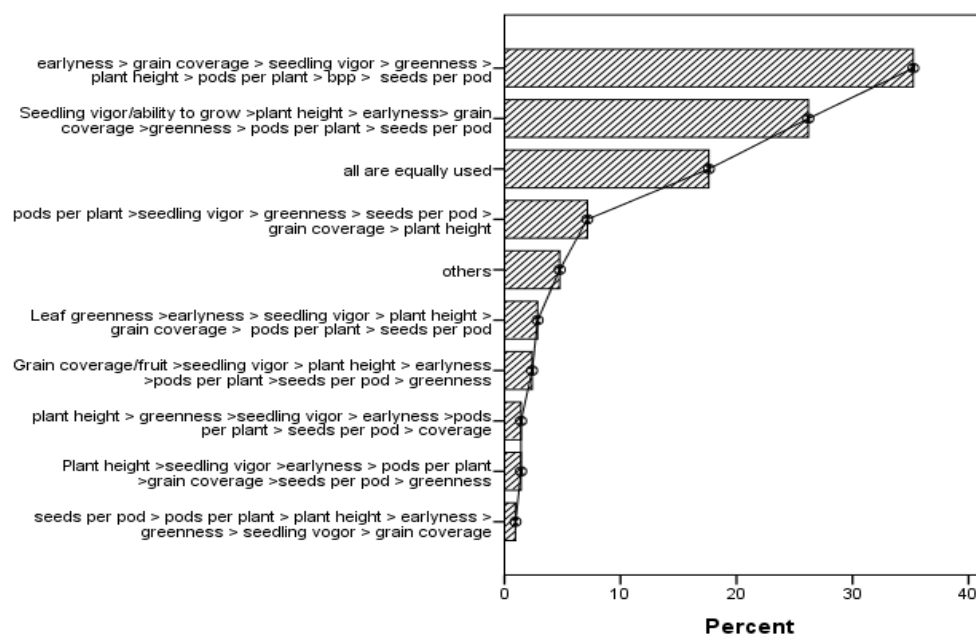


Figure 3. Farmer's morphological selection criteria of local peas. bpp : branches per plant

Yield and yield related traits prediction using Exhaustive CHAID growth

The respondents from each district define each descriptor according to their knowledge. Therefore, the independent (predictor) variable that has the strongest interaction with the dependent variable for each agroecology should better be chosen using Exhaustive CHAID growing method. Exhaustive CHAID examines all possible splits for each predictor by merging categories of each predictor if they are not significantly different with respect to the dependent

variable. The green ones in the tree diagrams (Figures 4, 6, 7, 8, 9 and 10) indicate the predicted categories having strongest interaction with the descriptors determining the yield and yield related factors of the crop.

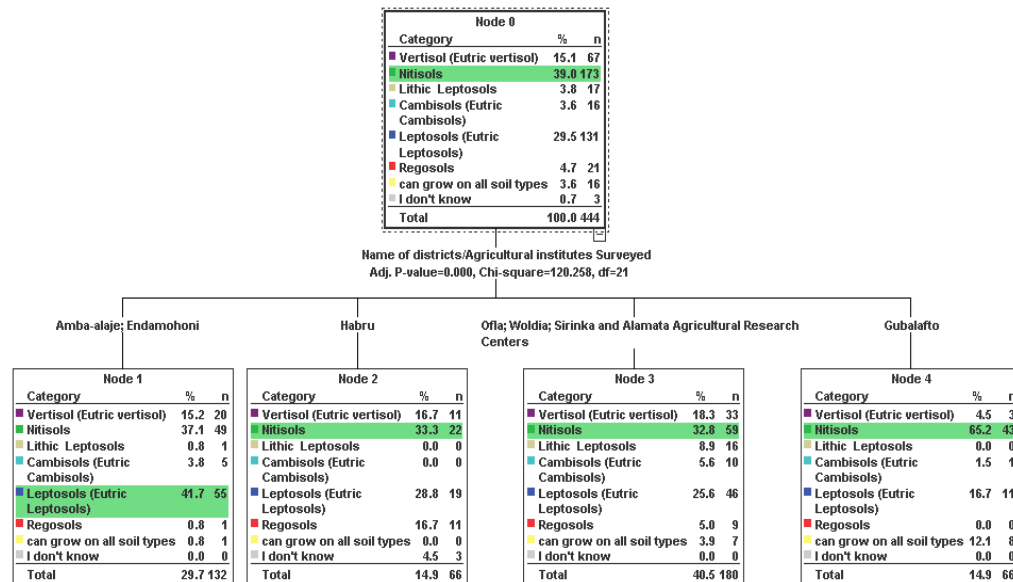


Figure 4. Tree diagram soil type preference of the crop (Risk estimate: 0.597, SE: 0.023)

Prediction 1: Soil type preference of the crop

Pisum sativum var. *abyssinicum* thrives better in Nitisol soil followed by Leptosol and Vertisol soils (Figure 4), respectively. Farmers from Amba-Alaje and Endamehoni areas grow the crop in Leptosols. It has excellent root protuberance in Nitisol soils (Figure 5a). Farmers traditionally conserve soil using different mechanism. A new and unfamiliar soil conservation practices using USAID white sacks (Figure 5B-D) were observed during the study time.



Figure 5. A. The direct physical effect of the soil type on the *Pisum sativum* var. *abyssinicum* excellent root protuberance efficiency grown in Nitisol soil in Gedober kebele, North Wollo; B-D. Traditional soil conservation practices using USAID white sacks in Mekan kebele, Endamehoni district, South Tigray, where (B). Sunken white sack for soil conservation, (C). Side view of the sunken white sack, and (D). Soil protecting ability of white sack (Photo by Berhane Gebreslassie. March 2017)

Prediction 2: Rainfall requirement of the crop

Abyssinian pea can perform good yield with about two good rain in all soil types and agroecologies (Figure 6).

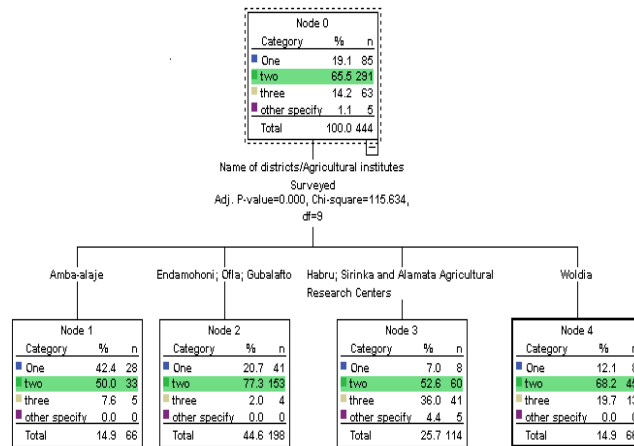


Figure 6. The pea rainfall requirement created using the Exhaustive CHAID growth method (Risk estimate :0.035, SE :0.023).

Prediction 3: Seeding rate of the crop

Results from the tree diagram (Figure 7) showed respondents knowledge as significant predictor of Abyssinian pea seeding rate. The overall category showed that, the common seeding rate (kg ha⁻¹) is 21-30 kg ha⁻¹, followed by 31-40 kg ha⁻¹ and 41-50 kg ha⁻¹, respectively. The overall significant predictor does not represent all districts as blanket (Figure 7), because they have different agro-ecologies like altitude (Table 1). Respondents from Amba-Alaje midland district and ASARCs experience a seeding rate of 41-50 kg ha⁻¹. Of the districts in this category, 36% articulated this seeding rate (Figure 7), lesser than the typical seeding rate. The forecaster seeding rate for Endamehoni and Woldia lowland areas and Habru is 21-30 kg ha⁻¹, where 86% of the respondents shared. Moreover, the seeding rate for the highland areas of Ofla and Gubalafto is 21-30 kg ha⁻¹, followed by 31-40 kg ha⁻¹ (Figure 7).

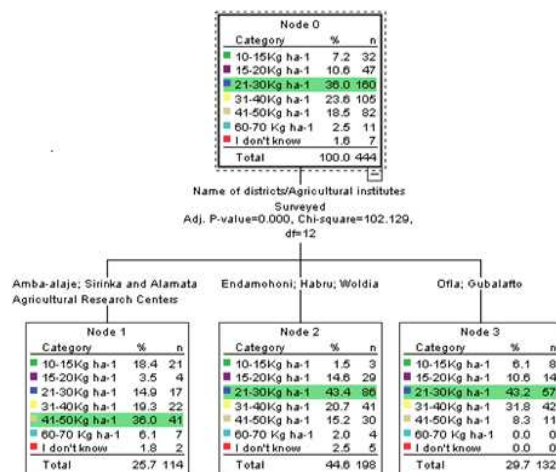


Figure 7. The pea seeding rate (kg ha-1) with (Risk estimate :0.059, SE :0.002).

Prediction 4: Flowering time of the crop

It is predicted that, Abyssinian pea require about one month and fifteen days for flowering (Figure 8). This is particularly common for farmers' landraces from Gubalafte where about 55(83.3%), Habru and ASARCs about 85(74.6%), Amba-Alaje and Ofra about 74(56.1%), respectively. For Endamehoni and Woldia lowland agro-ecologies, this is not the significant predictor where about 61(46.2%) of the total 132 informants approved.

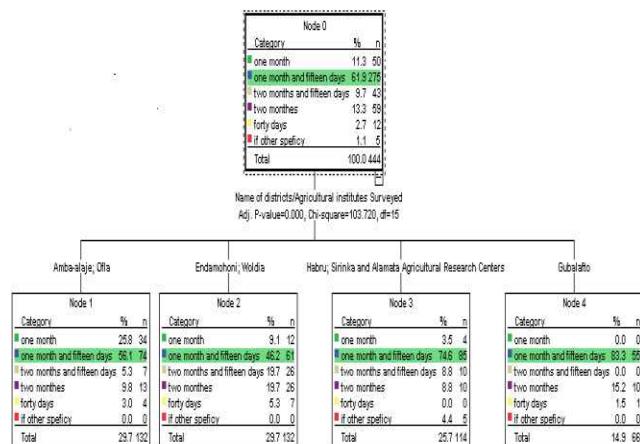


Figure 8. The pea flowering time (Risk estimate: 0.060, SE :0.003)

Prediction 5: Maturity time of the crop

Abyssinian pea matures in about two months and fifteen days in Average but varies across agroecologies (Figure 9).

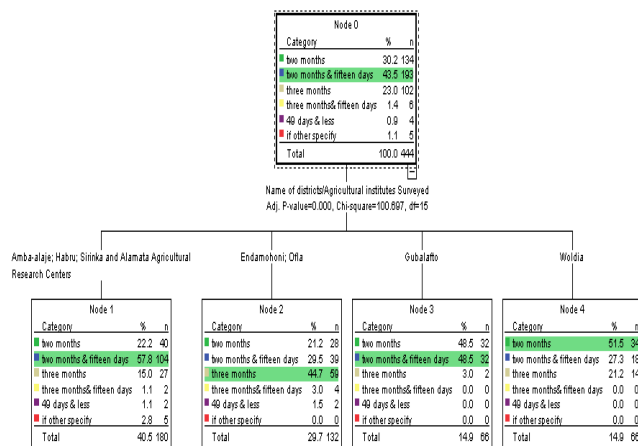


Figure 9. The pea maturity time (Risk estimate :0.060, SE :0.005)

Prediction 6: Yield (100 kg ha⁻¹) of the Crop

Yield per hectare of Abyssinian pea was predicted. The overall category indicated the common yield in kilograms per hectare (100 kg ha⁻¹) for Abyssinian pea is 300 kg ha⁻¹ for most districts (Figure 10). This could be because of the small seed rate. Better seed rates can yield up to about 400 kg ha⁻¹ of Abyssinian pea (Figure 10).

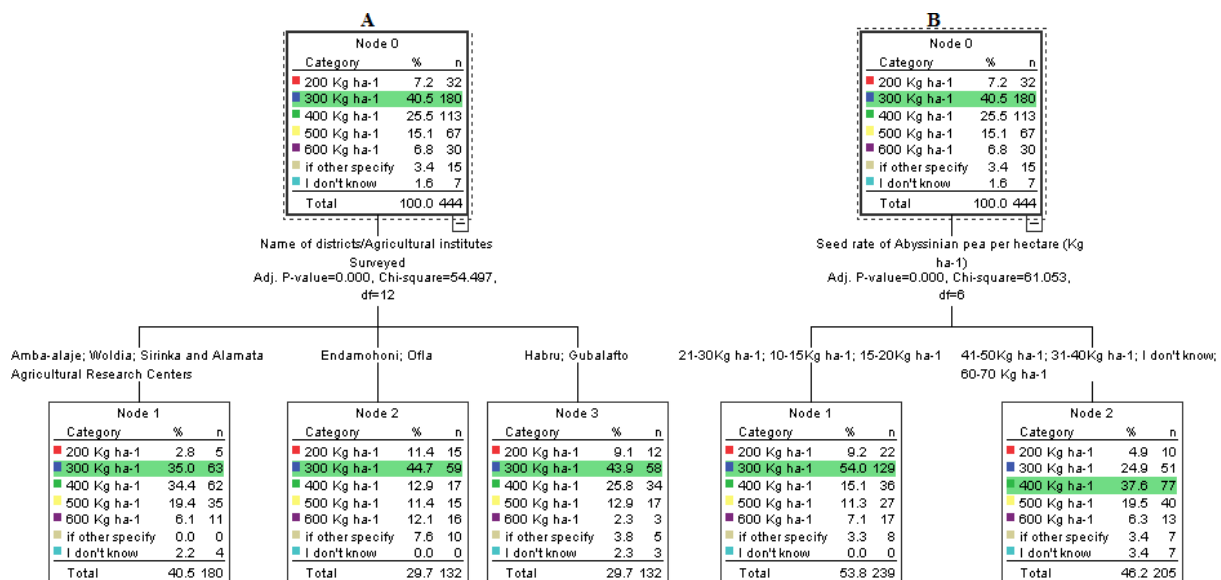


Figure 10. The pea yield (kg ha⁻¹) as affected by agroecology and seed rates.

Soil properties of the study areas where the landraces grown

Results of the one way ANOVA showed that, the textural class, exchangeable bases except exchangeable sodium of the soil samples collected from the *Pisum sativum* var. *abyssinicum* growing areas vary at $P \leq 0.05$ (Table 7). Soil samples collected from Sirinka area have a pH of

7.71±0.07, exchangeable bases (Ca, Mg, Na, and K) of 15.15±0.58, 2.71±0.14, 0.23±0.03, and 0.41±0.04 respectively. However, there is no statistically significant difference among the soil samples collected for available phosphorus, cation exchange capacity, organic matter, organic matter carbon content, and total nitrogen (Table 7). The micronutrient contents of the soil samples vary only for iron. There was also a statistically significant difference among the soil samples for field capacity and permanent wilting points (Table 7).

Table 7. Soil physical and chemical composition of the study areas

Landrace	Texture	pH	ExCa	ExMg	ExNa	ExK
Sirinka	Clay	7.71±0.07	15.15±0.58	2.71±0.14	0.23±0.03	0.41±0.04
Wenberet	Loam	7.00±0.11	13.63±2.95	4.30±0.16	0.23±0.05	0.23±0.04
Gedober	Clay loam	6.63±0.08	18.77±205	4.90±0.30	0.51±0.06	0.26±0.03
P ≤0.05	0.01*	0.00*	0.01*	0.01*	0.07 ^N	0.03*

Soil chemical composition of the study areas

Landrace	P	CEC	OM	OMC	TN	Mn
Sirinka	2.13±0.23	45.46±0.71	1.09±0.12	1.88±0.21	0.09±0.01	10.02 ±0.35
Wenberet	3.76±0.23	39.73±5.01	1.16±0.15	1.99±0.26	0.10±0.01	12.73± 1.31
Gedober	4.23 ±1.99	44.26±3.88	1.35±0.06	2.33±0.12	0.12±0.01	10.13±0.49
P ≤0.05	0.46 ^N	0.55 ^N	0.34 ^N	0.34 ^N	0.33 ^N	0.10 ^N

Note: Ex=exchangeable, *= indicates significant difference, and N= indicates non-significance

Landrace	Cu	Zn	ExAcidity	Fe	FC	PWP
Sirinka	2.40±0.04	0.45±0.10	0.45±0.07	5.61±0.28	39.37±.56	18.89±1.46
Wenberet	2.61±0.12	0.43±0.05	0.23±0.03	11.39±1.68	23.58±4.63	13.85±2.10
Gedober	2.73±0.07	0.28 ±0.01	0.08±0.00	8.01±0.48	35.05±.09	20.12±0.64
P ≤0.05	0.07 ^N	0.22 ^N	0.03*	0.02*	0.02 ^N	0.01 ^N

Note: Ex=exchangeable, and *= indicates significant difference, ^N= not statistically significant

Morphological characters of *Pisum sativum* var. *abyssinicum* landraces

Morphological traits of the three landraces vary across agroecology (Table 8 and 9). The plant height of the plant increases with decreasing in altitude. The maximum height was obtained from the highland crop (Wenberet) with plant height of 48.5±0.51 followed by Sirinka landrace with plant height of 47.4±0.26. There is a reduction in plant height as going from lowland to highland agroecologies (Table 8). But the days for 50% flowering, numbers of branches per plant and maturity time are longer in the highland areas compared to the midland and lowland agroecologies. There is a significant variation even within the same landraces grown at different aroecologies (Table 8 and 9). The midland landrace (Sirinka) grown at high altitude took the longest flowering time of 56.00±.04. Whereas, the maturity time was long for the lowland

landrace (Gedober) grown at highland are that was 74 ± 0.45 days. The lowland cultivar has also more number of branches per plant than the other two landraces (Table 8). Landraces grown at midland areas have more number of pods per plant than the highland crops their same. When highland landraces are grown at midland areas there is an increment in number of pods per plant but decrease in plant height (Table 8).

Table 8. A Univariate Analysis of Variance for morphological traits as affected by landraces of *Pisum sativum* var. *abyssinicum* and agroecology

Landrace grown at varying agroecology	PH(cm)	Morphological traits			
		D50%flowering	NBPP	Maturity days	NPPP
Highland					
Sirinka	35±0.26	56.00±.04	13±0.58	67±0.22	6±0.46
Wenberet	44.5±0.62	49.00 ±0.68	12±0.14	70±0.83	7±0.57
Gedober	34.4 ±0.11	50.00±1.03	18±0.72	74±0.45	5±0.97
P ≤0.05	0.02*	0.03*	0.01*	0.04*	0.00*
Midland					
Sirinka	38.4±1.32	45.22±1.03	15±0.33	60±0.40	6±0.77
Wenberet	45.1±0.78	47±0.91	14±0.80	66±0.55	8±0.08
Gedober	44.3 ±0.37	44±0.53	18±0.15	54±.71	7±0.11
P ≤0.05	0.01*	0.00*	0.00*	0.01*	0.00*
Lowland					
Sirinka	47.4±0.26	37±0.03	17±0.22	52±0.35	6±1.35
Wenberet	48.5±0.51	42±1.07	23±1.08	61±.56	4±2.20
Gedober	46.0 ±0.01	45±1.62	20±0.14	70±0.71	8±0.07
P ≤0.05	0.00*	0.01*	0.00*	0.03*	0.01*

Note: PH=plant height, D50%flowering= days required to 50% flowering, NBPP= Number of branches per plant, NPPP= number of pods per plant. *= indicates significant difference

The analysis of variance for yield traits of the landraces as affected by the type of landraces and agroecology indicated a statistically significant variation among the landraces as well as among the agroecologies at $P \leq 0.05$ (Table 9). Number of seeds per pod of all the landraces was more in the midland agroecology where the lowland landrace (Gedober) pronounces the better seed number that is 19.72 ± 2.00 (Table 9). The same landraces grown at lowland areas have smaller seeds per pod than highland and lowland areas. All the yield related traits of the landraces were less in the lowland agroecologies. Seed yield per pant, test weight, biological yield per plant and harvest index were better in the midland agroecology for all the landraces of this study (Table 9). Even within the same altitudinal gradient there is a variation of the yield traits measured and calculated. Gedober landrace is better performer than the other two in the midland areas even its biological yield is lesser (Table 9). However, farmers of the midland areas in North Wollo are

not still producing this icon crop. It is relatively better cultivated in the lowland and highland areas. There are farmers rarely growing the crops after teff harvest or at the edge with less fertile soil of other stable crops growing areas in midland areas. In South Tigray, the landraces are nowadays cultivated both during the long rainy season (rarely like the case in North Wollo), using the spring short rain, and via irrigation (Personal observation).

Table 9. Analysis of Variance for yield traits as affected by landraces and agroecology

Landrace grown at varying agroecology NSPP	<u>Morphological traits</u>				
	SYPP(g)	Test weight(g)	BYP(g)	Harvest index (%)	
Highland					
Sirinka	13.25±5.35	4.74±0.23	156±0.24	1600±0.52	0.29±0.11
Wenberet	14.16±3.61	5.04±0.33	157±0.51	1781±0.71	0.28±0.01
Gedober	16.53 ±4.12	3.66 ±0.25	154±0.42	1548±0.43	0.24±0.24
P ≤0.05	0.00*	0.00*	0.00*	0.01*	0.00*
Midland					
Sirinka	15.08±7.06	4.98±0.12	161±0.33	2100±0.65	0.24±0.07
Wenberet	16.00±5.39	5.10±0.22	164±0.21	2643±0.78	0.19±0.25
Gedober	19.72 ±2.00	6.00 ±0.11	167±0.24	1874±0.01	0.32±0.43
P ≤0.05	0.00*	0.01*	0.01*	0.00*	0.00*
Lowland					
Sirinka	12.5 ±3.68	4.63 ±0.26	149±1.22	1580±0.32	0.29±0.21
Wenberet	10.30±2.40	3.01±0.44	150±0.80	1471±0.35	0.20±0.24
Gedober	13.49±4.15	3.49 ±0.27	155±0.51	1641±0.22	0.21±0.22
P ≤0.05	0.00*	0.01*	0.00*	0.00*	0.00*

Discussions

Socioeconomic features of respondents

The current study showed gender gap persistence in the crop diversity, cultivation and production knowledge similar to the case stated by [37] in the US states where women gaps remain in societies understand of the relation between income inequality, health and agriculture. Similar idea was stated by [35] where hitherto women farmers are consistently found to be less productive than male farmers. The study is also consistent with the indication of [38] declaring women as a group tend to work fewer weeks per year and hours per week than men. But this contradicts with the traditional property rights of gender-crop roles within rural societies [13, 39]. Health wise, this contributes to the nutrition related diseases that affect pregnant and lactating women as stated by [39].

The knowledge about the crop is less in the potential young respondents (age group 18-30) though the crop is said worth marketable, provide job seeking for trading and income source for local exchange. The production of the crop is still through traditional means with little literacy and numeracy skills. This is alike the finding of [16]. Most of the respondents knew the crop for the last thirty years ago actually even *Pisum sativum* var. *abyssinicum* is a primitive landrace that displays traits usually associated with initial steps in the domestication process [4]. It has domesticated some 4000–5000 years ago in the now Northern highlands of Ethiopia. *Pisum sativum* var. *abyssinicum* as one among the crops with high genetic diversity in Ethiopia because of its origin as described by [25]. The crop cultivation practice has a long history in Tigray region study sites, where farmers had growing for the last thirteen years ago across all agro-ecological areas.

Survey of indigenous knowledge on *Pisum sativum* var. *abyssinicum* and factors affecting it

The current study indicated that the crop sporadic distribution comparable to the claims of [3, 4]. The main reason for limitation in distribution of the crop is its agroecology preference that is not restructured with food system of Ethiopia as stated in the work of [40, 41]. Cultural bias against peasant crops and lack of expansion by extension experts to other areas is the reason the crop got least attention in reverse of its importance in the highland and midland areas of Amhara region. Similar to the idea of [42] stating cultural bias against peasant crops is an ultimate calamity because plants that poor people grow are the very type well-suited to feeding the hungriest and most vulnerable sections of society.

Farmers' agronomic descriptors and use value knowledge on the crop

Majority of the respondents (of both regions) in the present study cultivate *Pisum sativum* var. *abyssinicum* keeping the seasonal rainfall. There is a great variation in seeding rate among agroecologies which may be due to planting date, soil type, relative humidity, temperature and the like factors the agro-ecologies possess. Sowing time was evaluated to understand the growing seasons and to improve the crop harvest as growing seasons define geographical areas suitable for crops [43]. Still the seeding rate of the crop is below the seeding rate stated by [28] for early variety, with small seed that is planted in good time on infertile soil in a dry region may need a seeding rate of about 50 kg ha⁻¹. The short life span and early flowering of the crop might be due

to the crop ELF3 gene, a key prehistoric adaptation to shorter growing seasons stated by [7] for some pea varieties. The price of the crop is expensive analogous to the assertion by [3] for the same crop at Betmara.

Morphological and physiological variations among the Crop's landraces

Differences in seed's size, seed coat color and resistance to the pea seed weevil of the crop farmers' landraces were observed during the study time. This could be due to the variance in their adaptation and interaction to different environments. This is similar to the finding of [44] on pea genotypes. Studies from [45, 46] confirm the difference used as selection criteria of the various types of peas available by breeders. Pea seeds difference in resistance to pea weevil larvae boring is due to difference in color [Figure 2F; 44] and nutritional content [28].

Yield and yield related traits prediction using Exhaustive CHAID growth method

Soil type preference of the crop

Pisum sativum var. *abyssinicum* prefers more Nitisol soil types. The existence of more than half of all Nitisols in tropical Africa; in the highlands (>1000 m.a.s.l.) and 12.5% of the Ethiopia highlands where field pea is dominant pulse [30, 47] give an impression of the crop adaption for this soil.

Rainfall requirement of the crop

Pisum sativum var. *abyssinicum* performs better with two good rain at germination and flowering and seed setting times respectively. This is mostly common to highland areas that have higher humidity because peas have the ability to benefit from some rain at flowering and seed set with 70% relative humidity [28].

Seeding rate of the crop

The seeding rate for *Pisum sativum* var. *abyssinicum* varies with agroecologies as agroecology affect environmental requirement of the seed [18]. This is comparable to result of [46] which revealed seeding rates vary with cultivar, soil type, seed size, climate, disease pressure and seeding method for *Pisum sativum*. In Ethiopia the best altitudes for pea ranges 1500-2200

m.a.s.l. with rainfall less than 600 mm, and 2200–2300 m.a.s.l. with rainfall more than 600 mm per year [28]. The seeding rate farmers are using is lesser than the seeding rate for smaller seeded pea varieties described by [28].

Flowering time, maturity time and yield of *Pisum sativum* var. *abyssinicum*

Pisum sativum var. *abyssinicum* flowers within 45 days. This is similar to the findings of [4,5 and 7] stating *Pisum sativum* var. *abyssinicum* flower in short days. It matures within two months and fifteen days earlier [5 and 7]. Early maturing helps peas for better seed set during dry season [28]. This is similar to the growth period for green seed or pods; even there is variation depending on farmers' cultivar, climatic conditions, and planting date of the agro-ecologies [28]. The production of the crop is below the good average yield compared to green pea pods which is 6.5-7 MT ha⁻¹ [28]. This seeks urgent intervention to fill yield gap [8]. Little productions were observed during the study period in some sporadic areas of Endamehoni lowlands, and Ofla and Gubalafto high land areas which are belg season productive districts [17 and 18].

Soil properties of the study areas where the landraces grown

The soil properties differed from soil to soil across agroecologies. These variations can cause variation on the morphological and yield related traits of the landraces. Soil organic matters of the agroecologies are productive which are above the organic content considered unproductive by [46] that is 0.8 percent. Soil characterization was to investigate soil ecosystem health. Because, the dramatic increase in crop production of the last 50 years has reduced the number of chronically undernourished people. However, these massive production gains have come at high environmental costs, which have affected soil and ecosystem health [46]. Soils are living environments in which particularly abundant and diverse microbiome and fauna are evolving. The resulting biological functioning on soil has a direct impact on the plants grown [27]. In classical agronomy it is often used to refer to the set of climatic and soil conditions that define the productive potential of a certain location crop yield [48].

Morphological characters of *Pisum sativum* var. *abyssinicum* landraces

In the lowland areas the landraces tend to flower earlier to escape the environmental stress such as water lodging and high temperature and pest. The low productivity in lowland area of the

landraces was because of agroecological unsuitability. Peas produce low or do not thrive in heat or lowland tropical climates [49]. The harvest index of Gedober landrace grown in mid-altitude has almost similar to the average harvest index (0.32 ± 0.43) of grain legumes (lupin, field pea, faba bean, lentil, chickpea, and vetch) all having 0.37 followed by Sirinka landrace grown in high and mid altitudinal gradients [50]. Beyond the altitudinal gradients, textural class, exchangeable bases exchangeable sodium of the soils have affected the overall performances of the landrace thereby bring difference on their performances.

Conclusion

In conclusion, the results showed that, *Pisum sativum* var. *abyssinicum* productivity is socioeconomically influenced by gender, family size, age, education, small landholding, and expensive price for poor of the seed. *Pisum sativum* var. *abyssinicum* productivity was observed to be higher by men and educated respondents. The knowledge on agronomic descriptors like soil preferences, rainfall requirement, seed rate, flowering time, maturity period and yield and affecting factors like the reasons for limitation of the crop on some sporadic areas varies across agro-ecologies. Morphological and physiological variations among the landraces' seeds were observed. Currently, the crop productivity is highly decreasing because of combination of expensive price to purchase for poor farmers and their small land holdings. Evaluated predictors like the crop rain fall requirement, soil type preference, seed rate, flowering and maturity time, and yield showed that the landraces adapted differently to the agro-ecologies. Therefore, improve farmers' educational status and awareness on agronomic descriptors would enhance the production of the crop. Altitudinal gradients and soil quality factors brought a statistically significant difference among the *Pisum sativum* var. *abyssinicum* landrace. Even same landraces grown in different agroecologies have different phenotypic performances. Midland altitudes are good agro-ecologies for vigirousity and overall yield of *Pisum sativum* var. *abyssinicum* landraces. In the highland areas, *Pisum sativum* var. *abyssinicum* landraces are less vigorous and shorter in plant height. In the lowland areas, *Pisum sativum* var. *abyssinicum* landraces are longer in plant height than the other agroecoloies but their overall performances is lower because of mainly soil factors and the altitudinal gradients. Gedober landraces perform best in harvest index in midland altitudes. Therefore, from this study it can be recommended *Pisum sativum* var.

abyssinicum should be cultivated considering their life span, altitudinal gradient and the soil preference for better yield while the crop can grow in all soil types.

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Declarations

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