Trends of Crop Variety Release and its Impact on Productivity and Food Systems in Ethiopia: A Review

Mekonnen Hailu[1], Solomon Abate[1], Fitsum Daniel[1], Asnake Fikre[2] and Medemdemiaw Neknike[3]

[1]*Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia*
[2]*Debrezeit Agricultural Research Center, EIAR, Debrezeit, Ethiopia*
[3]*Ethiopian Agriculture Authority, Addis Ababa, Ethiopia*

Abstract

The research system since 1970 released and registered 1,489 improved varieties of 149 crops. Among the total released crop varieties, 74 of them are forages. Cereal crops accounted for 501 varieties, pulse crops; oil crops, and tuber, roots and vegetable have a total of 277, 126 and 313 varieties, respectively. The major cereal crops wheat, maize, barley, tef, and sorghum have higher number of varieties released. Proportionally higher allocation of research budget, existence of international collaborations, exposure of researchers to different research systems and availability of project funds have contributed to the significant difference in number of released varieties among crops. Though, increased productivity cannot be associated only with the use of improved varieties, the contribution of varieties and agronomic practices take the lion share of the improvement. The trend in yield for major crops show considerable increase in the last twenty years which might be associated with the use of varieties, seed supply system, application of fertilizer, crop protection, and better extension services. However, there is poor coherence between rate of new variety release, their uptake and productivity gains. The research system since its establishment has generated, other than varieties, other production packages that are partially applied in the production system. However, a significant number of these technologies did not reach to the beneficiaries due to many reasons including lack of consistent and progressively vibrant linkages. Thus, this review would shade light on crop varieties' generation versus their degree of utilization and influence in the production and productivity improvement, in setting the futuristic crop improvement endeavour of affiliated institutions.

Keywords: Improvement, NARS, trend, technology, variety,

Introduction

The Government of Ethiopia has embarked on a ten-year economic development plan (2021-2030) where agriculture is on the top of priority sectors, particularly crop sub-sector. Among the ten programs in the 10 in 10, seven of them are crop and crop related programs. Crop production had a lion's share in agriculture accounting for 65.1 percent whereas animal farming & hunting accounted for 26 percent, forestry accounted for 8.6 percent and fishing accounted for 0.2 percent by 2020/21. In terms of growth, crop production expanded by 5.7 percent, animal farming & hunting

(including fishery) and forestry registered 3.8 and 3.9 percent expansion, respectively by 2020/21 (NBE, 2021). The ten-year development plan and the 10 in 10 programs aims at boosting agricultural export revenues and substituting imports by reducing production costs. To achieve this, the government seeks to leverage on developing huge unutilized arable land, modernizing production systems and improving the uptake of crop varieties and other improved technologies to expand development efforts.

Crop variety development in Ethiopia has been gone more than half a century and the oldest varieties registered in 1970 were DZ-01-99 and *Enatit* (DZ-01-354) in tef; and Albar 637, A-333-57 and Reba B.50 in cotton. Since then several varieties have been released with increasing rate that hits maxima in 2000's (Asnake, 2018). The same authors reviewed the involved institutions in the release as research centers, universities, private companies, seed enterprises, ministry of agriculture (MoA), and Consultative Group for International Agricultural Research (CGIAR), with about two-third contributions from the Ethiopian Institute of Agricultural Research (EIAR). There are about 1,489 varieties registered in the national variety registry book till 2021 (Ethiopian Agriculture Authority (EAA), 2021)). Based on empirical evidences, information about modern varieties spreads slowly to farmers. It takes several years before any significant promotional activities are made by extension workers and seed producers; and the lifespan of released varieties, the period a variety should be under production, and is not clearly regulated.

Since the information channel from the National Variety Release Committee (NVRC), Ministry of Agriculture (MoA), research organizations to seed producers and extension agencies, and to the farmers appears very long, there has been irregular and insufficient communication about released varieties, their yield potential, disease resistance, etc. resulting in mismatch of information among different bodies. In 2003, requests of seeds by agricultural offices were made for only 152 varieties out of 711 released varieties available that time, with some of the requested varieties were as old as 30 or more years, while new varieties released during the last five years were on the shelf.

Important questions including, how much of the varieties are utilized to bring an impact? How much of the varieties should be out of production? What criteria should be used to maintain a variety under production? What are the investment recovery options? How much should be the optimum yield or genetic gains in subsequent varieties for each crop? Are critical in devising the breeding road map and set appropriate regulation on the area of improved varieties development.

It is also a matter of great concerns that there are no real genetic gains or progress being made unlike the proof of concept to any of the crops. For instance 100 of the wheat varieties released over the last 5 decades, would have moved wheat industry to multi fold level high than it is realized today (3t/ha).

However, it is still a matter of regulatory concern on the longevity of varieties in use (Adefris and Mekonnen, 2012), yield gaps between research field and farmers' field, whether regulation has to be in place to delist obsolete varieties and conversely promote new varieties and measure the overall rate of production gains. Obviously yield of properly managed varieties which receives recommended agronomic packages is significantly higher than the one grows with incomplete production packages. This review tries to discuss the trends in variety release for major research programs, and assess if the breeding is attaining the right genetic gains so that more strategic variety development options can be devised for effectiveness of value for money principles. Hence, the objectives of this review are:

- To analyze trends of crop varieties development
- To assess the adoption rate of improved crop varieties
- To review the impact of crop varieties on yield, income and household food security

Research methodology

The research was undertaken through literature review approach to assess the trend of improved crop varieties development and their contribution on agricultural productivity, household income and food security. This review involves a qualitative and quantitative analysis of the trend and current development of improved crop varieties registration and release, and also their contribution on Ethiopian agriculture. The research has indeed employed an intensive review of various literatures including government official documents, official reports, peer-reviewed articles, books, proceedings, and conference papers that were previously published as the sources of the findings.

Given the broad range of topics related to crop improved varieties development and their impact, we purposively sampled and identified various topically relevant and published systematic and scoping reviews to provide a baseline state of the evidence. Using three databases (Google Scholar, Research Gate, and EIAR's D-space), we gathered and collected additional articles and books using key word searches aligned with the terms "improved crop varieties development" and "contribution of crop varieties". Then, the reviewed literature was thematically collected, summarized, analyzed, interpreted, narrated, and then discussed.

Table 1: Data sources, data collection methods and data analysis

Specific Objectives	Type of Data Needed	Sources of Data Needed	Methods of Data Collection	Methods of Data Analysis
Specific Objective 1	- No. of released crop varieties for each commodity & commodity groups	https://agri.kukunetdigital.com/	- Website browsing - Decoding the base data of the website	- Trend analysis
Specific Objective 2	- Rate of adoption - Intensity of adoption	Crop varieties adoption studies conducted on various crops & varieties (if possible)	- Literature review	- Descriptive statistics - Content analysis of literature with careful organization & presentation of results
Specific Objective 3	- Impact on productivity - Impact on households' income - Impact on food & nutrition security	Crop varieties impact studies conducted on various crops & varieties (if possible)	- Literature review	- Content analysis of literature with careful organization & presentation of results

Results and Discussion

Variety release and registration system of Ethiopia

Breeding procedures

Breeding a new variety is a long process and complex depending on the desired end result. Adefris and Daniel (2012) have made fundamental review on varietal development and procedures which universally is applied in Ethiopia. After thousand years of breeding, the process of developing the perfect varieties is yet to be achieved. The main objective of plant breeding program is to develop new plant varieties that can enhance crop adaptation, production and productivity. Although breeding new varieties vary from crop to crop, a common characteristic among them are high cost, personnel, and time. Between creation and marketing of a variety, it is subjected to various forms of evaluation and testing for performance and registration and release. Ethiopia has released/registered more than 1400 crop varieties to date (Figure 1**)**. About a fourth of varieties are realized as accessibly influential in the agricultural system **(**አስናቀ, 2010).

Depending on the pollination behaviour, lifetime and the stage of tested material, six types of varietal development with average required years are known in Ethiopia. These includes adaptation trail (annuals and perennials) [1-3 years], pure-line varietal development [4-8 years], population varietal development [4-8 years], hybrid varietal development [8-10 years], clonal varietal development [4-5 years], perennial varietal development [5-14 years]. In sum, varieties are released for improved traits including yield, resistance to diseases and pests, adaptation/resilience/, quality, plant form, cropping system, taste or processing suitability. In most cases the crop breeding cycle starts from observation nursery (PVT, NVT, and VVT).

Procedurally major components of varietal development include acquisition of germplasm; hybridization; selection and evaluation, varietal testing, verification, variety maintenance. In addition, strategic studies on G x E, defining selection criterion, inheritance, heterosis breeding, etc. are conducted.

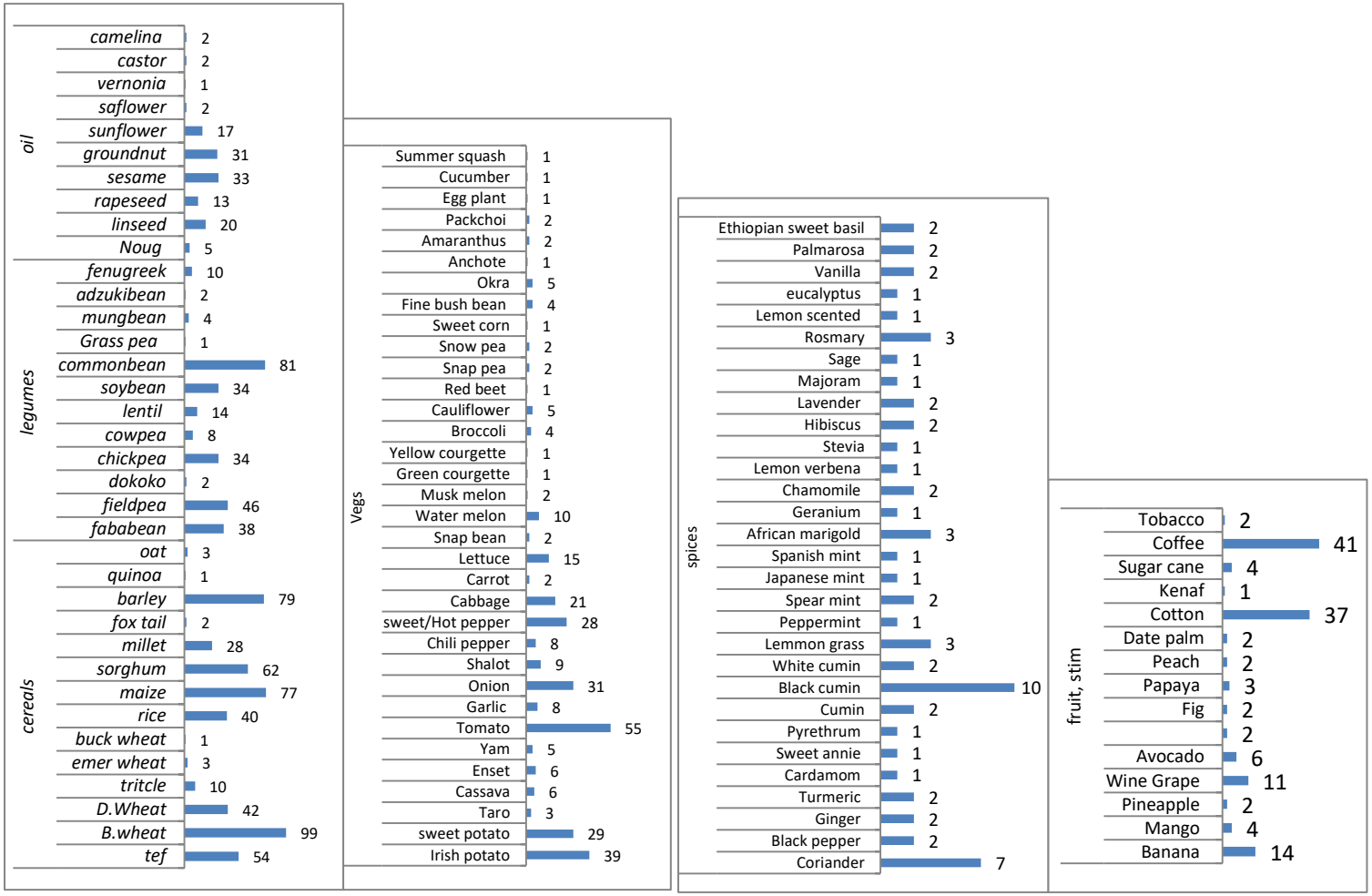


Figure 1 Varieties released by crop categories between 1970 and 2021

Variety release, regulation

According to the seed proclamation, no 782/2013 variety release and registration is mandatory in Ethiopia, and the proclamation indicates that any variety intended for the domestic or export market shall be registered. However, the proclamation exempts registration of the varieties if it is only if importing unregistered varieties and multiplying exclusively for reexport purposes. In order to release a variety, the applicant shall submit an application before May 30 for rain-fed and September 30 for irrigated crops along with data that show the performance of the variety so as to justify the potential of the candidate variety. The application goes to the secretariat office (Plant Variety Release, Protection, and Seed Quality Control Directorate (PVRSQC)). The National/Regional yield trial has to be conducted for two/three seasons in three/two locations respectively and one season additional verification trial in one on station and two on the farm for the respective location. The submitted application and its performance at the verification trial evaluated by the technical committee along their recommendation has to be provided to the national variety release committee (NVRC) who are responsible for the final decision on whether to release a variety.

The independent plant variety tests, both for DUS and VCU/NPT tests have not been implemented in Ethiopia as per the prescribed (international) technical guidelines by independent body. However, the performance tests (both the national and regional variety trials) have been entirely managing by applicants (variety developing institutions) themselves, though administered (final evaluation, decision) by MoA-PVRSQC directorate via the National Variety Release Committee. This brings a question of independency and impartiality. Due to the absence of DUS testing in Ethiopia, it is difficult to know whether some of the already released varieties are the same implying there is no clear description for those released varieties, which significantly affect the seed certification process and the adoption rate of the varieties by the farming community.

In Ethiopia, the first Plant Breeder's Right (PBR) Proclamation No. 481/2006 was ratified in 2006. However, without any attempt to implement this proclamation, it was revised, and the new PBR Proclamation No. 1068/2017 was endorsed in the late 2017. Even if the proclamation is in place since 2006, PVP has not yet implemented in the country. The absence of PBRs implementation discourages private companies to invest in the country for variety development and seed multiplication. It also doesn't motivate the public breeding institutes (breeders) to develop superior varieties under the context of 'competition.

Trends of crop variety development

Crop varieties release over the years

Registration of new varieties of crops has been made employing 20~25 different agronomic, yield and yield related descriptors of each crop, including plant architecture, seed properties, their optimum management, productivity on research and farmers land, adaptation areas, recommended ranges of altitude and rainfall. While year based report of released varieties is shown in Figure 2, a complete list of crops which are released/ registered by the National Varieties Registration Committee is summarized in Figure 3.

Trend assessment of released varieties in Ethiopia shown that there was a steady increase in crop type and number of varieties registered by different research institutes until 1994 (Figure 2), contributing for the sum of 10% to the total released varieties. Out of 1,489 total varieties released until 2021, about 90% are released in 27 years after 1994, with an average of 52 varieties per annum. The maximum number of released varieties was recorded during 2013, where 101 varieties of 40 crops (6 cereals, 4 pulses, 3 oil seeds, 2 root crops, 15 vegetables, 3 fruits, 1 cotton, 5 herbs and 1 forage) were released. After 2016, however, there is a tendency of reduction on the number of released varieties.

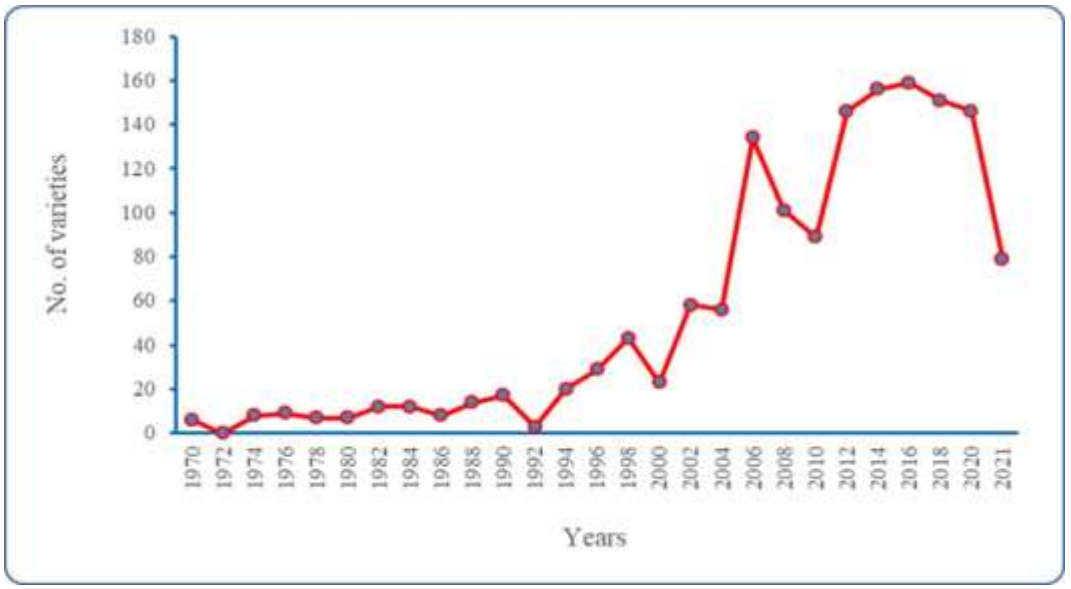
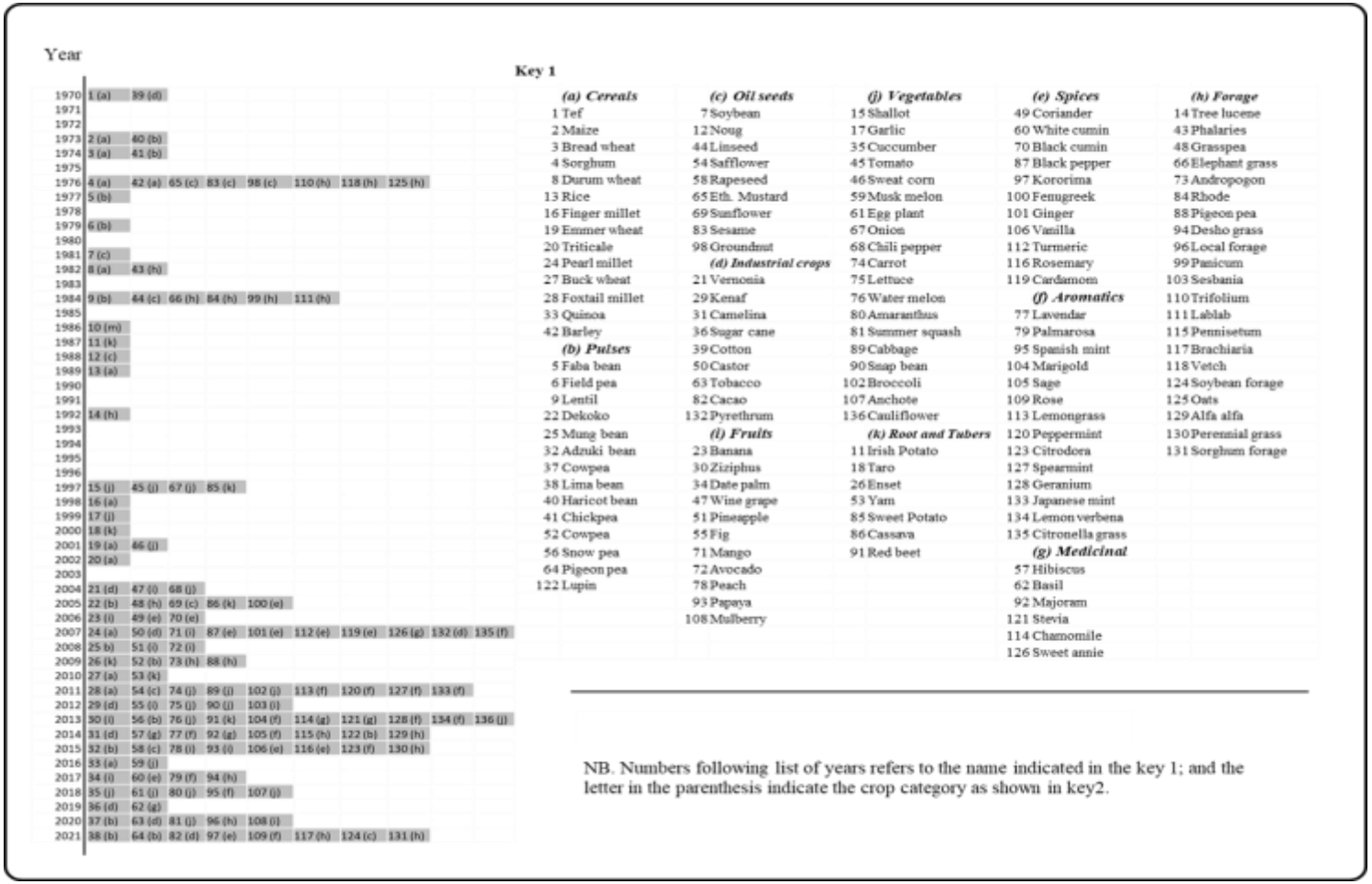


Figure 2 Trend of variety release in Ethiopia (1970-2021)

Crop types included in the breeding programs and their releases for production

Two varieties of tef, *DZ-01-99* and *Enatit*, and four varieties of cotton, *A-333-57, Albar 637, Reba B.50* and *Acala 1517/70* were registered as the first crop in the row five decade back by Debre Zeit Agricultural Research Center and Were Agricultural Research Center, respectively. Since then, the number of crops being included in the variety registration has been increasing at least by one except for few years (Figure 3) and the maximum number of new crops included in the varieties registration was 10 during 2007 and 2010, which was followed by 2011 where nine new crop types were registered. Until 1986 only varieties of cereals, pulses, oil seeds, cotton and forage were registered. Among the currently produced 14 pulse crops, first registration was made on Faba bean (variety, *CS-20-DK*) in 1977 by Holleta Agricultural Research Center. Since then, there have been a total of 38 varieties of faba bean registered until 2021. Field pea, Lentil and Dekeko were the three pulse crops that had many years of breeding activities following Faba bean. In the case of oil seeds, soybean, *noug* and linseed were the three important crops that have varieties registered many years back, such as *Davis, Wiliams* and *Davis* for soybean, *Fogera* and *Este-1* for Noug, and *C1-1525 and C1-1652* for Linseed.

The first coffee variety 741 was registered in 1986 by Jimma Agricultural Research Center, followed by the release of Irish potato variety as root crop named *Alemaya 624* by Haramaya University. In vegetable research, first registration of varieties was made in 1997 for shallot (one variety, *Huruta*), onion (one variety, *Melkam*); and two varieties of tomato (*Melka Shola* and *Melka Salsa*) during 1997, all from Melkassa Agricultural Research Center. Among 11 different fruit types included in the National breeding program, 12 banana varieties were first released in 2006. During the same year, one variety of coriander called *Walta-1* and one black cumin variety, *Darbera* were released as a first spice crops both by Sinana Agricultural Research Center. With respect to aromatic and medicinal plants, a total of 20 plants are included in the breeding program and from which the first release of varieties was made in 2011 for four plants, vis. Peppermint (*Liyu*), Spearmint (*WGSM-03*), Japanese mint (*Wondo-1*) and Lemon grass (*Lomisar-1*) by Wondogenet Agricultural Research Center.



Year									
1970	1 (a)	39 (d)							
1971									
1972									
1973	2 (a)	40 (b)							
1974	3 (a)	41 (b)							
1975									
1976	4 (a)	42 (a)	65 (c)	83 (c)	98 (c)	110 (h)	118 (h)	125 (h)	
1977	5 (b)								
1978									
1979	6 (b)								
1980									
1981	7 (c)								
1982	8 (a)	43 (h)							
1983									
1984	9 (b)	44 (c)	66 (h)	84 (h)	99 (h)	111 (h)			
1985									
1986	10 (m)								
1987	11 (k)								
1988	12 (c)								
1989	13 (a)								
1990									
1991									
1992	14 (h)								
1993									
1994									
1995									
1996									
1997	15 (j)	45 (j)	67 (j)	85 (k)					
1998	16 (a)								
1999	17 (j)								
2000	18 (k)								
2001	19 (a)	46 (j)							
2002	20 (a)								
2003									
2004	21 (d)	47 (i)	68 (j)						
2005	22 (b)	48 (h)	69 (c)	86 (k)	100 (e)				
2006	23 (i)	49 (e)	70 (e)						
2007	24 (a)	50 (d)	71 (i)	87 (e)	101 (e)	112 (e)	119 (e)	126 (g)	132 (d)	135 (f)
2008	25 b)	51 (i)	72 (i)						
2009	26 (k)	52 (b)	73 (h)	88 (h)					
2010	27 (a)	53 (k)							
2011	28 (a)	54 (c)	74 (j)	89 (j)	102 (j)	113 (f)	120 (f)	127 (f)	133 (f)	
2012	29 (d)	55 (i)	75 (j)	90 (j)	103 (i)					
2013	30 (i)	56 (b)	76 (j)	91 (k)	104 (f)	114 (g)	121 (g)	128 (f)	134 (f)	136 (j)
2014	31 (d)	57 (g)	77 (f)	92 (g)	105 (f)	115 (h)	122 (b)	129 (h)		
2015	32 (b)	58 (c)	78 (i)	93 (i)	106 (e)	116 (e)	123 (f)	130 (h)		
2016	33 (e)	59 (j)								
2017	34 (i)	60 (e)	79 (f)	94 (h)						
2018	35 (j)	61 (j)	80 (j)	95 (f)	107 (j)					
2019	36 (d)	62 (g)								
2020	37 (b)	63 (d)	81 (j)	96 (h)	108 (i)					
2021	38 (b)	64 (b)	82 (d)	97 (e)	109 (f)	117 (h)	124 (c)	131 (h)		

Key 1

(a) Cereals	*(c) Oil seeds*	*(j) Vegetables*	*(e) Spices*	*(h) Forage*
1 Tef	7 Soybean	15 Shallot	49 Coriander	14 Tree lucene
2 Maize	12 Noug	17 Garlic	60 White cumin	43 Phalaries
3 Bread wheat	44 Linseed	35 Cuccumber	70 Black cumin	48 Grasspea
4 Sorghum	54 Safflower	45 Tomato	87 Black pepper	66 Elephant grass
8 Durum wheat	58 Rapeseed	46 Sweat corn	97 Kororima	73 Andropogon
13 Rice	65 Eth. Mustard	59 Musk melon	100 Fenugreek	84 Rhode
16 Finger millet	69 Sunflower	61 Egg plant	101 Ginger	88 Pigeon pea
19 Emmer wheat	83 Sesame	67 Onion	106 Vanilla	94 Desho grass
20 Triticale	98 Groundnut	68 Chili pepper	112 Turmeric	96 Local forage
24 Pearl millet	*(d) Industrial crops*	74 Carrot	116 Rosemary	99 Panicum
27 Buck wheat	21 Vernonia	75 Lettuce	119 Cardamom	103 Sesbania
28 Foxtail millet	29 Kenaf	76 Water melon	*(f) Aromatics*	110 Trifolium
33 Quinoa	31 Camelina	80 Amaranthus	77 Lavendar	111 Lablab
42 Barley	36 Sugar cane	81 Summer squash	79 Palmarosa	115 Pennisetum
(b) Pulses	39 Cotton	89 Cabbage	95 Spanish mint	117 Brachiaria
5 Faba bean	50 Castor	90 Snap bean	104 Marigold	118 Vetch
6 Field pea	63 Tobacco	102 Broccoli	105 Sage	124 Soybean forage
9 Lentil	82 Cacao	107 Anchote	109 Rose	125 Oats
22 Dekoko	132 Pyrethrum	136 Cauliflower	113 Lemongrass	129 Alfa alfa
25 Mung bean	*(i) Fruits*	*(k) Root and Tubers*	120 Peppermint	130 Perennial grass
32 Adzuki bean	23 Banana	11 Irish Potato	123 Citrodora	131 Sorghum forage
37 Cowpea	30 Ziziphus	18 Taro	127 Spearmint	
38 Lima bean	34 Date palm	26 Enset	128 Geranium	
40 Haricot bean	47 Wine grape	53 Yam	133 Japanese mint	
41 Chickpea	51 Pineapple	85 Sweet Potato	134 Lemon verbena	
52 Cowpea	55 Fig	86 Cassava	135 Citronella grass	
56 Snow pea	71 Mango	91 Red beet	*(g) Medicinal*	
64 Pigeon pea	72 Avocado		57 Hibiscus	
122 Lupin	78 Peach		62 Basil	
	93 Papaya		92 Majoram	
	108 Mulberry		121 Stevia	
			114 Chamomile	
			126 Sweet annie	

NB. Numbers following list of years refers to the name indicated in the key 1; and the letter in the parenthesis indicate the crop category as shown in key2.

Figure 3 Release/registration start year for each crop in Ethiopia

Institutions involved in crop variety release/ registration

Figure 4 summarizes core research institutions involved in the development of crop varieties since official documentation started. Accordingly, the majority of variety registration (82%) was made by the Federal and regional agricultural research institutes, vis., the Ethiopian Institute of Agricultural Research, Oromia Agricultural Research Institute, Amhara Region Agricultural Research Institute, Southern Agricultural Research Institute, Tigray Agricultural Research Institute and Somali Region Pastoral and Agro Pastoral Research Institute, in their order of contribution. Out of the total 1489 crop varieties, 14% (215) of the registration was made by 50 private companies, of which 19 vegetables took 68% of this registration. There are different reasons for the lower involvement of private companies in variety release and registration. It has impact on having lower competitive environment for better varieties access particularly on tomato and onion. Companies contributed also for the registration of 31 varieties in cereals, two in forage, 13 for cotton, 15 in oil seeds and seven in root crops. The contribution of higher learning institutions for the variety development was about four percent, followed by the registration made by other public institutions, such as Ministry of Agriculture, Sugar Corporation, Ethiopian Seed Enterprise and National Tobacco Enterprise.

Out of the total 53 crop varieties registered by higher learning institutions, Haramaya University contributed to 81%, followed by Mekelle University with eight registered varieties on Barley and Durum Wheat. List of crops included in Haramaya University breeding program where varieties are registered include bread wheat, carrot, faba bean, garlic, ground nut, haricot bean, Irish potato, maize, sesame, shallot, sorghum and sweet potato. In the case of agricultural research centers, the maximum number of released varieties was observed by Melkassa Agricultural Research Center by releasing 184 varieties, which is 12.3% from the total crop varieties. Debrezeit and Holleta Agricultural Research Centers, also contributed to the significant number of released varieties, each releasing an average of 112 varieties.

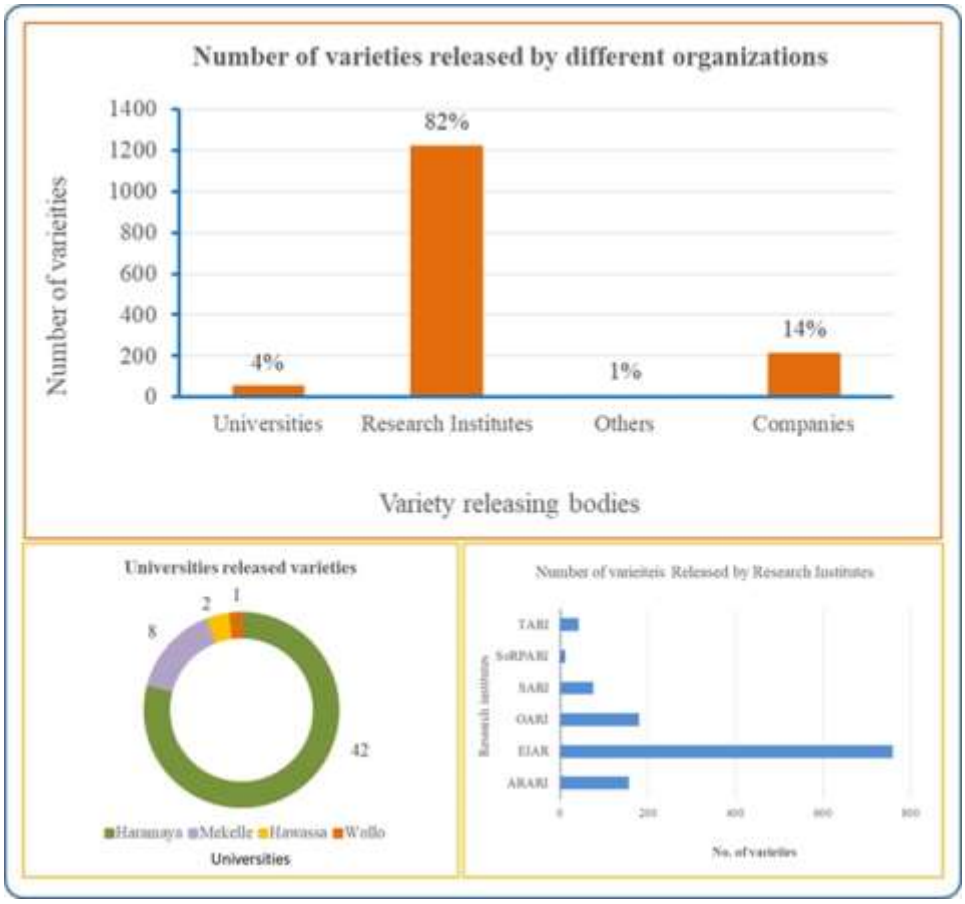


Figure 4 Involving research institutions in crop variety registration

NB: SC, Sugar Corporation; ESE, Ethiopian Seed Enterprise; NTE, National Tobacco Enterprise; MoA, Ministry of Agriculture; TARI, Tigray Agricultural Research Institute; SoRPARI, Somali Region Pastoral and Agro Pastoral Research Institute; SARI, Southern Agricultural Research Institute; OARI, Oromia Agricultural Research Institute; EIAR, Ethiopian Institute of Agricultural Research; ARARI, Amhara Region Agricultural Research Institute

Major crop categories in variety registration

Grouping crops into nine major categories as indicated in Figure 5 gives the overall picture of research focus, local vs. international collaborations and associated investments. From the total registered varieties, 509 belongs to cereals, which is followed by fruits and vegetables which contributed for 278 (18.5%) to the national varieties registration. The number of registered varieties for food legumes, oil seeds, root/tuber crops, herbs, forage, industrial crops and coffee was 238, 147, 89, 71, 77, 50 and 41, respectively.

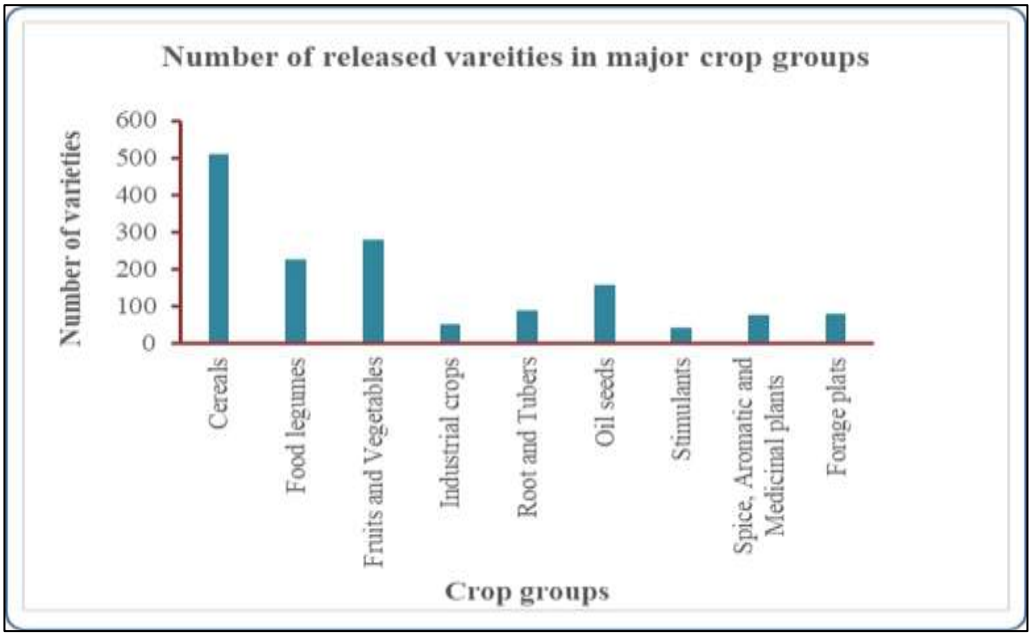


Figure 5 Released varieties grouped by major crop categories

Adoption and impacts of crop varieties

Adoption rate of crop varieties

The adoption of improved crop varieties has become an important issue in the development agenda for Ethiopia, especially (as a way contribute for productivity improvement and so impact on poverty reduction) to tackle poverty and low productivity. The government has shown strong efforts to the promotion of improved varieties and chemical fertilizer in improving and expanding agricultural extension services (Louhichi et al., 2019). Though the breeding system has been working on different crop commodities to release new varieties, clear information on adoption of many of these crops is not available as most adoption studies focuses on major cereal crops, and also most of the adoption studies are limited specific areas, which does not provide national adoption picture. Based on this limited information, adoption rates vary from one region to another, one variety to another and one farmer to another but displayed an increasing trend over time (Fentahun et al., 2017). Yet, the adoption rate of crop varieties has not reached the desired level. As a result, there is a productivity gap within the farming community (between leaders and followers) that can reach up to 50% and between the average farmer and the research station that can reach up to 70% (Fentahun et al., 2017). Even then, there are several showcases that the research system has made visible impact on the nation's agricultural production. As indicated in Table 2 below, a study conducted by Chilot et al. (2013, 2015, and 2016)

has tracked wheat and maize adoption levels using DNA fingerprinting. The result showed that about 96% of the respondents cultivated improved wheat varieties and 61.4% of them cultivated improved maize varieties. Wheat and maize have the highest adoption rate of 62-96% and 56-61%, respectively compared with other major crops. Moreover, tef has the adoption rate of 76%, lentil 12-16%, and chickpea 14-19%.

Table 2: Adoption rate of various crops

Crop	Estimated adoption rate	Author	Indicator	Data collection method	Area coverage	Study year
Maize	31	De Groot et al (2014)	HHs	HH survey	National	2010
	55.9	Chilot *et al.* (2016)	HHs	HH survey	East Wollega, West Shewa and West Arsi zones of Oromiya	2014
	61.4	Chilot *et al.* (2016)	HHs	DNA finger printing		
Wheat	62.5	Chilot *et al.* (2013)	Area	HH survey	National	2010
	52.8		HHs	HH survey		
	62	Chilot *et al.* (2016)	HHs	HH survey	East Wollega, West Shewa and West Arsi zones of Oromiya	2014
	96		HHs	DNA finger printing		
Tef	76		HHs	HH survey	Central highland	2012
Chickpea	19.4	Chilot *et al.* (2015)	Area	HH survey	National	2010
	17.4		HHs	HH survey		
	13.9		HHs	Community survey		
Lentil	12	Chilot et al. (2016)	HHs	HH survey	National	2010
	15.6		Area	HH survey		
	13.4		Area	Community survey		

Impact of improved crop varieties

a) Impact on yield

Field crops have had their yields rise noticeably over the past years in Ethiopia. Though increased productivity cannot be associated purely with research, the contribution of improved varieties and associated agronomic practices takes the lion share of the improvement. Plant breeding improves genetics of the plants, while improved pest control, mechanization, and fertilizer use contributes for the increase of crop yields by providing good growing conditions so that the plant can express its potential. Extensive evidence suggests that crop yields benefits the most from plant breeding (Abebe and Alemu, 2017; Yirga and Alemu, 2016).

The Ethiopian government is pursuing a strategy of improving yield primarily through intensification, involving an increased use of inputs, including improved crop varieties. Crop varieties development and adoption is an essential approach for increasing agricultural productivity in Ethiopia. High productivity success has been achieved with the release of different types of crop varieties in the country (Yirga and Alemu, 2016). The national average of all crops yield has increased from 7.3 quintals per hectare (qt/ha) in 1961/62-1969/70s to about 24 qt/ha in 2020/21 (CSA, 2021). These yield increases might be associated with the use of seeds of improved varieties, application of fertilizer, crop protection measures, and use of better extension services.

The trend of yield increase for major cereal crops show considerably higher result in the last many years could be highly associated with the use of seeds of improved varieties, application of fertilizer, crop protection measures, and use of better extension services.

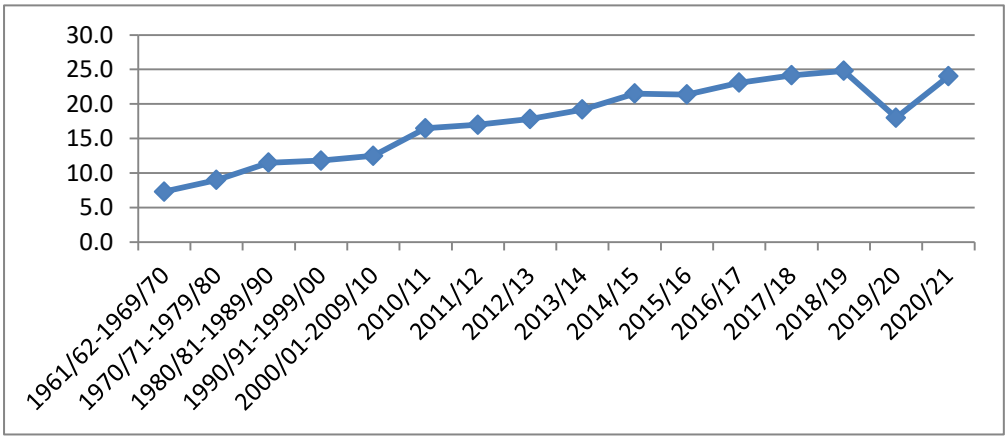


Figure 6 Productivity trends (quintal/hectare)
Source: CSA of various years

Maize demonstrated the highest yield increase over years compared with other cereal crops which increased from 17 qt/ha to 42 qt/ha between 2004/05 and 2020/21 (CSA, 2021). This high yield increment was associated with release of the most popular maize hybrids by the research systems such as BH660, BH661, BH540 and QPM (Fentahun et al., 2017). *Tef* gives the lowest yield compared to other cereal crops such as maize, sorghum, barley, and wheat (CSA, 2021); however, the yield performance indicated an increasing trend, which increased from 9.4 qt/ha to 18.8 qt/ha during the same period. The well-known *tef* variety *Quncho* elevated *tef* productivity as high as 30 quintal/ha (uniformity of measuring unites) (CSA, 2021). Although there is an increasing trend in cereals productivity, there is a considerable yield gap between the current actual yields and the potential yields with improved varieties; and the actual supply has not been sufficient for the demand of the population. Thus, it is important to exploit the opportunity to increase yield through the widespread adoption of improved varieties that brings significant benefits for smallholders.

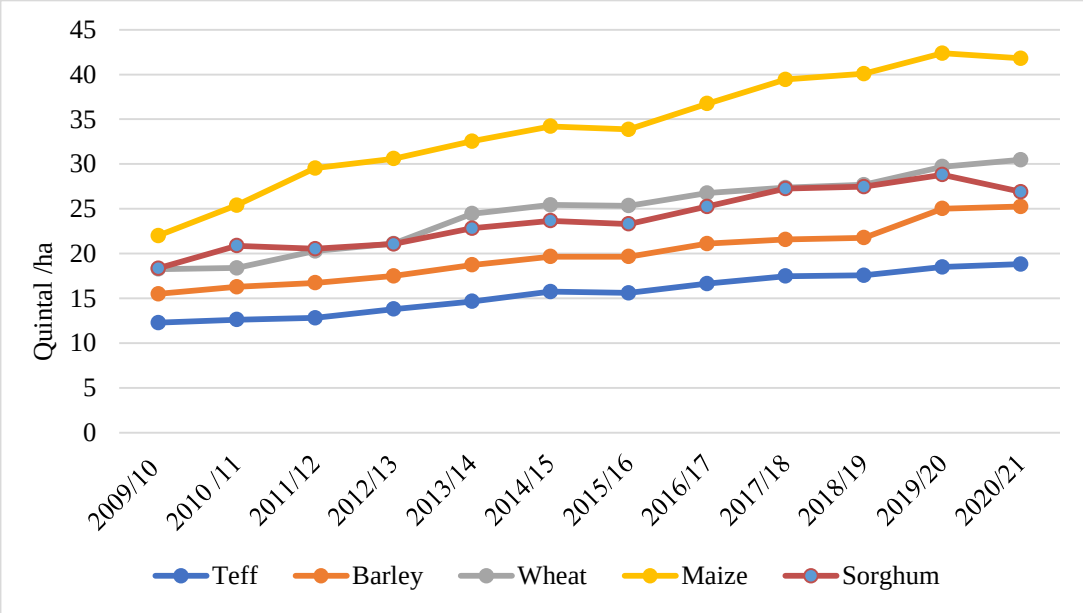


Figure 7 Cereal yield trend (quintal/hectare)
Source: CSA

The yield level of the majority of pulse crops are increasing over the years, but the increment of soybean was higher than most other pulse crops, which accounted for 25 qt/ha in 2020/2l (Figure 3); the yield increment over the years was 77% (CSA, 2021).

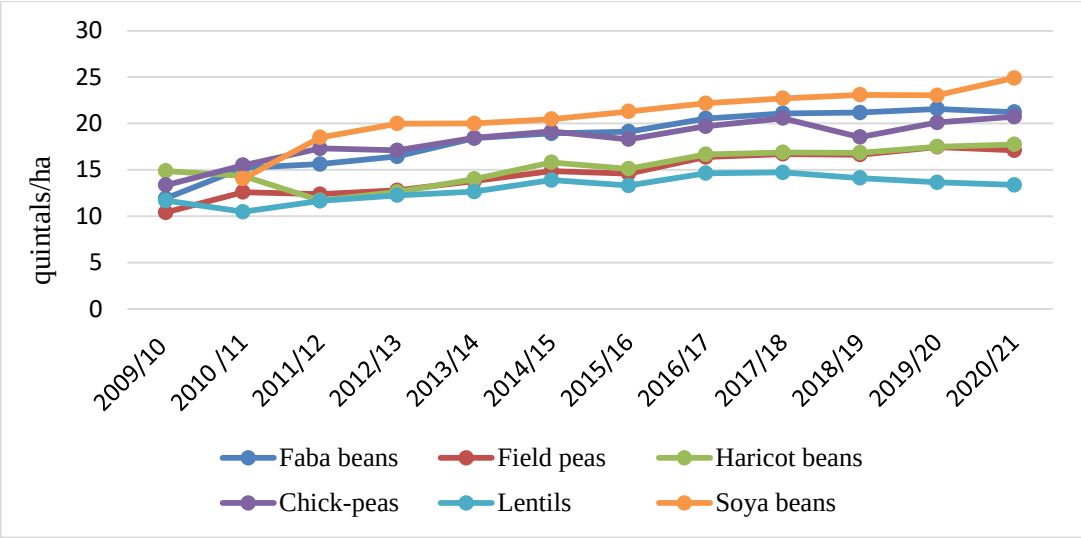


Figure 8 Pulse crops yield trend (quintal/hectare)
Source: CSA

The yield performance of rape seed is the highest of all oilseeds that increased from 11 qt/ha to 18 qt/ha over the years followed by groundnut with the same amount between 2009/10 and 2020/21. *Noug (Guizotia abyssinica)* also increased from 6 qt/ha to 11 qt/ha, while the yield performance of sesame fluctuated and reduced from 8 qt/ha in 2009/10 to 7 qt/ha in 2020/21. Sesame has the lowest yield of all oilseeds.

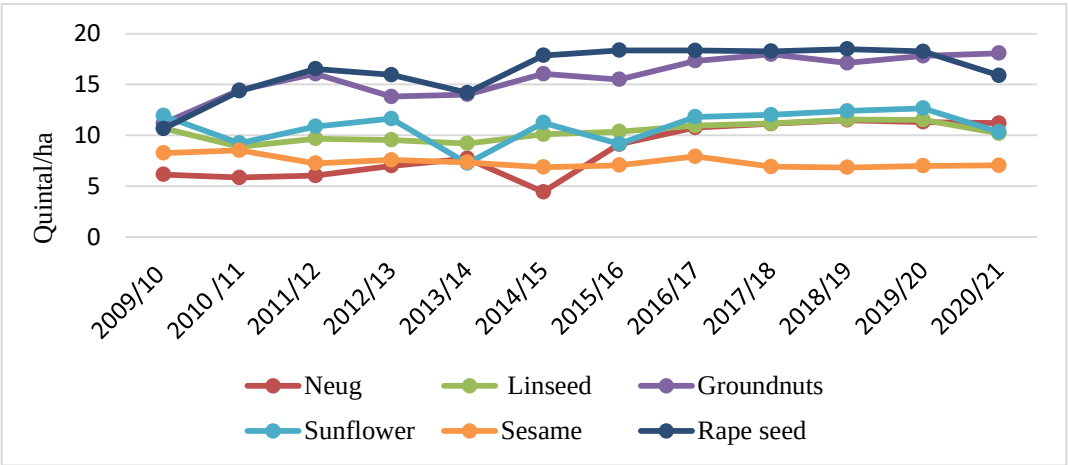


Figure 9. Oilseed crops yield trend (quintal/hectare)
Source: CSA

Table 3 Summary of the impact of improved crop varieties on yield

Crop	Author	Data collection method	Area coverage	Study year	Impact on food security/Income
Maize	Olasehinde et al. (2023)	HH survey	Nigeria	2023	↑the maize yield by 38.7%
Rice	Rahman & Connor (2022)	HH survey	Bangladesh	2022	↑the rice yield by 35%
Tef	Mekonnen et al. (2021)	HH survey	Amhara and Oromiya	2019	↑the tef yield by 388.7 kg/ha
Maize	Ahmed (2022)	HH survey	East Hararghe zone of the Oromia	2014/15	↑the maize yield by 331 kg/ha
Wheat	Zegeye et al. (2022)	HH survey	North Shewa, Amhara region	2020	↑the wheat yield by 13.56 qt/ha
Maize	Menale et al. (2015)	HH survey	National	2011	↑the maize yield by 850 kg/ha
Wheat	Tesfaye et al. (2016)	HH survey	Arsi zone	2013	↑the wheat yield between 25-50%
Wheat	Belay et al. (2019)	HH survey	Major wheat producing regions	2015/16	↑the wheat yield between 51-55%

b) Impact on poverty reduction, food security and household income

Improved crop technologies plays an important role in enhancing food security by improving crop yields and farm income (Menale *et al.,* 2015). Agricultural research and extension play an important role in rising productivity by introducing new technologies and spreading to the end-users. The agricultural sector's growth is highly dependent on successful innovation and its widespread adoption. The effectiveness of yield enhancing technologies such as improved varieties, chemical fertilizer, pesticides, and row planting practice depends on the choice of farmers on the type of technologies and practices.

Several studies show a significant positive impact of improved crop technologies on household food security of smallholders (Mekonnen *et al.,* 2021; Marenya *et al.,* 2018; Bekele *et al.,* 2014; Teklewold et al., 2019). According to Mekonnen *et al.* (2021), adopting improved tef varieties and agronomic practices enhanced household per capita calorie consumption, dietary diversity and food consumption pattern in Ethiopia. Similarly, a study by Bekele et al. (2014), reported using improved agricultural technologies significantly increased household per capita consumption expenditure (rewrite sentence to make meaningful). A study by Marenya *et al.* (2018) showed that adoption of a combination of improved maize variety and maize–legume diversification increases per capita calorie consumption and dietary diversity consumption in Ethiopia.

Table 4. Summary of impact of improved crop varieties on food security and income

Crop	Author	Data collection method	Area coverage	Study year	Impact on food security & Income
Tef	Mekonnen et al. (2021)	HH survey	Amhara and Oromiya	2019	• ↑per capita calorie consumption by 27.6%. • ↑dietary diversity by 22.6%. • ↑food consumption score by 21.4%.
Wheat	Bekele et al. (2014)	HH survey	National	2011	• ↑per capita consumption expenditure in the range of ETB 209-260
Maize	Marenya et al. (2018)	HH survey	Maize growing areas	2010 - 2013	• ↑per capita calorie consumption by 13.2% -28.5%
Sorghum, maize, wheat, potato, sweet potato, poultry, cattle breeds, animal feed & apiculture	Chanyalew et al. (2021)	HH survey	Oromia & Harari regions	2009 - 2016	• ↑food consumption score by the score of 8.97 • ↑dietary diversify by the score of 1.22
Wheat	Tesfaye et al. (2016)	HH survey	Arsi zone	2013	• ↑income of adopters almost 35% higher than non-adopters.
Wheat	Tsegaye & Bekele (2012)	HH survey	Southeastern Ethiopia	2012	• ↑per capita calorie consumption per day by 17% • ↑ consumption expenditure by 35.26%.

Agricultural Research Investment

Though the government of Ethiopia has endorsed the 2003 Maputo declaration for allocating 10% to the agriculture sector, the budget appropriation for the national research didn't reached the target set by the CAADP as 1% (Demese, 2015). Despite the positive trend, the intensity of Ethiopia's agricultural research investment remains far below the sub-Saharan African average and is one of the lowest in Africa standing just at 0.29%, and the CAADP target of 1% (Nienke and Tesfaye, 2018).

As indicated in Figure 10 below, there has been a slight increase in the government fund to research between 2013/14 and 2019, and slightly declining trends is observed starting from 2018/19 particularly for the crops including tef, wheat, coffee, vegetable etc. The decline in the share of each commodity spending reflects an increase in number of competing commodities, research centers, and an increasing of administrative costs of researchers such as salaries, incentives etc.

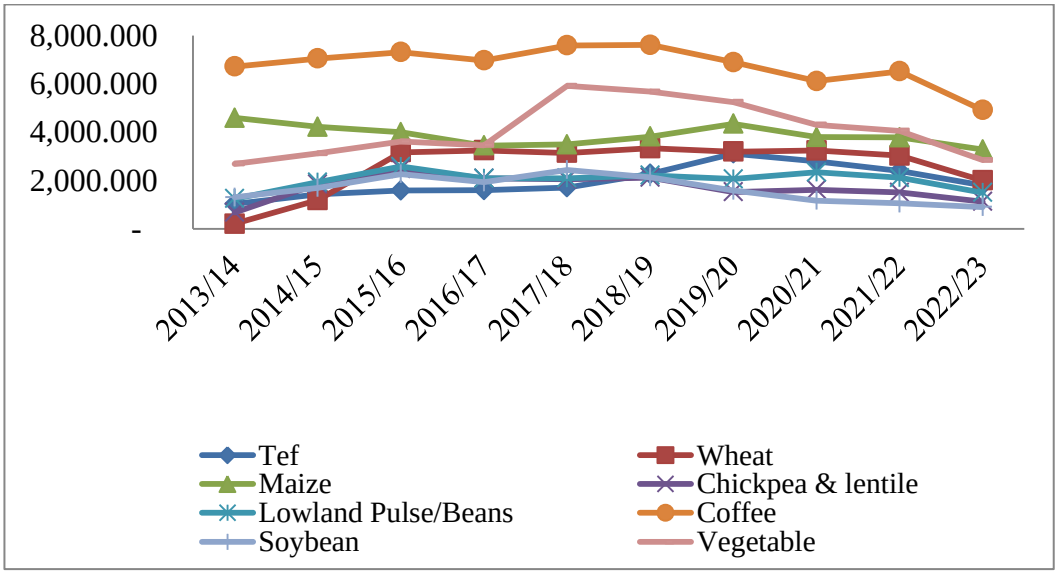


Figure 10. Trends of government fund allocation by the commodity (in million ETB)

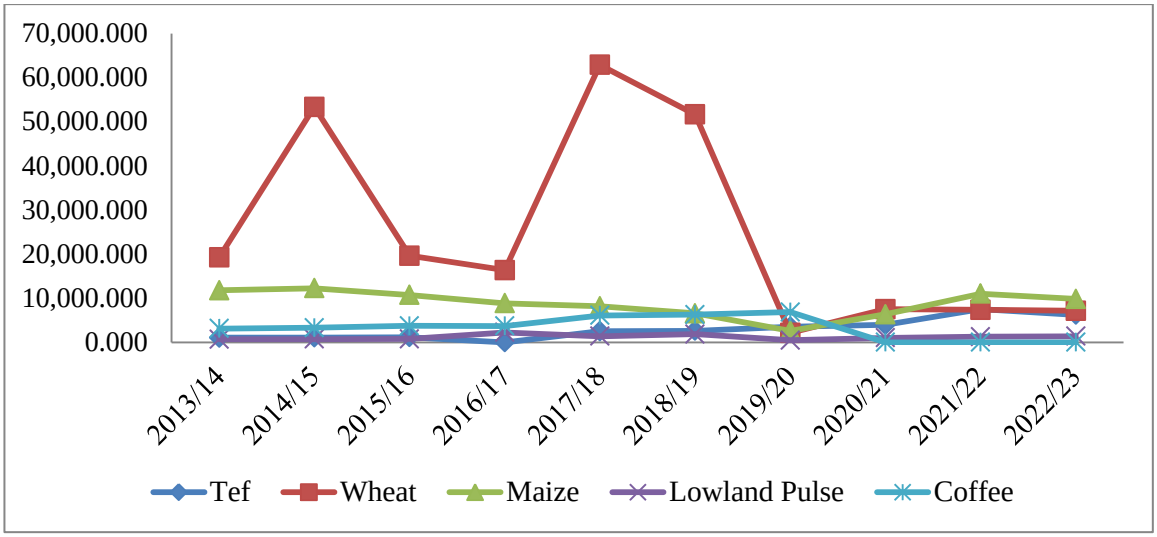


Figure 11. Trends of donor fund allocation by the commodity (in million ETB)

Conclusion

This study tried to assess and review the trends of crop varieties development, the adoption rate and its impacts on yield, income, and household food security. The research has indeed employed an intensive review of various literatures and involved a qualitative and quantitative analysis. The review indicated that more than 1489 crop varieties so far released and registered to various technology users. These technologies have made tremendous contributions and led to a massive increase in productivity as well as removing any concerns relating to a scarcity of food in the future. Enhancing rural households' income and food security through access to improved crop technologies is a key development strategy in Ethiopia. Ethiopia's successive governments have shown a keen interest in establishing, fostering, and maintaining a dynamic national agricultural research system (NARS) capable of developing and adapting improved crop varieties appropriate for the country's varied agro-ecologies and socio-economic conditions. The measurement of crop varieties impact is often a complex process. It can be measured with greater sophistication of returns to investment. The contribution of crop technologies can be looked through different dimensions, which are linked with purposes of research. Some of these dimensions are interpreted with impacts in terms of increased productivity (trends in the level of crop yields over the years), impacts on household food security, and impacts on household income.

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