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COFFEE RESEARCH ACHIEVEMENTS, THEIR BACKSTOPPING TO THE DEVELOPMENT OF THE SUB-SECTOR IN ETHIOPIA AND PRODUCTIVITY GAP BETWEEN FARM AND RESEARCH: A Review

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Abstract

Literature shows more of the world population turns to coffee consumption particularly Latin America, India and China. Demand for the beverage is estimated to increase by nearly 25% over the coming five years. On the other hand, global coffee production and supply is very unlikely to increase due to many factors. To fill the expected gap between production and consumption, Ethiopia has a better opportunity. Current productivity per hectare is about 647 kg which is lower than in many growing countries. Eventually, the research developed 42 coffee verities among which 35 are selections and seven of them are hybrids. As different coffee husbandry technologies enable to boost coffee production and productivity many agronomic practices are generated and recommended along with coffee varieties. Major coffee diseases like (Coffee Berry Disease, Coffee Wilt Disease and Coffee Leaf Rust) management options are also the knowledge developed by research. Integrated weed management practice developed to mitigate weed infestation from coffee farms enables us to reduce 65% yield loss. Among coffee quality maintenance technologies developed is altitude based fermentation time. For altitudes ≤1200, 1200-1500, and >1800 meter above sea level recommended 24, 24-48 and 48-72 hours fermentation period respectively. Improved coffee seed production also remains the responsibility of the research. In this regard, until now, about 300,000 kg of improved seed supplied in which estimated to cover about 300,000 hectares of land. Despite these all technologies, there is a wide productivity gap among the research, modern plantation, and the national average productivity. Even though developed technologies made considerable contributions to coffee production, productivity, and quality improvement in Ethiopia a lot is remaining. The national average productivity only reached 30% of the research results. This big gap in productivity range requires a wide utilization of research output by development is crucial. Actually, this demands: (1) Aggressive scaling-up of proven technologies (2) Managing coffee stands through mobilizing coffee sector rehabilitation and wide utilization of technologies (3) Addressing research in unaddressed areas (4) Establish & support sustainable coffee seed system (5) Establish viable extension system and consolidate the relationship of research and extension so that existing technology can be disseminated. In general, the major interest of this review paper is to bold out the outputs of existing national coffee research and to clearly show the gap between research results and development wing. On the other hand, it will try to show how concerted efforts should be made to improve both the volume and quality of coffee to the expected result to increased export revenue to the country.

Keywords: Coffee productivity; Coffee technology

1 Introduction

Coffee is at the center of Ethiopian culture and economy, which contributes for 29 – 31% of export earnings of the nation, 4.7 million small-holders directly involved in producing coffee and about 25 million people directly or indirectly depend on the coffee sector for their livelihoods (CSA, 2015; Taye Kufa *et al.*, 2016). Despite the natural endowment of the country and the economic importance of the crop to Ethiopia, both the value and the volume of coffee exported from the country do not show a substantial increase in the past few decades. An improvement in coffee productivity and quality has a direct impact on the livelihoods of a large number of resource-poor people. Appropriate management practices along with a better understanding of the crop behavior are important requirements for improving the growth, productivity, and bean qualities of coffee trees (Adugna, 2016). Thus, research on this commodity is crucial for the country.

The national coffee research in Ethiopia was established in late 1967. The ultimate goal of the coffee commodity research is to provide all the relevant technologies that are essential to revamp the Ethiopian coffee industry and thereby maximize the country's foreign exchange earnings from coffee and improve the livelihoods of the resource-poor smallholder coffee farmers and that of all other actors in the value chain. With this general objective, the research system tried to develop different coffee production technologies. Developed technologies revolve around variety improvement, coffee processing and quality maintenance, entomological, pathological and weed studies, the advance of agronomic practices (spacing, hole size, weed control, fertilizer rate, etc.).

The current productivity per hectare is about 647 kg (CSA, 2018/19) which is lower than in many growing countries. The government targeted to reach the productivity of 990-1080 kg/ha at the end of Growth and Transformation Period (GTP-II). Aligning with the national coffee sector development plan the national coffee research strategy is also designed to enhance coffee production and productivity by generating appropriate coffee technologies with its full packages. Since the establishment of national coffee research ample coffee production technologies were generated. The prominent are the development of 42 coffee varieties among which 35 are selections and seven of them are hybrid varieties (Bayetta and Labouse, 2006; Fekadu *et al.*, 2008; Tadesse, 2017; MOALR, 2017; Ashenafi, *et al.*, 2017).

Coffee Berry Disease (CBD) is one of the biggest challenges before the release of these varieties. The change that these varieties brought to the coffee sector are one of the glorious results in the coffee subsector especially gave relief for high CBD prone areas. To generate high yielder, disease resistant, and quality varieties, it is important to collect, evaluate and maintain coffee germplasm. In this regard, to maintain arabica coffee germplasm and utilize for further research program accessions are maintained at nationally coordinated coffee research centers (Fekadu *et al.*, 2008; Tadesse, 2017). On the other hand, to overcome the coffee variety adaptation problems, different varieties across different coffee growing environments were studied and well-adapted varieties recommended for respective coffee growing areas.

As different coffee husbandry technology enables to boost coffee production and productivity, many agronomic practices are generated and recommended along with coffee varieties. Coffee nursery management practices, coffee seedling planting, young coffee management, old coffee management, cycle changing, appropriate shed tree identification, organic and inorganic fertilizer application practices are to be mentioned.

Major coffee diseases like [(Coffee Berry Disease (CBD), coffee wilt disease (CWD), and coffee leaf rust (CLR)] management options are also the knowledge developed at the research centers (Taye, *et al.*, 2016; IAR/JARC, 1996; EIAR, 2017). Weed is also one of the big challenges in coffee production. Integrated weed management practice developed to mitigate weed infestation from coffee farms enables to reduction of 65% yield loss (Tadesse and Getachew, 2008). Arabica coffee grown in Ethiopian is in general quite good quality. Most of the time quality maintenance is the biggest challenge apart from coffee production. The national coffee research program developed different coffee quality maintenance technologies to advise coffee producers. Among quality maintaining recommendations given were, coffee fermented under shade takes more time, yet, using shaded fermentation tanks help to achieve a uniform fermentation process and better quality coffee (Behailu and Solomon, 2006). Parchment coffee drying also studied and recommended drying depths of 3 to 4 cm by covering during very strong sunshine hours gave better values of cup quality (Solomon and Behailu, 2006). Describing of the quality status of released coffee varieties were also conducted to provide information for growers (Behailu *et al*., 2008). Improved coffee seed production also remains the responsibility of the research centers. Due to the perennial nature of the crop no commercial seed producer engaged, yet the research centers shouldered the responsibility to disseminate.

Despite these all production technologies developed; there is still a wide gap among the productivity achieved at research the center and national average productivity. The national average productivity per ha is 647 kg per ha (CSA 2018/19) while that of the research ranges 1500-2600 kg per ha. It is believed that productivity can be doubled by using the technology at hand.

The current coffee demand scenario shows, more of the world population turns to coffee consumption particularly Latin America and the populous nations like India and China. Demand for the beverage is estimated to increase by nearly 25% over the coming five years (Sabrina, 2015). On the other hand, global coffee production and supply are very unlikely to increase since the world's largest producer, Brazil, is frequently facing recurrent drought, frost, and other climatic problems. Other coffee growing Latin American countries are not also expected to produce much because of the devastating coffee leaf rust disease which remains to be a persistent problem in this part of the world. Asian Countries like Vietnam, India, and Indonesia are not also expected to produce enough that can stabilize the market because of various internal factors such as land shortage, input supply, and high production cost, etc (ICO, 2013).

In order to fill the expected gap between production and consumption and stabilize the international coffee market, the world is eying at Africa to see other many countries to emerge. The continent also owes wide ranges of agro-ecologies and incredible landmass suitable for coffee production in all the 25 coffee growing countries of Africa. However, except Ethiopia, Uganda, and Cote d'Ivoire, all the rest countries are producing very small amounts and are not still ready to transform their coffee sub-sector. Currently, Ethiopia is the leading coffee producer in African and the world's fifth-largest producer. And it is likely to say Ethiopia can take this opportunity as coffee is highly related to the economy and social integration of the people.

So, the major interest of this review paper is to highlight the research outputs of existing national coffee research. Concurrently, support the reader to ultimately understand multi disciplinary research activity towards the technology development to the users working on coffee. On top of this readers can get a clue on how the coffee research in Ethiopia supports the development and indicate a lack of correspondence among them. It also shows the productivity gap between research results and farmers/growers. Finally, it will try to show how concerted efforts should be made to narrow down the productivity gap by forwarding possible recommendations.

2 Coffee Variety Development

The major thrusts of this research discipline are (a) collection and selection of Arabica coffee germplasm in Ethiopia; (b) selection scheme for specific purposes (CBD resistance); and (c) hybridization scheme. At present, a total of 6721 indigenous and exotic coffee accessions are collected and conserved at field gene bank (Table 1). A large number of these accessions were evaluated for yield, disease and insect pest resistance/tolerance, overall quality, and other traits of breeding interest while the remaining are currently under evaluation. Accordingly, a large number of promising accessions were selected and utilized in the breeding program for variety development (Tadesse, 2017; Fikadu *et al*., 2008).

Table 1 Summary of Arabica coffee germplasm collections maintained at field gene bank of JARC.

Batch of collection	Year of collection	Number of accessions
French mission collections and SN series	1966	73
CBD resistant selections	1973-1975	696
CBD resistant selections	1981-1987	568
National coffee collections	1970-1990	554
National coffee collections	2004-2009	941
Sub-total		2832
International coffee collection	1968-1984	190
Local landrace coffee collections	1994-2013	3699
Total coffee genetic resource		6721

source: Tadesse, (2017).

Accordingly from the existing vast coffee accessions the national coffee research program released 42 Arabica coffee varieties out of which seven are F1 hybrids that are currently under production at diverse agro-ecologies of the country (MOALR, 2017; Ashenafi, *et al*., 2017; Tadesse, 2017; Bayetta and Labouse, 2006; Fekadu *et al*., 2008). The release of these varieties has contributed to increasing production and productivity of coffee at the national level as well as in the reduction of production costs such as expenditure for chemical purchase for controlling major fungal diseases commonly attacking the crop. And the release of these coffee varieties gave chance to have an adaptable variety to many of the coffee growing agro-ecologies of the country. The summary of coffee varieties released depicted in Table 2 and 3.

Table 2 Summary of pure-line coffee varieties released from coffee breeding program in Ethiopia.

Year of release	Number of varieties	Clean coffee yield (kg/ha)	textArea of recommendation Altitude range (masl.)*
1978-1981	13	1220-1970	Low to high
1997	3	1660-1940	Low to medium
2002	2	2140-2540	Low to medium
2006	5	1540-2350	Medium to high
2010	11	1190-2120	Medium to high
2018	1	1980	Medium
Total	35	11.9-25.4	Low to high

Key*: Low=(1000- 1550), Medium=(1550-1750), High=(1750-2100). Source: Extracted from variety release data of coffee breeding at JARC.

Table 3 Summary of hybrid coffee varieties released from coffee breeding program in Ethiopia.

No.	Variety name	Year of release	Yield(kg/ha)	Production area (Altitude range)
1	Ababuna	1997	2380	1500-1750
2	Melko CH2	1997	2400	1500-1750
3	Gawe	2002	2610	1500-1750
4	EIAR50-CH	2016	2650	1000-1750
5	Melko-Ibsitu	2016	2490	1000-1750
6	Tepi-CH5	2016	2340	1000-1750
7	Gera 1	2018	2346	1800-2100

Source: Extracted from variety release data of coffee breeding at JARC.

On the other hand, the released varieties lack stable performance across wide environments (Yonas, *et al*., 2008). In order to solve such a problem conducting adaptation trials across different research centers and respective stakeholders are underway. Especially, this activity is implemented mainly in accordance with the landrace variety development program (Bayetta, and Jean Pierre, 2006). By now for most of the released varieties, the specific places where suitably grown is already identified. The adaptation work mainly focuses on areas that are not well identified for adaptation of each variety.

3 Disease and Pest Resistance Development and Prevention

Coffee Berry Diseases (*Colletotrichum kahawae*), Coffee leaf rust (*Hemileia vastatrix*), Coffee Wilt Diseases (*Gibberella xylarioides*), bean discoloration (*Pseudomonas syringae*), leaf blight (*Ascochyta tarda*), root-rot (*Armillaria mellea*), browneyespot (*Cercospora coffeicola*), and damping-off diseases of seedlings (*Rhizoctonia* spp., and *Pythium* spp.), Fruit-rot (*Fusarium* spp.), and thread-blight (*Corticium kolleorega*) were recorded associated with coffee in Ethiopia (Eshetu *et al*., 2000).

However, the three major coffee diseases namely are coffee berry diseases (*Colletotrichum kahawae*), coffee wilt disease (*Gibberella xylarioides*) and coffee leaf rust (*Hemileia vastatrix*) in this order. With the review study made by Kifle and Demelash (2015), it is reported that CBD is a major problem still in the coffee production of Ethiopia. Even for the rest of Arabica coffee producing African countries, its harvest loss may reach 60% (Mouen *et al*., 2008). Whereas, in Ethiopia, the overall national average loss due to coffee berry disease is estimated to range 25-30%, (Eshetu, 1997; Eshetu *et al*., 2000). In the recent survey study made by (Kumlachew *et al*., 2016) nearly sixty per cent of the surveyed districts had significantly higher levels of CBD incidence that ranged from 50 to 80%. In this study observed increased severity of CBD as compared to results of previous surveys in major coffee-growing regions of Ethiopia, with respective mean per cent values of 28.8 in Oromia and 36.0% in Southern Nations Nationalities and Peoples Region (SNNPR). The severity result is a bit higher than the previous estimate. Despite its good resistance to improved varieties in the survey study areas, it was observed only 7.2% coffee farm with resistant varieties planted. The majority of the surveyed farmers (nearly 70%) were found to grow a mixture of the local cultivars with the improved coffee varieties as the later ones are mostly preferred for their resistance to CBD and giving more yield. Extensive planting of susceptible local coffee landraces might be the reason for high incidence and severity. Another study showed that recent climatic changes like increased amount and duration of rainfall have reasonably predisposed and favored the coffee berries to infection by CBD pathogen (Kifle and Demelash, 2015). From these observations, it can be concluded that the dissemination of improved and resistant coffee varieties has to get due attention. To overcome this problem CBD resistant coffee varieties are developed for many CBD prone areas. As a result, this enables no fungicide application and greatly contributed to organic coffee production.

It is also tried to develop many coffee disease prevention and control technologies developed for CWD and CLR diseases (Demelash and Kifle, 2015; Girma *et al*., 2009; Kifle *et al*., 2016). Current Crop protection activities are conducted mainly to develop appropriate methods of controlling diseases, insect pests, and weeds with special emphasis on developing integrated disease and pest management practices which is cost-effective and efficient.

In Ethiopia out of 47 insect spp. attacking coffee identified. Out of the identified insect pest species; Antestia bug (*Antestiopsis* spp.) and Coffee blotch leaf miner (Leucoptera spp.) are considered as a major pest (Essayas *et al*., 2008). The control and prevention method also developed by researchers apart from categorizing as major, potential and minor insect pest problems (Essayas *et al*., 2008; Million and Bayissa, 1986). Currently, some of the minor problems are also becoming major. Periodical assessment and surveillance study undergo by the national coffee research team. Some of common insect pest species in Ethiopian coffee production and their problem status are depicted in Table 4.

Table 4 List of insect pest species and their problem status.

Scientific Name	Common Name	Order	Family	Pest Status
Antestiopsis facetoides (Greathead)	Anthestia bug	Hemi.	Pentatomidae	Major
Antestiopsis intricata (Gquiere and caryon)	Anthestia bug	Hemi.	Pentatomidae	Major
Lecoptera coffeina Washboum	Coffee blotch miner	Lep.	Lyonetidae	Major
Ceroplastates bravicauda Hall	White waxy scale	Homo.	Coccidae	Potentially Important
Coccus allipinus De Lotto	Green scale	Homo.	Coccidae	Potentially Important
Diathrothrips coffea Williams	Coffee thrips	Thys.	Thripdae	Potentially Important
Hypothenemus hampei (Ferriere)	Coffee berry borrer	Coleo.	Scolytidae	Potentially Important
Selenothrips rubrocinctus (Giard)	Coffee thrips	Thysano.	Tripidae	Potentially Important
Stictococcus fomicarious (Newselead)	Coffee coushion scale	Homo.	stictoccocidae	Potentially Important
Antestiopsis orbitalis qhesquieri Caryon	Anthestia bug	Hemi.	Pentatomidae	Minor
Leucoplema dohertyl (Warren)	Coffee leaf skeletonizer	Lep.	Epiplemeidae	Minor
Toxoptra aurantil (Boyer de fanscol)	Coffee aphids	Homo.	Aphidedae	Minor

source: Essayas *et al*., 2008; Million and Bayissa, 1986.

On the other hand, weed is a very serious production problem in the coffee production corridors of Ethiopia. Many of coffee production areas being high rainfall areas, weeding is considered as the major production cost. Some of the weed species affecting coffee production in Ethiopia are identified and listed out as noxious and minor (Tadesse and Getachew, 2008; Demelash, 2018).

It strongly affects the coffee production due to competition and may reach 65% loss when severely affected (Tadesse and Getachew, 2008). Integrated weed management (IWM) uses all available knowledge to manage weeds and prevent them from causing economic loss without adversely affecting the environment (Opile, 1995). Cover cropping, mulching, slashing and digging, shading, land preparation methods and herbicides can be logically integrated depending on the environmental situation where the coffee is growing to obtain maximum benefits from IWM program. In this regard, the national coffee research developed prevention and control of weeds known as integrated weed management practice which is eco-friendly and cost-effective (Tadesse and Getachew, 2008; Tadesse, 1998; Demelash, 2018;). The relative merits of different weed control methods as evaluated in different measures presented in Table 5.

Table 5 Relative merits of the different weed control methods.

Measures	Different weed control Methods				
	Slashing and digging	Mulching	Cover cropping	Herbicide	Integrated control
Cost	+	+++	++++	++	++++
Time	+	++	+++	++++	++++
Yield benefit	+	++	+++	+++	++++
Crop safety	+	+++	+++	+++	++++
Soil moisture	+	+++	+++	+	++++
Soil erosion	+	++++	++++	+	++++
Soil nutrient benefit	++	++++	++++	+	++++
Weed flora change to undesirable types	+	++	+++	+	++++
Overall sustainability	+	+	++	+	++++

Key: +=*Low merit* ++=*Fair merit* +++= *Medium merit* ++++= *High merit. Source: Demelash, 2018.*

4 Agronomic Technologies Development

Agronomy and physiology discipline research focused to solve the bottleneck agronomic constraints and challenges in the areas of nursery and field management and processing (pre- and post-harvest) technologies or practices that would increase production, productivity and quality of coffee products and thereby contribute to increased income of the growers. Developed variety can give enough production if and only if it is managed well. Contextually, it can be said the poor agronomic practice can be a killer or best practice is an enhancer of productivity of a given germplasm. The national coffee research system developed different agronomic practices that start from nursery to cycle changing.

4.1 Nursery Management

Pre-sowing seed management is one of the critical technical issues in nursery management. Stages of the harvest of the cherries, the condition of processing and drying affect the germination of coffee seeds. In studies conducted by the national coffee research, results revealed that seeds sown immediately after harvesting and processing were found to be the best option for higher germination rate and better seedling growth (Anteneh, 2015). With prolonged storage the seed viability decreases (Figure 1).

Figure 1. Effect of time of storage on germination of coffee seed. Source: Tesfaye *et al*. (1998)

The development partners usually use the pre-germination of coffee seeds. This practice is implemented to get enough time for nursery preparation. Yet, it is at the expense of coffee seed viability reduction. On the other hand, pre-germination is the primary cause of multiple and crooked tap roots and eventual tree death in the field (Bayetta and Mesfin, 2005; Anteneh, 2015). Hence, coffee seeds should be seeded directly in seedbeds or polythene tubes for the production of seedlings with a normal root system than following the pre-germination techniques.

Thus, to overcome this practical problem and support smallholder farmers' research work conducted to use different seed storage conditions and material (locally available) rather than using pre-germination. Among locally available storage materials earthen pot stored seed & seeds stored under grass hut storage condition showed better germination (Table 6). While sowing, if seed viability is doubtful, two seeds per hole should be seeded and then thinned to one plant. Furthermore, coffee seeds should be sown after removing the hard seed cover (parchment) and soaking the seeds in cold water for 24 hours as the practices enhance germination and seedling growth (Anteneh, 2015).

Table 6 Percentage coffee seed Germination under Different storage condition and Storage materials.

Storage condition	Storage Material	Germination%	Rank
Seeds stored under concrete building on the wooden table	Earthen pot	63.94	1
	Tin	53.58	4
	Glass jar	31.89	6
	Paper bag	63.57	2
	Polythene bag	52.29	5
	Sacks	62.2	3
	Mean	54.59	
Seeds stored on the ground under grass hut	Earthen pot	62.77	2
	Tin	65.82	1
	Glass jar	45.23	6
	Paper bag	53.68	5
	Polythene bag	55.27	4
	Sacks	85.5	3
	Mean	56.96	
Seeds buried in the ground under grass hut	Earthen pot	59.8	1
	Tin	38.26	2
	Glass jar	29.53	4
	Paper bag	36.88	3
	Mean	41.12	
Mean of storage materials	Earthen pot	62.17	1
	Tin	52.55	4
	Glass jar	35.54	6
	Paper bag	51.37	5
	Polythene bag	53.77	3
	Sacks	59.59	2
	Grand Mean	52.4	

Source: IAR progress report of the coffee department, 1988.

With regard to nursery soil, coffee seedlings can be grown on raised beds (15 cm height) or in polythene tube (10 - 12 cm diameter and 22-25 cm height) filled with forest soil collected from the top 5 - 10 cm depth. However, in the absence of forest soil (FS), it was recommended to use blends of topsoil (TS) and compost (C) only or TS, C and sand (S) following the order of 3TS:1C:0S > 2TS:1C:1S > 2TS:1C:0S > 6TS:3C:2S. Likewise, Taye (1998) and Taye *et al.* (1999) revealed that a mixture of locally available organic manure and TS in 1:4, 2:4 and 3:4 ratios had promoted both shoot and root growth of coffee seedlings. However, if this media blend is suspected to be low in plant nutrients, the addition of 2 g DAP/seedling after the seedling attain two pairs of true leaves would improved seedling growth (Taye *et al.*, 1999). For maximum germination, sowing coffee seeds at a depth of 1 cm with the grooved side placed down and embryo tip-up had improved germination (Yacob, 1986).

After sowing the seed, mulching and watering are the subsequent activities. It was observed that coffee seed beds covered with 3 - 5 cm thick mulch need to be watered at 2 days interval until seedling emergence during the dry season. After emergence by removing mulch and providing moderate overhead shade, watering seedbeds twice a week until seedlings attain 2 to 4 pairs of true leaves and then after, at a week interval produced vigorous seedlings for field planting (Tesfaye *et al.*, 2005; Anteneh and Taye, 2015).

Methods of transplanting had substantial influences on the percent survival rate of coffee seedlings. Polythene pot raised (ball root transplanted) coffee seedlings showed 92.92% field survival as compared to those raised on seedbed (bare root transplanted) seedlings with a mean value of 62.44% (Figure 2). Thus researcher advises growers to use polythene raised seedlings.

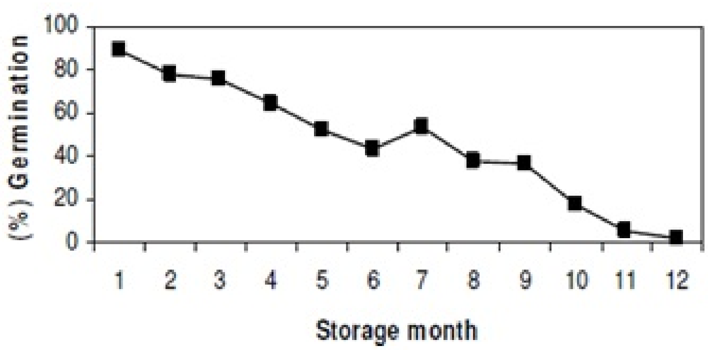

Fig. 1 The effects of transplanting method. Source: Taye *et al.* (2001); Anteneh, *et al.* (2015)

The survival rate of coffee seedlings also increased with increasing hole size; though, the response varies among ecological conditions (Figure 3a). Moreover, appropriate time of transplanting is also important to ensure better survival of coffee seedlings; although proper planting time has to be best predicted and modeled using several years' weather data (Anteneh *et al.*, 2015). May/June and July/August transplanting resulted in better field survival rates of coffee seedlings in most of the study sites (Figure 3b). This is mainly related to the onset of rain.

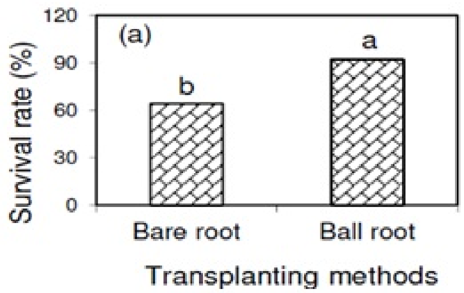

Fig. 2 The effects of transplanting method. Source: Taye *et al.* (2001); Anteneh, *et al.* (2015).

4.2 Field Management

In the center of origin, Ethiopia, Arabica coffee has been found growing naturally under the canopy strata of various shade tree species and, thus, it flourishes best when grown under shade than open sun condition (Yacob *et al.*, 1996). In addition to their apparent roles in soil fertility enhancement, moisture conservation, weed suppression and modulation of light, leguminous shade trees have tremendous use in promoting organic coffee production in the country (Yacob *et al.*, 1996; Taye and Tesfaye, 2001). Accordingly, *Millettia ferruginea*, *Acacia abyssinica*, *Albizia* sp., *Erythrinia abyssinica*, *Calpurinea subdecondra* and *Cordia african* were found to be suitable shade tree species for coffee production (Table 7) as most of them have wider canopies and feathery leaves to provide coffee plant beneath with moderate light regime and replenish organic matter through decomposition litter fall.

Table 7 The influenced by planting patterns on coffee yield and some desirable traits of the prominent shade tree species.

Strip planting		Intercropping		Characteristics of shade trees		
Shade tree species	Yield (kg ha_{-1})	Shade tree species	Yield (kg ha_{-1})	% light interception	Litter fall (kg $ha_{-1}yr_{-1}$)	Canopy diameter (m x m)
Milletia + Albizia	2158^{a}	*Milletia ferruginea*	1809^{a}	40	4271.34	8 x 8
Leucaena + Acacia	1896^{b}	*Albizia* spp.	1521^{bc}	26	1240.00	18 x 18
Milletia + Gravillea	1343^{d}	*Acacia abyssinica*	1534^{bc}	30	2167.00	20 x 20
Calpurnea + Acacia	1693^{c}	*Erythrina abyssinica*	1485^{c}	19	1022.33	16 x 16
Albizia + Acacia	1255^{de}	*Calpurnea subdecondra*	1467^{c}	-	452.33	6 x 6
Tephrosia + Erythrina	1136^{def}	*Cordia africana*	1204^{d}	36	4511.67	16 x 16

Means with in a column followed by the same superscript letter(s) is not significant at 0.05 probability levels.
Source: Yacob *et al.* (1996), Tesfaye *et al.* (1998) and Endale *et al.* (2008).

Canopy volume, which is dictated by the number of bearing heads, branch angle, and plant height, determines spatial arrangement and optimum spacing in coffee (Yacob *et al.*, 1996). It is a strong genetic trait that can be used to group coffee into three broad canopy classes identified as open, intermediate, and compact types, each of which requires its own spacing (Yacob *et al.*, 1996). In support of this (Tesfaye *et al.*, 1998) suggest, taking into account the morphological nature of coffee trees and pruning systems to be used, optimum spacing, and the corresponding population density has been recommended for each canopy classes. For modern coffee plantation the density/spacing recommendation for single and multiple stem pruning (Table 8).

Table 8 Density/spacing Recommendation for Single and Multiple Stem Pruning.

Canopy class	Spacing (m)	Trees/ha
Single stem		
Open	1.8-2.20	3068-2066
Intermediate	1.70-2.00	3460-2500
Compact	1.60-1.80	3906-3086
Multiple stem		
Open	2.00-2.50	2500-1600
Intermediate	1.80-2.20	3086-2066
Compact	1.60-2.15	3906-2163

Source: IAR/JARC. 1996.

Field trial results showed that coffee yield linearly increased with increasing population density or close spacing under open sun conditions probably because of mutual shading. However, the efficiency of close spacing varied among agro-ecologies (Figure 4b). For instance, in low altitude areas like Tepi, the efficiency of close spacing declined after four crop harvests (Figure 4a). An increase in the proportion of dead primary branches and a decline in crop bearing surface, which is directly associated with the increased level of mutual shading or reduction in light interception by the individual tree, could be accounted for the early exhaustion and decline in coffee yield at Tepi. On the other hand, significantly high yield gain (Figure 4b) and long-lasting efficiency of close spacing were evidenced at Gera and Wenago (both high altitude areas) (Figure 4a). Furthermore, results obtained at Metu (mid-altitude area) had revealed the increased efficiency of close spacing in enhancing the yield performance of compact Arabica coffee (Endale *et al*., 2008).

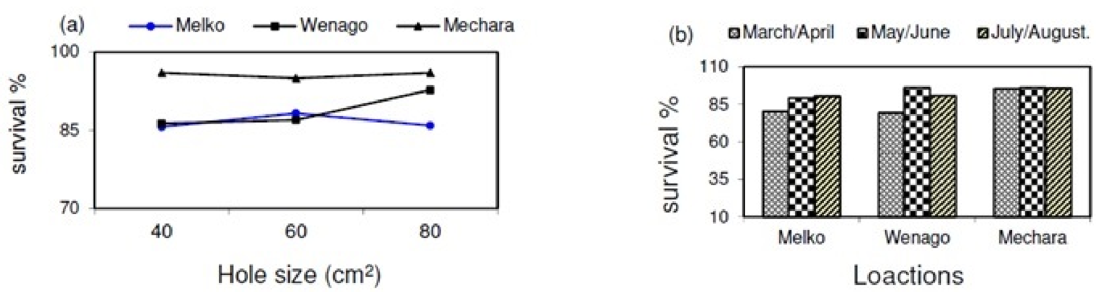

Fig. 3 The influence of crop season (a) and population density (b) on mean clean coffee yield at Tepi, Gera and Wenago.Source: Taye *et al*., (2001) and Endale *et al*., (2008).

After coffee trees being exhausted due to various environmental factors or aging, it needs to be rejuvenated. Although the conventional practice in Ethiopia is stumping, old and exhausted coffee trees can also be renovated during cycle conversion and become productive by different rejuvenation practices, *viz*. agobiado, topping, decote and eskeltamento (Yilma, 1986). It has been reported that stumping coffee trees in a slant position (45^o angel) at 30 - 45 cm height above the ground renovate old coffee orchards and make it productive (Paulos, 1997).

5 Soil Nutrition Technologies

In Ethiopia, Arabica coffee is predominantly grown on highly weathered and leached *Nitosols* which is deficient in nitrogen and phosphorus. Coffee is a heavy nutrient feeder. It has been documented that more nutrients are removed annually by the harvested products in comparison to other tree crops like Cocoa and Tea (Coste, 1992). However, the nutrient requirements by the crop may vary among the coffee varieties, age of the tree, crop load, type of production (forest, garden, plantation, and open and low shade), soil fertility status, soil reaction, and plant population.

The use of decomposed coffee husk compost at a rate of 10 ton ha^{-1} (4 kg $tree^{-1}$ on a dry weight basis) with 50% soil incorporation and the remaining half surface application was found to be superior in terms of yield performance of coffee trees. Hence, it can be concluded that depending on the availability of organic inputs and plant ecological factors, the use of organic inputs at the rate of 5 to 10 t ha^{-1} (2 to 4 kg $tree^{-1}$) is advisable for Arabica coffee production (Taye, 1998; Taye and Tesfaye, 2001). In other studies carried out at Jimma and its sub-center that represent the major coffee growing agro-ecologies of the country Paulos (1994) come out with a set of recommendations (Table 9) that are of immense value to the grower. Accordingly, forest coffee, low yielding, and young trees (less than three years) and rich soil (fertile soil) should be applied low amount than the recommended full dose. On the other hand, open and low shaded coffee plantations, high yielding varieties, and mature trees on poor soils should be given the full dose of the recommended fertilizers (IAR, 1996).

Table 9 Location specific NPK fertilizer recommendation for coffee.

Location	Recommendation domain	Recommendation rate (kg $ha^{-}1$)		
		N	P	K
Melko	Jimma,Maa, Seka, Gomma and Kossa	150-172	63	0
Gera	Gera	No fertilizer	No fertilizer	No fertilizer
Metu	Metu, Hurumu, Yayou and Chora	172	77	0
Tepi	Tepi	172	77	0
Bebeka	Bebeka	172	77	0
Wonago	Wonago, Dale, Aleta Wondo and Fiseha Genet	170-200	33-77	0
Bedessa	Habro, Kui and Darelebu	150-235	33-77	62

Source: IAR (1996).

6 Soil and Water Conservation Technologies

Coffee husk, grasses as mulch material, and cover crops such as desmodium are found to be important in minimizing soil and moisture loss, suppression of weed seed germination, and smothering of its growth in plantation coffee (Anteneh *et al.*, 2015). Soil and moisture conservation techniques such as ridging (tied and untied ridges) enhanced yields of CBD resistant coffee cultivars in coffee plantation over the control plot, and flat land (Figure 5).

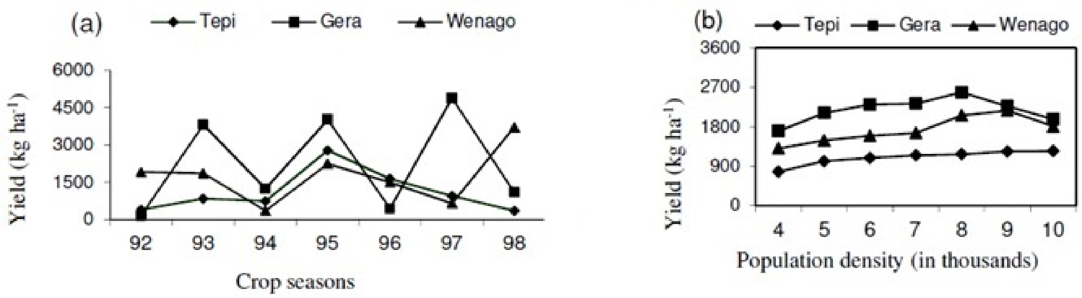

Fig. 4 The influence of soil and moisture conservation techniques on yield of modern Arabica coffee cultivars.
Source: Tesfaye *et al*. (1998); Endale *et al*. (2008).

7 Coffee Quality Management Technologies

Quality is critically important to the coffee industry. Coffee that has good inherent quality may be rejected unless good processing practices are strictly followed. Developing and promoting improved pre- and post-harvest processing technologies that enhance the quality and productivity of coffee for different agro-ecologies throughout the country are key study areas of quality section.

Coffee plays a dominant role in the Ethiopian national economy (Davis *et al*., 2012) but, it is generally characterized by low productivity and low quality (Alemayehu *et al*., 2008). Strengthening the position and price of Ethiopian coffee on the world market requires a systematic analysis of the impacts of practices and procedures on coffee quality throughout the value chain, from farm to the point of delivery of green beans to the exporters.

The quality of coffee consists of (i) physical attributes: length, size or weight of coffee beans (ii) organoleptic characteristics: acidity, aroma, body, aftertaste, flavor, overall preference and balance and (iii) chemical constituents such as caffeine, trigonelline, chlorogenic acid (Agwanda *et al*., 2003; Behailu *et al*., 2008). The national coffee research tried to develop different coffee quality maintenance and quality enhancer technologies.

It was confirmed that there is a long fermentation time difference for washed coffee processing. Optimum quality was achieved at 64 hours at Melko, 78 hours at Limu Kosa and total fermentation time of about 48 hours at Bebeka. Based on the altitude, fermentation time in the range of 24 hours for $\leq$1200 masl; 24 to 48 hours for 1200-1500 masl; 48 to 72 hours for 1500-1800 masl and above 72 hours for above 1800 masl were preferable to have coffee with superior cup quality in all aspects (Woelore, 1993; Behailu *et al*., 2008).

In the washed coffee production, final quality, among other factors is greatly dependent upon the fermentation process (Woelore, 1993). It has been confirmed that under-water soaking following “dry” fermentation, i.e., two-stage fermentation enhances the appearance of both raw and, particularly and consistently, the roast of coffees compared to ‘dry’ fermentation only (IAR, 1969). On the other study, it was confirmed that, although coffee fermented under shade takes more time, using shaded fermentation tanks help to achieve uniform fermentation process and better quality coffee (Behailu and Solomon, 2006). With regard to washed coffee drying, parchment coffee drying depths 3 to 4 cm and covering during very strong sunshine hours gave better values of cup quality and recommended (Solomon and Behailu, 2006). In addition quality status of released coffee varieties were described (Behailu *et al*., 2008). This result enables to know the quality status of each variety released.

8 Environmental Protection

Growing coffee is protecting the environment. While we grow coffee we maintain the shade trees and if we maintain the tree by implication we conserve the soil and water. On the other hand, the byproduct of coffee processing subjects the environment for pollution if proper management is not implemented. There are research results that enable us to offer proper advice for producers. One of the issues of pollution is coffee washing station effluent management. Failure of monitoring and evaluation activities of the existing processing stations has resulted in the generation of huge amounts of processing byproducts that have the potential of polluting the environment. In general, water pollution is a pressing problem in developing countries, particularly, where there is high population growth, great development demands, high waste production without well-developed waste treatment technologies, and a lack of comprehensive environmental policies and water quality monitoring systems and standards (Yared, 2008). In his study, the negative impacts in terms of river pollution, health risks both to humans and livestock and other effects were well understood.

For effluent treatment, many technologies were adopted and vetiver is the one. It is reported that using vitiver grass for successfully treating the effluent. In Ethiopia, different coffee farms are thriving to adopt the technology for treating the effluent discharged from coffee pulpery (Ashenafi, 2015).

The significance of shade tree and vetivar plant in Ethiopian coffee-growing agriculture can benefit not only for conservation purposes and have multiple use apart from environmental protection. So, farmers and growers have a chance to use the research recommendations.

9 Seed Provision, Hybrid coffee Multiplication through cuttings and Biotechnology

Even though there is no formal coffee seed system in Ethiopia, the coffee research centers shouldered responsibility for the production and supply of improved coffee seeds from the released and adaptable coffee verities. According to informal information, the contributions of farmers' coffee seed system in the major coffee-growing areas of the Oromia and SNNP regional states is immense, though comprehensive results are inadequate and await investigations (Taye *et al.*, 2011). This includes the production of uncertified coffee seeds from the released and adaptable coffee varieties by small-scale farmers, private investors and privatized state coffee farms, which produce and use for themselves, on top of transferring to other users in their vicinities.

Though the data need updating, demand shares in most years is more than 80%, indicating the untapped opportunities for the interested private and public institutions to involve in the coffee seed business. As described by Negusie *et al.*, (2008) the research centers cannot meet the rapidly growing demand for improved coffee varieties in the country. Yet with the existing capacity research centers are providing seeds of improved varieties which give chance to growers. In this regard, the national coffee research centers produced about 270,000 Kg of seed which is expected to cover about 270,000 ha of land (Ashenafi *et al.*, 2017) up to 2017. Up until now reach 300,000 kg and cover equivalent amount hectare.

With the attempt of exploiting heterosis from hybrid coffee; Ethiopian coffee breeders developed seven hybrid varieties (Table 3). The hybrid varieties developed can be propagated sexually (direct hand pollination and crossing of the two parents to get F1 seed) or by asexually taking orthotropic stem cuttings. Seed propagation, which is associated with hand pollination to get F_1 seed, requires a large number of skilled labors. Consequently, using F_2 leads to a lack of uniformity as a result of segregation. Propagation of coffee by vegetative cuttings guarantees uniformity.

Research results showed that a combination of a single node with softwood cuttings with one pair of leaves taken from the orthotropic shoot and rooting media composed of topsoil, sand, and manure in 2:2:1 ratio were recommended for propagation of hybrid coffee. It was observed that this practice resulted in the highest rooting ability of stem cuttings (89.2%) and survival rate (63.3%) at hardening off stage (Behailu *et al*., 2006). With this procedure, the researchers are disseminating hybrid coffee varieties and offering training for subject matter specialists and farmers.

Cuttings generate relatively low multiplication rates as they can only be obtained from orthotropic branches. Plant tissue culture is a form of vegetative propagation used for the large-scale production of plants known as micro propagation (Ahloowalia *et al*., 2004). Multiplication by tissue culture techniques could provide the best alternative than the former two methods of coffee propagation especially in terms of getting high number of planting materials of hybrid coffee. Biotechnologists over the world and in our country made much effort (Wondyifraw *et al*., 2008; Elias, 2017) and started to propagate hybrid coffee in different approaches. Apart from optimizing the tissue culture protocol coffee research biotechnology lab is propagating and disseminating just to familiarize growers with seedlings prepared through tissue culture.

10 Economics of Coffee Production and Technology Popularization

Existing national coffee research has generated a number of technologies that were disseminated to the users. These coffee technologies include varieties, agronomic, protection, harvesting, and post-harvesting management. In this regard, there are questions like how strategic is the system in exploiting the potential gains from the utilization of the available technology, knowledge and information, in general, and queries on the content of the production technology package, the scale of extending/promoting the technologies and the linkages among different institutions, in particular (Admasu and Zekarias, 2008).

In coffee, parallel to generating various technology transfer mechanisms were employed to promote the wide use of improved technologies across the country rapidly. Various attempts to introduce and accelerate the dissemination of improved coffee technologies were made. These include pre-scaling of improved technologies, supplying production sources-improved seeds and seedlings, training and advisory services, field-days, farmers' research group, partners' council forums, publication distribution services, communication media-on-air, etc. There is a great need of capacitating small-scale farmers, cooperatives and unions, private investors and others involved in the value-chains through training services and knowledge sharing events (Negusie *et al*., 2008).

Lack of strong extension service on coffee and the absence of commercial coffee seed multiplying agency necessitated the research centers' involvement in the production and distribution of seeds of improved varieties and other related technologies. A variety of approaches and mechanisms were employed by the Research-Extension department to trigger of dissemination and diffusion of improved coffee technologies. These include among others: on-farm and on-station demonstrations, hands-on training, workshops and conferences, field/open days and visits, written extension materials, exhibitions and displays, video, seed and seedling dissemination (Negusie *et al*., 2008). As coffee-growing farmers are numerous and vast production area coverage is in place there is a high need to strengthen the extension system and consolidate the relationship of research and extension so that existing technology can be disseminated. Based on coffee technology adoption studies, there exist gaps between the available levels of knowledge, information and technology, and the existing system of coffee production (Admasu and Zekarias, 2008).

11 Gap Analysis

In Ethiopia, more than 90% of the total volume of coffee production comes from small-scale farms, whose average land size is less than one hectare with low average yields ranging from 200-250 kg /ha (Workafes and Kassu 2000). Small-scale growers have not fairly benefited and remain more vulnerable to risks related to volatile coffee prices and climate change. To support these resource-poor farmers and growers the existing research system developed many technologies per-se varieties, agronomic practices, crop protection, nutrition, harvesting and the like. Despite these all production technologies developed; there is still a wide gap among the productivity achieved at the research center and national average productivity. The national average productivity per ha is quite less than the research results (Figure 6). The country has not fully exploited existing research technologies and its vast natural endowment of genetic and unique natural coffee forest environments due to several factors, including insufficient access to finance and poor input distribution mechanisms for small-scale coffee farmers, the predominant use of local landrace coffee types, traditional management, harvesting and post-processing practices as well as lack of quality differentiated marketing system and in general lacking strong institution which leads the sub-sector development.

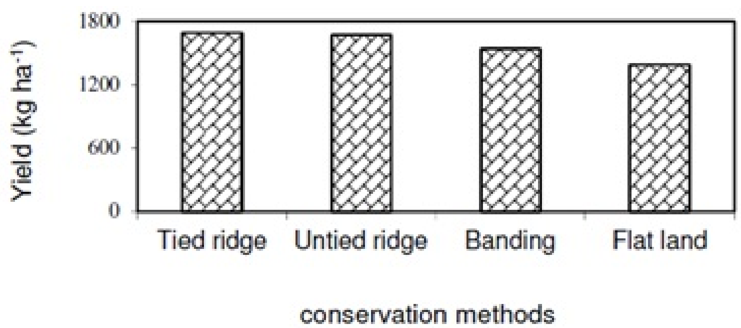

Fig. 5 The productivity gaps between Research and Different Farming Systems of Ethiopia.
Source: Taye Kufa. 2018.

The Ethiopian government is successively targeting to increase the productivity of coffee per unit area. Aligning with the national coffee sector development plan the national coffee research strategy is also designed to enhance coffee production and productivity by generating appropriate coffee technologies and disseminating existing once with its full packages. The national average productivity is nearly 30% of the research results. The big gap in productivity range requires a wide utilization of research output by the development wing. This could be possible if concerted effort make in place. From existing information, it can be estimated that by narrowing the gap between research achievements and the national average much increment on national average production can be made.

12 Conclusion

Ethiopia has a goal to become the second leading arabica coffee producer and exporter in the world. To this end, the national coffee strategy plan has been developed with ambitious targets for coffee production and export earnings. First, it needs to see that; is it really possible that the country has a competitive advantage than other producing counties over the world? As more of the world population turns to coffee consumption demand for the beverage is estimated to increase. On the other hand, global coffee production and supply are very unlikely to increase since the world's largest producer countries are frequently facing different challenges and some of them are also shifting due to various internal factors such as land shortage, input supply, and high production cost, etc. So, they are not expected to produce enough production that can stabilize the market. Ethiopia can take this threat as an opportunity and produce more coffee production and quality. In order to fill the expected gap between production and consumption over the world and stabilize the international coffee market, Ethiopia does have a better chance as the country laid better ground. There is also the greatest opportunity, in many ways, than any other producing countries to exploit the opportunity from this rising world coffee consumption. This is due to the predominant role of coffee (*Coffea arabica* L.) in the Ethiopian economic, social and cultural dimensions dates back to several centuries the large population involvement, favorable environment, different coffee quality types and long experience in the sub-sector are some reasons among others. Cognizant of the deep-rooted attachment of coffee to the Ethiopian community and its multitude of importance to Ethiopia it is possible to make a difference.

In the body of this write-up, a lot has been discussed on existing research technologies. Yet, there is a wide productivity gap among the research, modern plantation farmers practice. Coffee technologies developed by the research different disciplines is much encouraging. Even though developed technologies made considerable contributions to coffee production, productivity, and quality improvement in Ethiopia a lot is still remaining to address a number of challenges facing the Ethiopian coffee industry. This big gap in productivity range requires a wide utilization of research output by development is crucial. Actually, this demands: (1) Aggressive scaling-up of proven technologies (2) Managing coffee stands through mobilizing coffee sector rehabilitation and wide utilization of technologies (3) Addressing research in unaddressed areas (4) Establish & support sustainable coffee seed system (5) Establish viable extension system and consolidate the relationship of research and extension so that existing technology can be disseminated.There is also a great need of capacitating small-scale farmers, cooperatives, unions and private investors by access to finance.

This requires strong national coffee institutions and creating synergy among existing institutions viz research, higher learning institutions, extension, and other key actors in the coffee value-chains. As marketing is the driver for production, it has to be more modernized and farmers are able to get better prices in continuously searching better market. This may demand supporting farmers' organizations, cooperatives, and unions to sustain their power in creating ideal environments and supporting capacity development. If this happens; possible to double the current production and productivity through wise utilization of existing technologies.

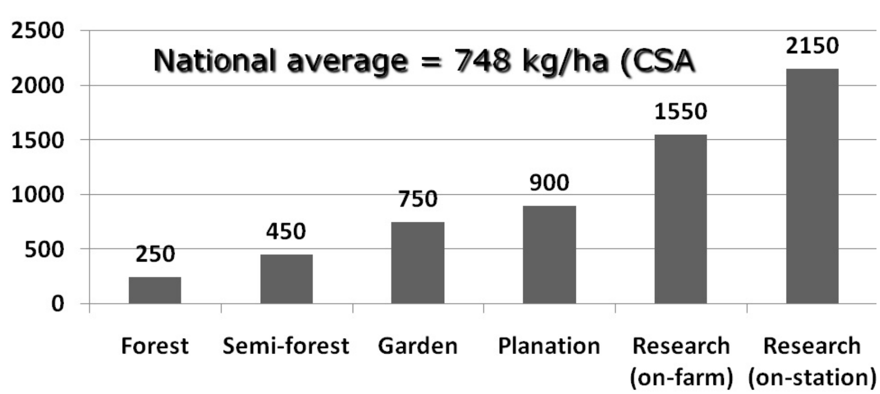

Fig. 6 Flow chart of crude extraction of the leaves of *C. macrostachyus*.

Conflict of interest

The author declare that no conflict of interest.

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