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REVIEW ARTICLE

The contribution of climate change on the production and distributions of *Tef* [*Eragrostis tef* (Zucc.) Trotter] associated with its breeding enhancement phases in Ethiopia: Review

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ABSTRACT

Agriculture is the leading sector in Ethiopia and its economy highly depend on it. Hence it accounts about 50% GDP with 85% employment and more than 85% export revenue. *Tef* has the leading share of cereals in production area and vital in nutritional aspect more than 15% of all calories spent via 90 million people and exporting injera for foreign currency returns. Therefore, this review targeted with the objectives of delivering information on the role of *Tef* production in food security with global market value and the impact of climate change and challenge on production and productivity over its breeding enhancement. Currently agriculture highly exposed to climate changes and strongly distresses the productivity altering areas crops grown. Climate change supposed via alterations in variability of properties in temperature, rainfall, increased atmospheric CO_2 levels and relative humidity. It is evidently known and highly vulnerable caused food insecurity. For instance, 20% of Ethiopian economy production deficit and 25% of poverty level is caused by rain fall variability. *Tef* is seasonal crop on rainfall all over Ethiopia, so its production distributions and productivity still very limited only at Amhara, Oromia, SNNP, Tigray and Benishangul Gumuz Regions while Afar, Somali, Harare and Gambela regions are not still included in its production profiles. There is also research gap with the relation and consequence of climate change. Hence filling the gaps will be critical in the future for improving the production efficiency via characterizing agro-ecologies and designing breeding strategies for stress environment variety development.

Keywords: Climate, Distribution, Impacts, Production, *Tef*

INTRODUCTION

Ethiopia is one of the second most populous countries in Africa which rely mainly on agriculture and agriculture is the pillar for its economy has a significant role managing their life and serving as a source of lively hood income (Di Falco et al*.,* 2012). Hence it is the leading sector for Ethiopian economy, accounts more than 50% of GDP with 85% of the total employment and more than 85% of the export revenue (Yumbya et al., 2014). Livestock and crop productions are the two pillar components in Ethiopian agriculture. Even though the comparative involvement of livestock and crops vary from time-to-time MOFED estimates sited livestock's involvement at about 25% of total agricultural GDP while crop production mainly cereals are the major food crops both in terms of the area coverage and volume of production accounted more than 95% of agricultural production and 88% of the grain production in Ethiopia (CSA, 2019). While economic involvement of *Tef* has shown that the actual output on average accounted 6.1% of the actual GDP, whereas growth in actual *Tef* output accounted 6.4% of the total growth in real GDP which means.0.67% of the 10.7 % growth in actual GDP (Fantu et al., 2015).

Tef is a C_4 self-pollinated, chasmogamous annual only a very few 0.2 to 1.0% possibility of out-crossing and an intact cereal crop internationally comparing with other cereal crops such as maize; wheat; sorghum and barley (Harriman, 1998). It accounts for the leading share of cereals in the production area coverage and the most essential remarkable crops for Ethiopians' commonly grown staple food and the highest economical cash crop through exported by means of prepared injera for foreign currency returns (Kebede et al., 2018). However, its low yields, *Tef* has little prospective both to address the country's food security problems and for commonly grown exchange. So, the crop has the confines in the complete utilization of the prevailing prospective of the crop (Abraham, 2015).

Currently agriculture becomes highly vulnerable to climate change and strongly distresses the sector varying the productivity and altering areas where crops can be grown. Several research findings also confirmed that this is because of various biotic and abiotic constraints mainly climate change and its seasonal dependence on rain fed agriculture, poor economic growth, inadequate misadventure management abilities, and weak official skill become serious challenge for agriculture at the movement. The current planning on vulnerability and insufficiency in Africa (Thornton et al., 2006) situates, Ethiopia as one of the most exposed countries to environmental variability and disparity. The key drivers of agricultural replies on environmental variation are biophysical influences and socio-economic aspects (Parry et al*.,* 2004). Climate change is variations in the climate supposed via alterations in variability of confident properties for instance temperature, rainfall, soil temperature, increased atmospheric CO_2 levels and relative humidity that continue ended years (Parry et al., 2004; Sumelius et al. 2009; Di Falco et al. 2012). Rendering to Raisanen and Tuomenvirta (2008) instability in climate ascend as a consequence of natural variability along with human movement. Gebretsadik (2012) and Yumbya et al*.* (2014) also showed that climate change is a real worldwide challenge and its impressions have entirely altered agriculture status of the world and it aches from repeated droughts and persistently food insufficiencies.

Different scientists stated that Ethiopia has the land area coverage about 112.3million hectares of which only 16.4millin hectares of land are suited for crop production (Deressa et al., 2009). This is due to various factors of which climate change is the significant one hindering the land resources in the production entirely. According to Yusuf et al*.* (2008) and Tembo (2018) report, Ethiopia is one of the most vulnerable among African countries by climate change and frequently exposed to poverty due to drought for several years such as in (1965, 1974, 1983, 1984, 1987, 1990, 1991, 1999, 2000, 2002 and 2011 in Ethiopian calendar). Yumbya et al. (2014) also showed that Tigray was highly vulnerable and affected by this factor through the event of droughts in (1990; 1991; 1999; 2000; 2011; 2014). Similarly, the year 1985 was also the worst historic in Ethiopia mainly around Wollo areas and it was called 'kifuken' where most people were suffered, died and displaced from their initial settlement to other areas through hanger as a consequence of drought. Mostly during these periods, the annual rain falls and other climatic features had critical influence on the production and productivity of major crops mainly *Tef* at this province.

The influence of climate change is primarily responsible for the cause of food insecurity mainly in the smallholder farmers in Ethiopia (Gebretsadik, 2012). It is evidently known that climate change highly exposed in the low altitude regions (Reilly et al., 2001). According to the study findings *Tef* (*Eragrostis tef*) is an earliest tropical cereal crop and the northern Ethiopian highlands is its center of origin and diversity where it is conceived to have been cultivated (Harriman, 1998; Fikadu et al., 2019). It is obviously identified that agricultural crop production is mostly seasonal reliant on rain fall mainly *Tef* production is entirely depend on rainfall throughout Ethiopia, as a result of this its production distributions and productivity still now in the country is very limited only Amhara, Oromia, SNNP, Tigray and Benishangul Gumuz Regions are responsible for its production while Afar, Somali, Harare and Gambela regions are not still included in *Tef* production profiles.

Food security guarantee is evaluated in the situation of climate change and ambiguity about coming environmental circumstances (Molla and Fitsume, 2017). While climate change is a long-term incidence and its measure engaged over the coming years will be serious. The basics necessity for reactive, adaptive agricultural advancement and strategies provision people decrease their vulnerability to environmental variation, while at the equivalent time flagging the manner of improving adaptive ability with effective management of ecological variations, characterizing *Tef* agro ecologies and considering climate variability during technology improvement, and designing breeding strategies using revolutionize breeding tools, evolving stress resistant/tolerant *Tef* technologies, then establishing artificial stress environments for evaluating and promoting improved varieties will have a significant role improving its production and productivity there by contributing to enhance the food security and human health in the country and increasing global export to have revenue. Therefore this review targeted with the following objectives (1) to deliver information on the role of *Tef* production for food security and its nutritive value in the country and global market value, 2) to provide insight on the trends and variability of *Tef* production outline over time, 3) to review the impact of climate change and its challenges on *Tef* production and productivity, 4) over view of *Tef* breeding enhancement phases and its contribution from the past to date and its future prospects in the climate change.

ROLE OF *TEF* PRODUCTION FOR FOOD SECURITY AND ITS NUTRITIVE VALUE

Tef is essential for nutritional aspect which accounted more than 15% of all calories spent via about 90million people in Ethiopia and primarily used for injera making and beverage preparation using the local system through fermentation (Fikadu et al., 2019). It has an excellent amino acid composition mainly its lysine content is higher than other cereals except rice and oats (Jansen et al., 1962) and has a significant amount of iron (Fe) content (Mengesha, 1966). The In the earlier studies, Jeffrey (2015); Washington Post (2016) and Abate et al. (2018) reported that *Tef* is also the leading crop in its calcium (Ca) content compared with all other cereal grains. Most cereal crops like wheat, barley and rice grains are rich in gluten which cause celiac disease through abnormal T-cell while this nutrient is free in *Tef* (Spaenij-Dekking et al., 2005). The dietary value of *Tef* in the mill is very vital due to its gluten-free of the nutritional composition which makes it better than other crops to manage human health with blood sugars, lower blood pressure and retains a sentiment well food, little in drenched over weight, flavors numerous and reduces constipation therefore its demand is sharply increasing time to time not only in the country Ethiopia, but also globally. The great demand of *Tef* is not only for its grain source in the diet but also its hay has a significant role for live stocks' feed because of its straw is highly nutritive and extra palatable compared with other cereals straw mainly at the off season which means without main season at the dry period (Araya et al., 2015). Due to the overhead advantages *Tef* is expansively cultivated in Ethiopia through yearly exposure about 2.8 million hectares. In most Ethiopian people, *Tef* injera has the highest social value in the society mainly used as a privilege food for gusts in their home and other social ceremonies. This crop has also distinctive valuable characters in cooperation for the producers and consumers. Intended for *tef* is lenient to extreme environmental conditions such as comparatively resistant/tolerant to several biotic and abiotic factors for instance the grains are not easily affected by storage pests like weevils (FAO, 2015), but now it is extremely affected by climate change.

According to the report indicated by Spaenij-Dekking et al. (2005) and Ayalew et al. (2011), now a day *Tef* has an acceptance globally gratitude via clients for its preeminent nutrient value and health benefits for diabetics as well as victims of immune reactions to wheat gluten and rich in minerals and protein. Cereal crops grown on 81.4% of the total area cultivated and about 88.0% of total agriculture grain production shared CSA (2019). However, *Tef* is untouched multipurpose crop; it is the first accounted about 24.2% share of the total cereal crop's cultivated area while maize is the second following *Tef* by 18.6% area coverage of the production. But, *Tef* is the second associated with the total cereal grain production (17.2%) next to maize with the amount of 30.08% (CSA, 2019).

THE IMPACT OF CLIMATE CHANGE AND ITS CHALLENGE ON THE DISTRIBUTIONS OF *TEF* PRODUCTION AND PRODUCTIVITY IN ETHIOPIA

Climate change is not only a marvel of the coming; but we are at present existing through its challenge. Several instances, such as sea level increase, glacial ice melting, intense storms, floods, droughts, warmness waves, and others, are probable to happen as a consequence of climate variability (Stocker, 2013). Various studies convinced that temperature (T°) will increase and RF rise in some places, whereas in another areas RF will decline (Yumbya et al., 2014), yet, there is overall covenant between researchers that nutritional crops are delicate to the varying environment (Muller, 2013). The scientists also confirmed that the productivity of *Tef* at present highly influenced by climate variability for instance at sowing date and through the cropping season (Araya et al., 2015).

The concept of adaptation and suitable environments for Tef production

The definition of an adaptation is a change or modification to enhance the crop, or to make it suitable for a different situation (Simonet, 2010). It is also defined as minimizing the hazards exhibited by environmental variation to people exists and livelihoods. Adaptation dealings with the influences of climate change and have the impartial of dipping the exposure of human and natural techniques overall. *Tef* is conventionally grown in the highland areas, but it can also grow in an extensive diversity of agro ecologies, including advancements from 0 to 2800m.a.s.l with extensive variability of humidity, temperature, and soil fertility status in Ethiopia. However several findings indicated that the ideal growing environments concur through its conventional cultivation ranges for instance, Harriman, (1998) stated that the preeminent performance of *Tef* ensues between 1800 to 2100m.a.s.l with mean annual RF of 750-850mm and the temperature range of 10-27°C, Hailu and Seyfu (2000) also reported that the optimum altitude range from 1100 to 2950m.a.s.l while Hassen et al. (2018) confirmed that the transitional highland areas with an altitude range between 1800 to 2200m.a.s.l is the most suitable for *Tef* production. Despite the fact that Ethiopia is its center of origin and diversity its production and productivity is challenged across the country and it is not well adapted till date. In our point of view the altitudes above sea level is not the only determinant factor for *Tef* production because we observed that even though the areas have an altitude of optimum level and greater than 1100m.a.s.l, the production and productivity of *Tef* is still challenged and very low.

The CSA (2019) report has shown that *Tef* is not produced in various regions of Ethiopia including Afar, Somali, Gambela, Harare and Dire Dawa while it is produced only in Benishangul-Gumuz, SNNP, Tigray, Oromia and Amhara regions increasing order of its productivity prospective shown in **Table1.** Conferring to this report Amhara region is the first (1.83 t ha^{-1} and 34.2%) in its annual mean productivity and area coverage respectively from the total cereal crops followed by Oromia region (1.82 t ha^{-1} and 29.4%) in its productivity and production area coverage in similar manner whereas in Tigray, Benishangul-Gumuz and SNNP regions; its production efficiency till date is very low. Most scenarios have agreed that altitudinal variations above sea level, annual RF distributions, temperature and soil fertility variants has a significant role for its production and distribution, but there is study gap about the relationship between soil temperature and relative humidity with *Tef* growth phases. In general, now a day climate change becomes a determinant factor for the production efficiency of crops mainly for *tef* in Ethiopia.

Table1. The production and productivity status of *tef* at the regional levels of Ethiopia

No	Region Name	Number of holders (millions)	Area (million) of Hectares	Production in (millions of tons)	Yield (t ha^{-1})	Total cereal area in million (ha) covered by the region	Tef area shear (%) in the region
1.	Tigray	0.51	0.18	0.28	1.60	0.79	22.5
2.	Afar	*	*	*	*	*	*
3.	Amhara	2.70	1.20	2.20	1.83	3.51	34.2
4.	Oromia	2.57	1.43	2.60	1.82	4.86	29.4
5.	Somali	*	*	*	*	*	*

6.	Binishangul-Gumuz	0.05	0.03	0.04	1.45	0.18	16.5
7.	S.N.N. P	0.95	0.24	0.35	1.46	0.92	26.1
8.	Gambala	*	*	*	*	*	*
9.	Harare	*	*	*	*	*	*
10.	Dire Dawa	*	*	*	*	*	*

Source: CSA, the 2018/2019 main production season. The sign''*" indicates, there is no *Tef* production in the region and S.N.N.P = Southern Nations Nationalities and people.

In Benishangul-Gumuz Region to some extent *Tef* is produced at Metekel, Assosa and Kamashi zones and Maokomo Special District (CSA, 2018), however its production and productivity is very low with diverse known and unknown constraints. According to the CSA report, *Tef* is the 6th potential crops next to maize, sorghum, wheat, finger millet and barley in its productivity which accounted 0.3million ha area coverage with 0.43million tons production and 1.4 t ha^{-1}productivity in the region. Assosa Agricultural Research Center (AsARC) is located about 680km far from Addis Ababa in the North West direction in Benishangul Gumuz Regional State. Geographically, it has an altitude range of 1541 to 1553m.a.s.l with mean annual RF about 1166mm and the minimum and maximum temperature range of 14.9-27.97°C and the dominant Nitosol soil type (Yaregal and Firew, 2022). Climate variability had a significant contribution for *Tef* production and productivity from season to season which makes suitable for the incidence of termite, shoot fly, lodging, soil degradation, shattering and fungal diseases (rusts) considered as an important determinant issue in the areas (Addisu, 2018; Dereje et al., 2018).

Pawe Agricultural Research Center is also located in this region at Metekel Zone about 575km far from Addis Ababa an altitude of about 1120m.a.s.l and latitude/longitude):11°19'N and 36°24'E, 1400.4mm - 1587mm annual RF distributions, 33.8°C and 17.4°C maximum and minimum mean T° respectively with major Nitosol and a little Verti and Luvi soil types. In place of several years various *Tef* genotypes were evaluated at the station, however no amongst the genotypes adapted in the area. Still now at pawe and around the District *Tef* is not a cultivable crop. This is due to some identified similar determinant factors confronted at Assosa areas for several seasons first there was seed germination problem even it can be germinated at vegetative stages and panicle initiation stages as indicate in the figure (Fig1). Even some genotypes tried to go under head formation it become dried and injured. The cause of this problem some experts said as head smudge (*Helminthosporium miyakei Nisikado*), yet scientifically there is a gap investigating the literal cause. Such problem happened for various successive years and redeemer.

As mentioned earlier Pawe ARC has a nice topography where most research crop commodities demeanor such as legumes like soybean and ground nut, cereals including rice and maize, oil crops like sesame trials which also has moderate to highest annual RF distribution, maximum and minimum temperature, and high relative humidity (RH) which is suitable for those crops listed in (Table 2 and Table 3) except the existence of excessive RF and savior wind blowing starting from the end of August to October causing lodging problem mainly for maize trials. However, *Tef* is didn't provide satisfactory data at this site. There are scientific gaps to be studied in the future at Pawe District about the questions why the site is not suitable for *Tef* production and expectations being the reason of production limits in the study of futurity (1) about the soil macro and micro nutrient availability and suitability of the crop (2) the association and impacts between relative humidity, soil temperature and high night and day temperature with *Tef* production, (3) the critical sowing date associated with agro-meteorological parameters for its production. This problem aggressively affected the trials and devastated owing to the above prospects (Figure1). From the experiences suggested that the existence of high RF distribution at vegetative and flowering stage is not suitable for *Tef* that rinse the florets which makes infertile and the highest daily T° at flowering stage also motive for the abortion in the reproductive stages. Conversely, this opinion is contradicted with the previous investigation reported by Tadele and Assefa (2012) as *Tef* is the most suited in moisture limited areas. In general, this review indicated that areas which has similar agro-ecologies and difficult for *Tef* production needs further research effort to detect the associated reasons.

Chamberlin and Schmidt (2012) agreed that the optimum development situations for *Tef* is with the mean annual RF of 750 to 1000mm; and an annual T° of 10°C to 27°C. The minimum temperature showed in the table (Table 2) significantly decreasing trend through monthly time scale from May to December during the trial season at the site. The two months from September to the first October were the time of booting and starting seed provision of *Tef* at the site.

Figure 1. The problems encountered the *Tef* trials during the 2019/2020 main season at Pawe Agricultural Research Center on station.

Table 2. The 2019 Main Cropping Season Monthly Meteorological Data

Month	RF (mm)	RH (%)	Tmax (°C)	Tmin (°C)	Soil T°c (10cm)	Soil T°c (20cm)
May	97.3	73.6	35.6	21.5	26.3	26.8
June	310.7	84.0	30.3	18.7	25.6	26.3
July	413.2	86.5	27.8	18.5	23.5	23.0
August	242.1	89.1	27.7	18.4	24.0	23.3
Sep.	342.3	87.8	28.8	18.2	24.5	23.7
Oct.	242.8	88.7	30.1	17.8	25.1	23.9
Nov.	36.8	85.0	30.9	16.8	26.0	27.2
Dec.	3	85	32.7	14.5	-	-

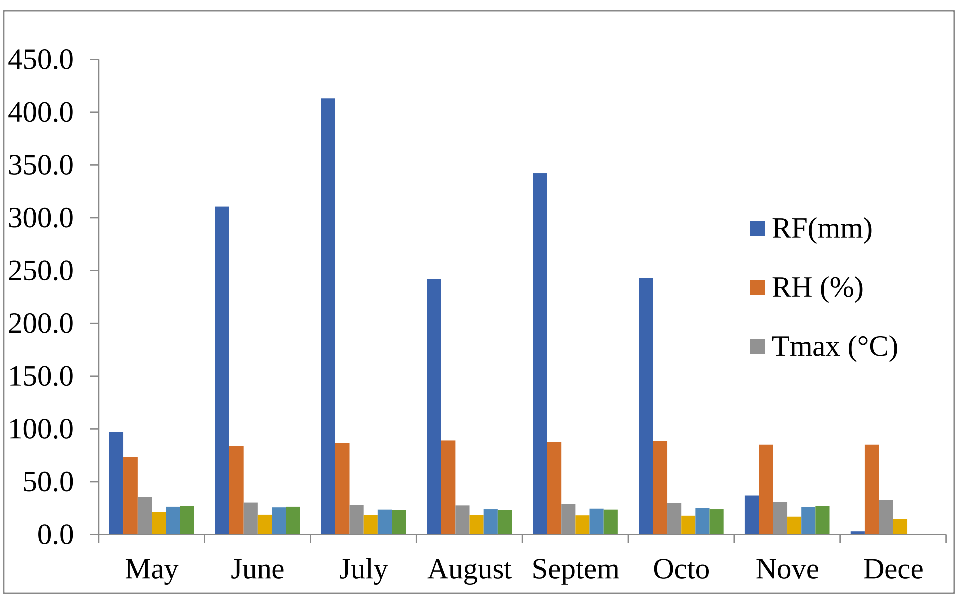

Figure 2. Graphical representation of Pawe Agricultural Research Center Meteorological Data During the 2019. *Note:* RF = the sum of the daily rain falls in a month in millimeter, RH = the average monthly relative humidity in percentage, T^{o}_{max} = the average maximum daily temperature in a month in°C, T^{o}_{min} = the average daily

minimum temperature in a month in ˚C, Soil T° C (10cm) = the average soil temperature in˚C at ten-centimeter soil depth in a month and Soil T°C (20cm) = the average soil temperature in ˚C at twenty-centimeter soil depth in a month.

Table 3. Pawe Agricultural Research Center Meteorological Data from 2015 to 2019 (January to December)

Yeas	RF (mm)	RH (%)	T°max (°C)	T°min (°C)
2015	1148.4	84.9	32.9	17.1
2016	1336.9	87.7	32.8	16.9
2017	1910.4	76.4	32.3	17.3
2018	1515.5	75.5	33.2	17.1
2019	1726.4	78.7	32.8	18.0

Note: RF (mm) = the sum of rain fall distributions from January to December in millimeter in each year, RH (%) = the average relative humidity in percentage from January to December in each year, T°max (˚C) and T°min (˚C) = the average maximum and minimum temperature in ˚C from January to December for each year.

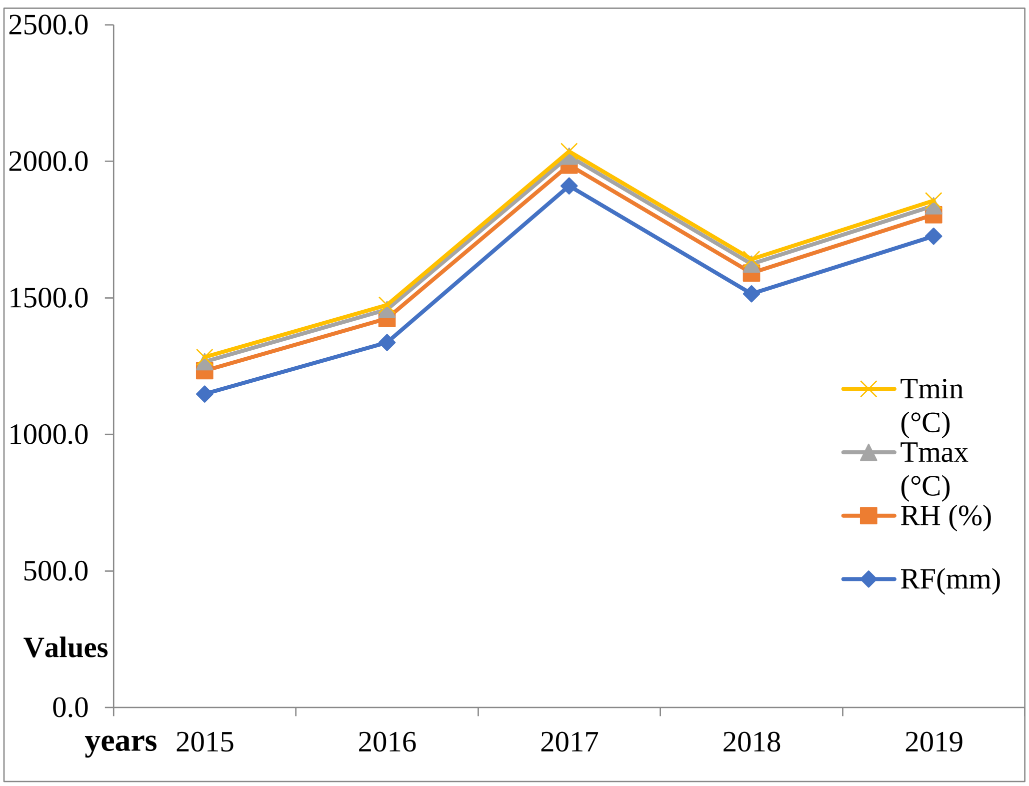

Figure 3. Graphical representation of Pawe Agricultural Research Center Meteorological Data from 2015-2019

However, the production area coverage and its productivity t ha^{-1} with the number of farmers producing *Tef* continues to increase; the 22 consecutive production years in the trend has shown in the table (**Table 4**), but its productivity stil now is very low in the country. The production area coverage reliably increased approximately from 1.75million to 3.08million hectares similarly its productivity was increased from 0.7million t ha^{-1} to 1.8million t ha^{-1} in the years. But; the production in millions of metric ton was not consistence from season to season. For instance, in 1999/2000 it was 1.75 million metric tons while this figure highly reduced from 2000/2001 to 2003/2004 as shown in the table (**Table 4**). This is an indication of climate change and its constraint. Previously we revealed that the number of *Tef* varieties released increased from time to time, but its productivity is limited and not consistent.

Table 4. Tef production characteristics over time.

S. No.	Production Year (Season)	Number of holders (millions)	Area (millions of hectares)	Production in (millions of metric tons)	Yield (metric t ha^{-1})	Total cereal (million hectare)	*Tef* area shear (%)
1.	1997/1998	*	1.75	1.31	0.7	5.6	31.3
2.	1998/1999	*	2.09	1.64	0.8	6.7	31.2
3.	1999/2000	*	2.12	1.75	0.8	6.7	31.6
4.	2000/2001	*	2.18	1.74	0.8	7.6	28.7
5.	2001/2002	4.4	1.82	1.63	0.9	6.4	28.4
6.	2002/2003	*	*	*	*	*	*
7.	2003/2004	4.6	1.99	1.68	0.8	7.0	28.4
8.	2004/2005	4.9	2.14	2.03	0.9	7.6	28.2
9.	2005/2006	5.2	2.25	2.18	1.0	8.1	27.8
10.	2006/2007	5.4	2.40	2.44	1.0	8.5	28.2
11.	2007/2008	5.9	2.57	2.99	1.2	8.7	29.5
12.	2008/2009	5.8	2.48	3.03	1.2	8.8	28.2
13.	2009/2010	5.6	2.59	3.18	1.2	9.2	28.2
14.	2010/2011	6.2	2.76	3.48	1.3	9.7	28.5
15.	2011/2012	6.3	2.73	3.5	1.3	9.6	28.5
16.	2012/2013	6.3	2.73	3.77	1.4	9.6	28.4
17.	2013/2014	6.6	3.02	4.42	1.5	9.9	30.5
18.	2014/2015	6.5	3.02	4.75	1.6	10.2	29.6
19.	2015/2016	6.6	2.87	4.47	1.6	10.0	28.7
20.	2016/2017	7.0	3.02	5.02	1.7	10.2	29.7
21.	2017/2018	7.0	3.02	5.02	1.7	10.2	29.7
22.	2018/2019	6.8	3.08	5.40	1.8	10.4	29.6

Different time periods of the meher crop productionn season reprted by CSA. The star"*"sign indicated that data was not accessible.

The impact of climate change and its challenges on Tef production and productivity

Agriculture primarily crop production is significantly influenced biophysically by climatic variables through increasing temperatures, varying rainfall, and increased atmospheric CO_2 levels. Biophysical impacts of environmental variation will be affirmative in certain agricultural schemes and adverse in others which vary over time (Parry et al., 2004). Watson (2009) previously also reported that Africa is the most exposed region to climate change which imposed to hamper the adaptive capacity of the crop. Environmental variability is the aggregate consequence that hinders the crop production potential mainly to convey *Tef* the vanguard improvement and enhancing the livelihoods of smallholder farmers engaged on the climate change and increasing advanced *Tef* technologies responsible to the problem. Currently the study conducted on maize using a long-term data in Africa, combined with daily climate data exhibited a nonlinear association between heating and yields. Every degree day spent above 30°C drops the yield by 1% in ideal RF environments (Lobell et al., 2011). The resent climate variability, trivial variation in the accessibility of RF can lead to a substantial impact on crop production (Grover, 2016). It is evidently identified that the production potential of the crop extremely be contingent on the availability of moisture in the soil from plating to harvesting stages of the crop. According to Molla and Fitsume (2017), higher volume of RF habitually associates with improved yield in addition to minor variability in yield. Hence about 20% of the Ethiopian economy production deficit and 25% of poverty level is caused by RF variability (Birara et al., 2018). For example, this inspiration braced by Fikadu et al. (2019) who revealed that climate variability is one of the significant aspects for *Tef* productivity hinder.

There are various references shown that climate change and global warming effects caused via ever increasing population growth with its necessity on the perimeter of existing cultivable land resources. The periodic emblematic of RF is an imperative climatic component that changes the productivity and invention probable of yields in the survival agrarian sector. Ethiopia is nature gifted in various agro ecological regions with variant soil classes and fertility status. These circumstances favor and make the country to be the main center of origin and diversity for numerous economically prominent crops including *Tef* (Vavilov, 1951). However, *Tef* has huge probable for development, it has been ignored for the periods in study, advancement and promotion related as most important cereals like wheat and maize. The genus Eragrostis is situated universally in the world with (Vavilov and Ivanovich, 1997; Laca, 2009; Dekking et al., 2005). The cram reported by Sumelius et al. (2009), climate vulnerability is précised as vulnerability = (adaptive capacity) - (sensitivity + exposure). Generally, the adverse impacts of climate variability can cause the following main consequences in the country:

- Nutrient diffidence consequently hampering the production and productivity of crops mainly the nutrient to be mined from *Tef* due to the existences of droughts and other climatic variability.
- Occurrence of crops and human disease such as diabetic and anemia in humans due to absence of mineral nutrient in the diet which can be acquired from *Tef*, fungal diseases (head smudge) and insects like shoot fly, lodging and shattering problem associated with rain fall.
- Land degradation and soil erosion due to extensive rainfall there by poor productivity for *Tef*
- Economic instability and bargain the annual GDP attained from crop production in the country and foreign currency

OVER VIEW OF *TEF* BREEDING ENHANCEMENT PHASES

Standpoint of tef improvement phases and techniques

In Ethiopia officially and scientifically *Tef* enhancement research was started next to the establishment of training centers like Jimma and Haromaya Agricultural Technical Schools in the 1950s then after 1950's obviously it was known as the history of *Tef* enhancement through research at these schools mainly at Jimma Agricultural Technical School finally shifted to Debre Zeit Agricultural Research Center (DARC) still now it is the national center of excellence for *Tef* research coordinating center while others are implementing in Ethiopian Institute of Agricultural Research (EIAR). Collection and selection of lines from the land races was the principal effort ended to advance the productivity of *Tef* initially. However, it was not successful, certain years after there was a mission and idea for further enhancement of *Tef* in terms of both quantity and quality through hybridization skill.

The biology of *Tef* is distinct in nature in its floral opening time with a very small size of male and female reproductive organs which make it very difficult to emasculate for synthetic breeding mainly for crossing. In Ethiopia effective artificial *Tef* crossing work intended for advancement program is well conducted at DAZRC where there is comparatively skilled technical man power for crossing and crossing tools with equipment. However, there is a limited skilled experienced man power for emasculating and crossing with efficient tools like specialized crossing microscope, even in the entire of EIAR for further advancement through crossing skill. Since DZARC is the center of *Tef* enhancement entire responsibilities and application through the national research project in Ethiopia, it is better to be advanced the crossing and emasculating tools with the skill of manpower for further improving *Tef* with the collaborative centers where the trials sent to be evaluated as multi location evaluation at the federal and regional research centers. Mostly, the evolvement of advancement through breeding program expending various techniques preliminary from the initial to the present categorized through five consecutive phases with important achievements at each phase indicated via scientist's advancements as shown in the table below (Table 5).

Table 5. *Tef* advancement phases and major achievements at each phase

Breeding phases	Year of duration (E.C)	Major activities done and achievements	References
First phase	1956 to 1974	Stressed on germplasm enhancement through collection, characterization and evaluation. During this period, genetic enhancement was done depend on entirely through mass and or pure-line selection openly from the prevailing germplasm and beginning of induced mutation practices. Then after in the year of 1972 academicians confirmed that mutagenesis is one of the ways of constructing extra genetic variability.	Kebebew et al. (2011)
Second phase	1975 to 1995	Marked by the integration of intraspecific hybridization into the previously established breeding approaches ensuing the finding of the chasmogamous floral opening comportment of *Tef* flowers staring at about from 6:45 to 7:30 AM and thus the synthetic crossing system.	Berhe (1975). and Kebebew et al. (2011)
Third phase	1995 to1998	This was the beginning of molecular techniques having the progress of molecular markers and genetic linkage maps, and considerations of molecular genetic variability.	Kebebew et al. (2011)
Fourth phase	1998 to 2003	Prominently focused through the combination of in vitro culture approaches and inter-specific hybridization through re-appraisal of encouraged mutagenesis mainly for developing disease and lodging resistance like leaf rust and lodging tef varieties.	Tefera et al. (2003) and Kebebew et al. (2011)
Fifth stage	2003 to now	The including of an overview of participator breeding techniques in the preceded entire *Tef* genetic advancement schemes and continuous prevalent molecular and genomic study techniques.	Tefera et al. (2003) and Kebebew et al. (2011)

Research contributions through breeding for variety improvement

DZARC has been played a significant role for the enhancement of *Tef* through collecting, charactering, screening, crossing, evaluating, releasing and promoting of improved technologies existence as the leading center nationally together with the implementing research centers in EIAR since initially established to the present. Through the five breeding phases stated earlier conventional and non-conventional breeding approaches were applied for improving its production and productivity in the country. Various imperative molecular techniques and biotechnological tools also used to balance and enable the conventional *Tef* breeding techniques through the advancement of *Tef* genomics like molecular markers advancement, enhancement of genetic linkage maps, QTL analysis, sequence-based diversity analysis, genome size and ploidy valuation, genome sequencing, mutation and genetic transformation (Assefa et al., 2011).

Meanwhile this technical review has been written ongoing for several years released *Tef* varieties reached about 49 primarily through DARC with the collaborative centers in EIAR (MoANR, 2019). These varieties played an inviolable contribution reasonably improving the production and productivity of *Tef* enhancing food security in the small-scale farmers and foreign currency increasing GDP in the country. Even though numerous varieties released time to time, however most of them are not resistant/tolerant to diverse biotic and abiotic constraints and not also responsible for climate change, owing to such production limits across the courtiers.

Hence bearing in mind such regions and designing the breeding strategies as the climate change is very adverse concern to be resolved via developing resistance/tolerant varieties which is the only choice via efficient breeding techniques in the future. For instance, the report stated by the investigator showed that exchange of temperature-sensitive crops via further resistant ones is acceptable scientific idea (Bates et al, 2008). Efficient breeding techniques we mean that creating artificial environment for testing the advanced technologies according to their objectives and certify very well, integrating conventional and molecular breeding using molecular tools, improved *Tef* emasculating tools for artificial crossing and capacity building for breeders, technical teams and the crossing sites by itself to be successful.

CONCLUSION

Tef is an intact cereal crop at international comparing with other cereal crops such as maize; wheat; sorghum and barley. It is the most remarkable Ethiopians' staple food with economical cash crop through foreign currency returns. However, its low yields, has little prospective to address the country's food security problems and foreign exchange currency, due to Climate change mainly variations in the climate via alterations in variability of confident properties are the production limits and a long period of drought. Hence bearing in mind and designing the breeding strategies as the climate change is very adverse concern to be resolved via developing adaptive and resistant/tolerant varieties will be the only choice via efficient breeding techniques. Generally improving adaptive ability with effective management of ecological variations, characterizing agro ecologies and considering climate variability and designing breeding strategies using breeding tools provide a significant concern for the advancement of production and productivity of *Tef* thereby enhancing the food security associated with human health in the country and global revenue.

COMPETING INTERESTS

The authors declare that they have no competing interests

DATA AVAILABILITY STATEMENT

The raw data used to support the findings of this study are available from the corresponding author upon request.

REFERENCES

Abate, B., Solomon, C., Tebkew, D., Nigussu, H., Yazachew, G., Kebebew, A., & Zerihun, T. (2018). Dissemination, Constraints and Opportunities for Improving *Tef* Productivity: Evidence from Demonstration Trials. *Journal of Poverty, Investment and Development, 44*, 103-111.

Abraham, R. (2015). Achieving Food Security in Ethiopia by Promoting Productivity of Future World Food *Tef:* A Review. *Advances in Plants and Agricultural Research, 2*(2), 86-95.

Addisu, D. J. (2018). Evaluation of Adaptability and Improvement of *Tef* [Eragrostis *Tef* (Zucc.)Trotter] Varieties in Western Part of Ethiopia. *Greener Journal of Agricultural Sciences*, *8*(10), 300-303.

Araya, A., Girma, A., Demelash, T., Martorano, L.G., Haileselassie, H., & Abraha, A.Z. (2015). Assessing impacts of climate change on *tef* (*Eragrostis tef*) productivity in Debrezeit area, Ethiopia. *International Journal of Agricultural Science Research*, *4*(3), 39-48.

Assefa, K., Yu, J. K., Zeid, M., Belay, G., Tefera, H., & Sorrells, M. E. (2011). Breeding *Tef* [*Eragrostis tef (Zucc.)* trotter]: conventional and molecular approaches. *Plant Breeding*, *130* (1), 1-9. https://doi.org/10.1111/j.1439-0523.2010.01782.x

Ayalew, A., Kena, K., & Dejene, T. (2011). Application of NP Fertilizers for better production of *Tef* (*Eragrostis tef* (Zucc.) Trotter) on different types of soils in southern Ethiopia. *Journal of Natural Science Research*, *1*(1), 6-15.

Bates, B. C., Kundzewicz, Z.W., Wu, S., & Palutikof, J. P. (2008): Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

Berhe, T. (1975). A breakthrough in tef-breeding technique. Information Bulletin on the Near East Cereal Improvement and Production Project (FAO), XII: 11-13pp

Birara, H., Pandey, R. P., & Mishra, S. K. (2018). Trend and variability analysis of rainfall and temperature in the Tana basin region, Ethiopia. *Journal of Water and Climate Change*, *9*(3), 555-569.

Chamberlin, J. & Schmidt, E. (2012). Ethiopian agriculture: a dynamic geographic perspective.

Food and agriculture in Ethiopia: progress and policy challenges: 21-52.

Dekking L., Kooy-Winkelaar Y., & Koning F. (2005). The Ethiopian cereal tef in celiac disease. *New England Journal of Medicine, 353*, 1748-1749.

Dereje, G., Alemu, D., Adisu, T., & Anbessa, B. (2018). Response of yield and yield components of Tef [Eragrostis *Tef* (Zucc.) Trotter] to optimum rates of nitrogen and phosphorus fertilizer rate application in Assosa zone, Benishangul Gumuz region. *Ethiopian Journal of Agricultural Sciences*, *28*(1), 81-94.

Deressa, T., Hassan, R., Ringler, C., Tekie, A., & Mahmud, Y. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change, 19*, 248-255.

Di Falco, S., Yesuf, M., Kohlin, G., & Ringler, C. (2012). Estimating the impact of climate change on agriculture in low-income countries: household level evidence from the Nile Basin, Ethiopia. *Environmental and Resource Economics*, 52(4), 457-478.

Ethiopia, CSA (Central Statistical Agency), (2018). *Agricultural Sample Survey 2017/2018.Crop Production Utilization (Private Peasant Holdings, Meher Season). Addis Ababa: CSA.*

Ethiopia, CSA (Central Statistical Agency), (2019). *Agricultural Sample Survey 2018/2019. Crop Production Utilization (Private Peasant Holdings, Meher Season). Addis Ababa: CSA.*

Bachewe,N.F., Koru, B., & Taffsse, A. S. (2015). Summary of ESSP Working Paper 89, Productivity and efficiency of small holder *Tef* farmers in Ethiopia.

Fikadu, A., Wedu, T. D., & Derseh, E. (2019). Review on economics of *Tef* in Ethiopia. *Open Access Biostatistics and Bioinformatics*, *2*, 1-8.

Food & Agricultural Organization (FAO), (2015). Analysis of price incentives for *Tef* in Ethiopia Technical notes series, MAFAP, by Assefa B. Demeke M., Lanos B., 2015)., Rome.

Gebretsadik, M. (2012). The impact of climate change and adaptation through agro ecological farming practices (Master's thesis). Swedish University of Agricultural Sciences, Alnarp.

Grover, V. I. (Ed.). (2016). *Global Warming and Climate Change (2 Vols.): Ten Years After Kyoto and Still Counting*. CRC Press.

Hailu, T., & Seyfu, K. (2000). Production and importance of *tef* in Ethiopia Agriculture. Hailu Tefera, Getachew Belay and Mark Sorrels (*Eds*) Narrowing the Rift: *Tef* research and development-Proceedings of the international *Tef* Genetics and improvement: 16-19.

Hassen, I. W., Regassa, M.D., Berhane, G., Minten, B., & Taffesse, A. S. (2018). *Tef* and its role in the agricultural and food economy. The economics of *Tef*, exploring Ethiopia's Biggest Cash Crop.*International Food Policy Research Institute (IFPRI), Washington DC*, 11-37.

Jansen, G. R., DiMaio, L. R. & Hause, N. L. (1962). Cereal proteins, amino acid composition and lysine supplementation of *tef*. *Journal of Agricultural and Food Chemistry*, *10*(1), 62-64.

Jemal, M. K., Schmidt, E., and Tilahun, H. (2018). Market access, *tef* production, and fertilizer use over time. *The economics of tef: Exploring Ethiopia's biggest cash crop*, 131-148.

Kebebew, A., Sherif, A., Getachew, B., Gizaw, M., Tefera, H., & Sorrells, M. E. (2011). Quncho: the first popular *tef* variety in Ethiopia. International Journal of Agricultural Sustainability, 9(1), 25-34.

Kebede, W., Tolossa, K., Hussein, N., Genet, T., Bekele, A., Gebremeskel, K., & Assefa, K. (2018). *Tef (Eragrostis tef)* Variety 'Tesfa'. *Ethiopian journal of agricultural sciences, 28*(2), 107-112.

Harriman, N.A. (1998). *Tef*. Eragrostis tef (Zucc.) Trotter. *Promoting the conservation and use of underutilized and neglected crops*, 3. Sago palm, *Metroxylon sagu* . *Economic Botany, 52,* 77.

Laca, M. (2009). Biomass Production of 15 *Tef* Varieties Grown in Churchill County, Jay Davison, Area Forage and Alternative Crops. Specialist University of Nevada Cooperative Fact Sheet.

Lobell, D. B., Banziger, M., Magorokosho, C., & Vivek, B. (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature climate change, 1*(1), 42-45.

Mengesha, M. H. (1966). Chemical composition of *tef* (*Eragrostis tef)* compared with that of wheat, barley and grain sorghum. *Economic Botany, 20*(3): 268-273.

MoANR. (2019). Plant Variety Release, Protection and Seed Quality Control Directorate, Crop Variety Register, Vol Issue No. 21. Ministry of Agriculture and Natural Resources (MoANR), Addis Ababa, Ethiopia.

Molla, M. A., & Fitsume Y. D. (2017). Seasonal rainfall and crop productivity in South West Ethiopia: Preliminary analysis for recent climate. *International Journal of Water Resources and Environmental Engineering*, *9*(10), 211-217.

Muller, C. (2013). African lessons on climate change risks for agriculture. Annual review of nutrition, *33*, 395-411.

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. Global environmental change, *14*(1), 53-67.

Raisanen, J., & Tuomenvirta H. (2008). Interactions between Boreal Forests and Climate Change. Chapter 10, pp 479-493 in "Boreal Forest and Climate Change", *ed*. Hari P and Kulmala L, Advances in Global Change Research 34, Springer.

Regasa, D., & Afework, H. (2018). Determinants of Improved *Tef* Varieties Adoption and Its Impact on Productivity: The Case of Non-Traditional Tef Growing Areas of Western Ethiopia. *Journal of Natural Sciences Research*, *8*(22), 2224-3186.

Reilly, J., Tubiello, F., McCarl, B., & Melillo, J. (2001). Climate change and agriculture in the United States. US National Assessment of the Potential Consequences of Climate Variability and Change: Foundation, 379-403.

Simonet, G. (2010). The concept of adaptation: interdisciplinary scope and involvement in climate change. *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society*, (3.1).

Spaenij-Dekking, L., Kooy-Winkelaar, Y., & Koning, F. (2005). The Ethiopian cereal *Tef* in celiac disease.*New England Journal of Medicine, 353* (16),1748-1749.

Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., & Midgley, P. M. (2013). Climate change: The physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change, 1535.

Sumelius, J., Bäckman, S., Rötter, R., & Kahiluoto, H. (2009). General theoretical framework the SARD-Climate project.

Tadele, Z., & Kebebew, A. (2012). Increasing food production in Africa by boosting the productivity of understudied crops. *Agronomy, 2*, 240-283. https://doi.org/10.3390/agronomy 2040240

Tefera, H., Assefa, K., & Belay, G. (2003). Evaluation of interspecific recombinant inbred lines of Eragrostis *Tef* x E. pilosa. *Journal of Genetics and Breeding*, *57*(1), 21-30.

Tembo, M. F. (2018). The impact of climate change on *Tef* Production in Southeast Tigray, Ethiopia. *Journal of Agricultural Economics and Rural Development*, *4*(1), 326-338.

Thornton, P. K., Jones, P. G., Owiyo, T., Kruska, R. L., Herrero, M. T., Kristjanson, P. M. & Omolo, A. (2006). Mapping climate vulnerability and poverty in Africa. Nairobi (Kenya): ILRI, 200p. https://hdl.handle.net/ 10568/2307.

Vavilov, & Ivanovich, N. (1997). Five continents. Descriptions by Vavilov of his expeditions between 1916 and 1940, from manuscripts saved during the Second World War and the remainder of the Stalin era. (St. Petersburg: N.I. Vavilov Research Institute of Plant Industry and Rome: International Plant Genetic Resources Institute).

Vavilov, N.I. (1951). The origin, variation, immunity and breeding of cultivated plants. *Chronica Botanica*, *13*, 1-351. https://doi.org/10.2134/ agronj1952.0002196 2004400020016x

Watson, R. (2009). Climate Change, Food Security and the Role of Agricultural Science and Technology. Tyndall Briefing Note No. 35, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, 3p. https://www.greenfacts.org/ en/climate-agriculture-food-ecurity/index.htm

Yaregal, D., & Firew, M. (2022) "Evaluation of Acidic Soil Tolerance Indices in Maize (*Zea mays* L.) Varieties in Assosa, Ethiopia", *International Journal of Research in Environmental Science, 8*(2), 1-13. *http://dx.doi.org/ 10.20431/2454-9444.0802001*

Yesuf, M., Di Falco, S., Ringler, C., & Kohlin, G. (2008). Impact of climate change and adaptation to climate change on food production in low-income countries: Household survey data evidence from the Nile basin of Ethiopia. IFPRI Discussion Paper No. 828. *International Food Policy Research Institute. Washington DC*. 2pp.

Yumbya, J., Vaate, M., Kiambi D., Kebebew, F., & Rao, K. (2014). Assessing the effects of climate change on *Tef* in Ethiopia. A research project by: African Biodiversity Conservation and Innovations Centre (ABCIC) in collaboration with the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) and Institute of Biodiversity Conservation (IBC), Nairobi.