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Exploration of Systemic Barriers to *Tef* Research and Development in Central Ethiopia: A Coupled Structural-Functional Innovation Systems Analysis

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Abstract

Over the years, there has been a continuous increase in the demand for *tef* (*Eragrostis tef* (Zucc.) Trotter) due to population growth, average incomes and urbanization in Ethiopia, but its innovation system has not been fully explored. This research aims to determine the supportive effect of *tef* innovation system on its investigation and development as well as the systemic constraints in the process. A coupled structural-functional innovation system analysis was used to explore the barriers faced in Central Ethiopia. The results revealed the constraints affecting the innovation system, namely limited capacity of existing actors, weak interactions and partnerships among actors, weak enforcement of institutions as well as inadequate/poor infrastructure. They also showed that technology development, technology diffusion, entrepreneurial activities, market development, resource mobilization and legitimacy creation have been the weak functions of *tef* innovation. Furthermore, a failure in one of the functions has a knock-on effect on others, which causes an overall dysfunctional innovation system. Based on the results, failures of the structural elements along with weaknesses of functions have constrained the development of *tef* innovation systems sector. A combination of technological, institutional and technical intervention must be implemented to overcome this problem.

Keywords: agricultural innovation; cooperative; extension; functions; structure

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INTRODUCTION

Sustainable agriculture is one of the ways to achieve food and nutrition security in Ethiopia and it involves helping poor people manage their agricultural practices (Rainbow for the Future, 2022). *Tef* [*Eragrostis* tef (Zucc.) Trotter] is the most important cereal crop in the country where it plays a vital role in achieving food security (Assefa et al., 2011) in terms of production, consumption and cash crop value (Paff and Asseng, 2018; Chanyalew et al., 2019). Furthermore, it is the most commercialized crop in the cereal sector where it accounts for approximately 30% of the products sold (Hassen et al., 2018). The crop is annually grown by more than 7.1 million farmers on 24.1% of the national grain area and it is ranked first in terms of area coverage. After maize, *tef* is the second most-produced cereal and it accounts for 17.1% of the total production in the category (CSA, 2020). It also accounts for approximately 15%

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of all calories consumed and provides 66% of daily protein intake in the country (Berhane et al., 2011; Crymes, 2015). Additionally, *tef* is used as a nutritious feed for cattle but its price is higher than other cereals. It is widely used because no disease epidemic has threatened its performance and the grains can be stored for a long time without being attacked by weevils (Awulachew, 2020). *Tef* plays a very important role in the country's agriculture and trade sector because an increase in its production and export ensures food security (Tadele and Hibistu, 2022).

Over the years, there has been a continuous increase in its demand due to population growth, average incomes and urbanization (Lee, 2018). However, researchers, extensionists, development practitioners and policy-makers are faced with the challenge of meeting the rising demand. Since the late 1950s, efforts have been made by *tef* research and development (R&D) to improve its productivity (Genet et al., 2020). Its production in some ecological zones has increased due to its high adaptability under relatively different climatic conditions (Tembo et al., 2018). For example, the national *tef* research program has released more than 44 improved varieties of the crop along with production packages (MoA, 2019). These efforts significantly increased the average yield from 8 qt ha^{-1} in 2000/2001 to 18.5 qt ha^{-1} in 2019/2020 (CSA, 2020). The land covered by its extension package has also increased from 7% in 2002 to 35.5% in 2017/2018 (CSA, 2018). Furthermore, efforts have been made in the last half-century to improve its production system by implementing different agro-techniques and tools. There have also been important changes in *tef* innovation systems and value chain both at the production level and consumption side.

Domestic *tef* production has not been able to meet the increasing demand for the crop, consequently, the supply is below the domestic and foreign market demand (Berhe et al., 2011). Moreover, *tef* R&D has not been well-developed to support the livelihood of smallholders because the productivity is still low and the desired level has not been achieved (Merga, 2019; Genet et al., 2020). The use of improved technologies for the crop is also low and limited to a few varieties (Vandercasteelen et al., 2013; Duressa, 2015; Mirkane and Tassew, 2015; Vandercasteelen et al., 2016). *Tef* was historically neglected compared to other cereals and it remained largely excluded from advances in plant science, hence, it is categorized as an "orphan", "neglected" or "underutilized" crop (Assefa et al., 2011).

This poses the question as to why *tef* innovation system is not well-developed and functional in Ethiopia? Why smallholder farmers are unable to take advantage of new technologies and agronomic practices? What systemic constraints hinder the development of the its innovation system and prevent the diffusion of improved technologies from large scale to smallholders? Therefore, this research aims to determine the supportive effect of *tef* innovation system on its sector as well as to discover the constraints faced in the process. The innovation system approach recognizes the role of actors, institutions, actors' interactions, infrastructure and the historical dynamics of innovation processes (Kebebe et al., 2015). The structural-functional analysis components of the Agricultural Innovation System (AIS) framework were used to analyze the historical development of the crop's sector since *tef* R&D began in the late 1950s (Wieczorek and Hekkert, 2012) (Figure 1). It also recommends possible interventions that can address the systemic barriers in the system.

MATERIALS AND METHOD

Data source, type and collection

This is a qualitative methodology research, which obtained data from key informant interviews, focus group discussions and document review, as often carried out in innovation system diagnostic (Negro et al., 2012; Wieczorek et al., 2013). This was undertaken in two *woredas* of Central Ethiopia, namely Minjar Shenkora *woreda* from North Shewa Zone of Amhara Regional State and Ada'a *woreda* from East Shewa Zone of Oromia Regional State. Furthermore, the *woredas* represent potential areas for *tef* production with a better experience in using improved technologies. The data collection process considered both the national and *woreda* level. Key informants were then identified from agricultural research institutions, ministry of agriculture, bureau of agriculture, *woredas* agriculture offices, development agents (DAs), farmers' organizations, traders union, model farmers and community elders. All the informants

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are experienced and knowledgeable about *tef* research and development. Subsequently, six separate focus group discussions, each consisting of 6 to 10 participants were held with researchers and DAs with a standardized checklist. Another eight separate focus group discussions, each comprising of 8 to 10 participants were also carried with farmers and community elders.

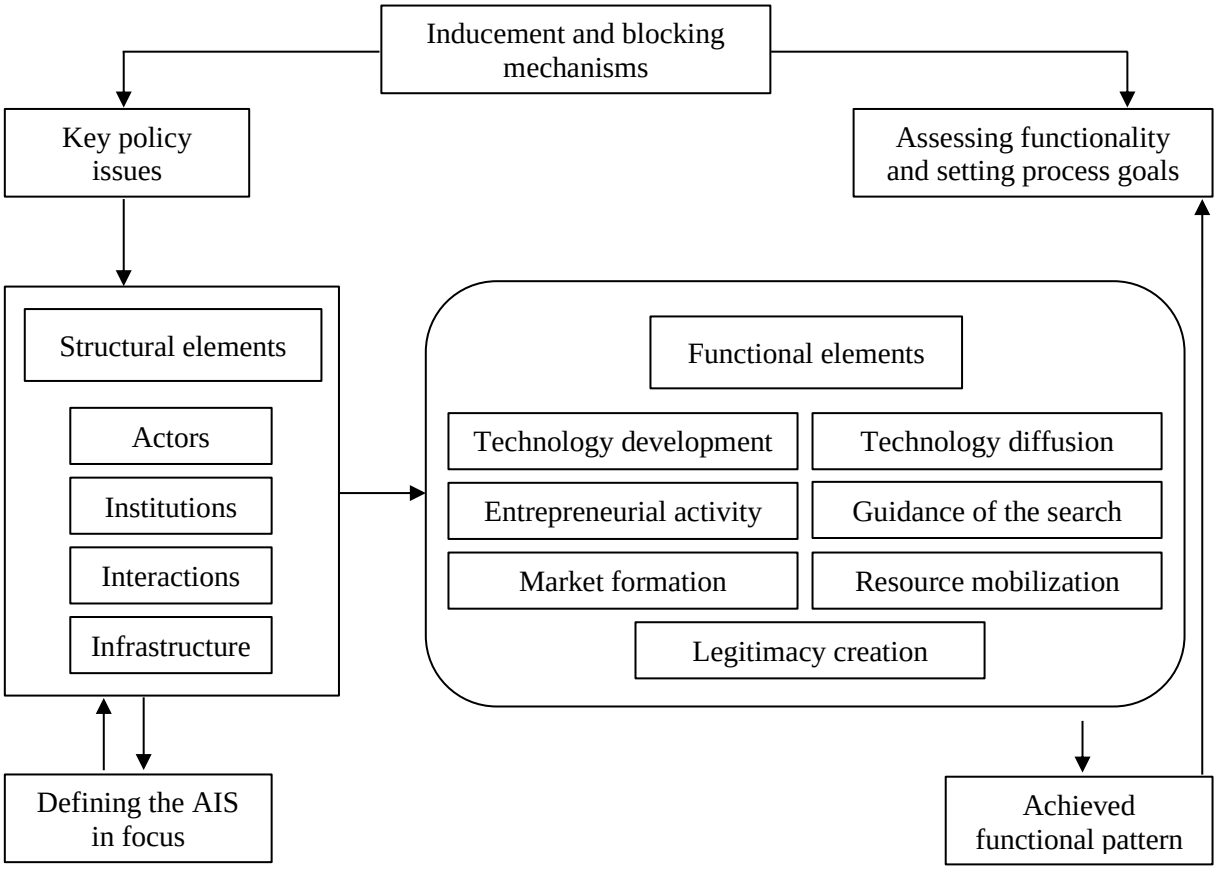

Figure 1. The structural-functional dynamics of AIS

RESULTS AND DISCUSSION

Structural analysis of tef innovation system

This section presents the performance of the four structural elements of *tef* innovation system. The analysis includes the presence or capabilities of the existing actors as well as the presence or quality of their interactions, institutional setup and infrastructure. Table 1 describes the structural analysis of *tef* technological innovation system in Ethiopia.

Functional analysis of tef innovation system

Technology development (F1)

Ethiopia's *tef* research program is majorly dependent on domestic research which focus is only on breeding, with limited applied research such as in the fields of socio-economics, agronomy, physiology, crop protection and mechanization. However, key informants claimed that there are improved technologies that can enhance the crop yield, but concerns were raised about their dissemination to smallholders. The performance of the research system is measured based on the number of new technologies and production systems developed, which does not ensure effectiveness. Among the total improved crop varieties (1,264), *tef* research program released 44 varieties. In *tef* row planting technologies, there is a need to increase the exposure of the components through extension, research, training for farmers and building cooperative organizations (Cafer and Rikoon, 2018). Despite these successes, no technology has been developed to resist lodging, acidity and waterlogging as a solution to critical challenges faced by smallholders. Lodging is one of the major constraints limiting the crop's productivity, specifically when it occurs during the grain-filling period (Berhe et al., 2011).

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Table 1. Structural analysis of *tef* technological innovation system

Time line	Actors	Interactions	Institutions	Infrastructure
1950s to 1974 (Imperial regime)	- Dominated by smallholders - Limited key actors - Input suppliers missing	- No policy framework for linkages between actors	- Extractive institutions	- Lack of *tef* R&D capacity - Underdeveloped supply chain - Poor infrastructure
1975 to 1991 (*Derg* regime)	- Dominated by smallholders - Lack of private input and service provision - Weak knowledge, research institutes and civil society	- The first Research-Extension Liaison Committee (RELC) in 1986 was established - Weak interaction among various actors	- Partially extractive institutions - Shifted *tef* with other high productive staple crops	- Very limited government resource to *tef* development - Limited *tef* R&D capacity - Limited infrastructure - Underdeveloped supply chain
1991 to present Ethiopian People's Revolu-tionary Democra-tic Front (EPRDF)	- State actors, NGOs actors, farmers' organizations, farmers and market actors - *Tef* production dominated is by smallholders - Shortage of input providers	- Different platforms have been established - Limited commitment among actor to harmonize interrelated roles and establish functional linkages	- Inclusive institution - Weak enforcement of existing rules and regulations	- Limited but improving R&D facility - Underdeveloped *tef* supply chain

Furthermore, the lack of pre- and post-harvest technologies has a negative impact on *tef* growers by increasing the output losses. Focus group discussants and key informants revealed that significant yield losses were incurred during threshing because it was carried out on the ground. The quality of the grain was also affected because it was mixed with soil, sand and other foreign matter. Although smallholders are demanding for technologies, no mechanization effort was made to solve the problem of row planting for the crop's production.

Technology diffusion (F2)

Agricultural extension in rural areas can help farmers to overcome barriers while adopting new technology or practice (Fayso, 2018). Furthermore, technology adoption is a behavioral decision made at a specific moment and place, while diffusion is the pattern of adoption across time (Abera, 2008). Improved technology diffusion is majorly carried out by the public in Ethiopia and it involves the active participation of various actors. The Ministry of Agriculture (MoA) and the Regional Governments have a core mandate to diffuse extension services. Klerkx et al. (2012) suggested that the research system must be efficiently linked and connected with other actors in the innovation system to promote and disseminate technologies. The presence of these actors was acknowledged by the key informants and focus group discussants, but their interaction and partnership in the value chain are limited and weak. Despite the availability of released technologies, the adoption of improved *tef* technologies was still low and limited to a few varieties (Assefa et al., 2013). This was mainly caused by the different perceptions of objectives, assumptions, capacities as well as lack of trust among the actors. This difference indicates the presence of "directionality failure", which refers to the lack of shared vision and collective coordination of fragmented change agents (Kebebe et al., 2015).

The technology delivery system still features the classical model of technology transfer (ToT) despite the participatory extension system (PES) approach implemented in 2010 (MoA, 2010). Leta et al. (2017) stated that the technology diffusion approach in the country is highly organized in a top-down technology transfer manner. DAs promote the use of technologies among farmers, but rarely promote them to develop and adapt technologies to their circumstances. The discussants revealed that

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although there is an annual demand forecast plan by the MoA, there is still a huge gap between the quantity, quality and form of *woreda* demanded and the technologies dispatched by the federal governments through cooperatives and other means. Consequently, farmers have to use their varieties, borrow from neighbors, use the available inputs or examine other choices.

Entrepreneurial activities (F3)

Entrepreneurship is a continuous process that involves creating a company to manufacture new goods and services (Bezabih, 2006). The key informants stated that entrepreneurial activities in Ethiopia were poor, underdeveloped and not modernized. Furthermore, the majority of farmers practiced subsistence farming and they sell their produces immediately after harvest without any value addition. The right post-harvest management strategy facilitates the storage of high-quality produces, which can sold at high prices in the global market (Kimatu et al., 2012). Several reasons contributed to Ethiopia's low entrepreneurial activity. Farmers and others respondents in *tef* value chain revealed that only few enterprises are involved in these activities due to actor capability limits because most of the agricultural businesses are small to medium-sized organizations. The base of entrepreneurship is largely dependent on agricultural outputs, but it is very backward and the resources are at a low level. The weak entrepreneurship skills and capacity of *tef* producers as well as the limited advisory service constrained the development of these activities in the country. Most of farmers lacked the skill to undertake entrepreneurship due to the limited advisory services. They have also not been adequately supported by knowledge and training. Additionally, cultural barriers and social constraints are responsible for the poor entrepreneurial capability of smallholders. The respondents stated that the majority of smallholders in the country do not make investments even when their returns are high due to low aspirations. The public-private partnership, which was created to support entrepreneurial activities are also weak and limited.

Guidance of the search (F4)

In Ethiopia, several policies and strategies have been designed and implemented to facilitate agricultural growth since the 1950s. The imperial regime was the first government in Africa to implement different development policies and economic development planning. During this period, the policies were implemented under three consecutive five-year agriculture development plans. The imperial government planned to increase production by encouraging investment among large-scale farmers (EEA, 2005). The military regime came into power in 1974 with new Ethiopian agriculture and land use policies. The communist *Derg* dictatorship, which ruled from 1974 to 1991 nationalized all means of production including land, houses, farms and industries. Consequently, smallholders who form the backbone of the agriculture sector were hesitant to risk producing surplus goods for the market due to uncertainty over their land rights. The *Derg* ended the previous system and transferred private ownership to public ownership to ensure the distribution of land to rural farm households.

The EPRDF/current government has made smallholder agriculture a priority for development through the Agricultural Development Led Industrialization (ADLI) strategy. The strategy aims to generate surplus agricultural output by using technological inputs on smallholder farms. During this period, the government implemented different strategies to realize the vision of ADLI. The level of productivity was increased, but it was still inadequate to ensure national self-sufficiency. However, the key informants stated that the policy and implementation strategies have been repeatedly changed and they are inconsistent. This inconsistency contributed to the lack of trust by farmers towards the state extension and planning system (Leta et al., 2017). Kassa, (2008) described it as “rapidly changing policy signals” where the state frequently sends signals that induce swift changes.

Market formation (F5)

Tef is mainly grown as a cash crop in several countries, particularly Ethiopia. Over the years, there has been a continuous increase in the demand for its products due to rapid population growth, rising income and urbanization. Its production is often carried out through traditional methods. The output market lacks large-scale processing and purchasing, which hinders benefits from economies of scale (Lee, 2018). The country has the biggest output volume of the crop, but no profits are realized from the international market (FAO,

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2015). Meanwhile, other countries are actively participating in *tef* marketing to capitalize on the growing market. The export volume has been declining since 2006 after the government imposed an export ban on unprocessed grain and flour of the crop to protect local consumers. Despite the ban placed, the domestic price was still high and the gap between the price of *tef* and other cereals, such as wheat and maize was widened (FAO, 2015). The discussants and informants stated that producers did not benefit from it due to the inefficiency and ineffectiveness of the input and output markets.

Several cooperatives and farmers' unions were identified in the research areas and they were mainly involved in supplying agricultural inputs, such as chemical fertilizer as well as collecting the produces. However, majority of the organizations do not provide the complementary inputs and services needed in crop production. Efforts have been made by the government to enhance the efficiency of the market by taking various measures, such as connecting the producers directly to the markets through cooperatives and farmers' unions. Cooperatives were established to increase the value of members' output by reducing the number of middlemen. They can also improve their members' marketing process by providing storage facilities. During field visits, various warehouses built by cooperatives were identified in the research areas. Furthermore, the focus group discussants acknowledged the presence of warehouses, which served as storage for smallholders to store their produces and get the premium prices. The MoA and different actors have also developed a working strategy to strengthen *tef* value chain by minimizing the intermediaries that influenced the output marketing.

Resource mobilization (F6)

The informant revealed that *tef* innovation system, particularly *tef* research, has a severe deficit of human resources in terms of quality and quantity. This limited the scope of breeding, agronomy and crop protection research. Furthermore, these resource shortages are compounded because it is an "orphan crop" and not supported by the international scientific community. The majority of researchers were young, juniors and had the BSc degree education, but their population continued to increase in the research system.

The amount of research expenditure in Ethiopia is still below the sub-Saharan African average and one of the lowest in Africa (Beintema and Haregewoin, 2018; FAOSTAT, 2019). *Tef* R&D has also not been adequately funded to undertake advanced research. The financial resource deficiency occurred because *tef* is an "orphan crop" and the receipt of donor funds is very small. This is primarily because it is endemic as a food crop to the country and when compared to other cereal crops, it is less likely to obtain external funding and adaptive basic research knowledge from the international scientific community. Therefore, adequate public budgets are required, at least on an equal footing with other cereals.

The informants stated that the majority of the research facilities and laboratories were old and obsolete. The sector also lacked precision equipment, advanced analytical facilities, farm machinery, irrigation facilities and information communication technology (ICT) infrastructure. Consequently, *tef* research system must follow conventional methods that do not predict outcomes in the process and require a longer time to develop technologies. The Advanced *Tef* Research Laboratory was established in 2020 with financial support from the Syngenta Foundation as well as the University of Bern and Ethiopian agriculture transformation agency (ATA). To promote best practices, the federal trade commission (FTC) must serve as hubs for knowledge and information sharing centers. During field observations, the Golo Dertu *kebele* FTC was closed down due to a lack of physical resources, facilities and support from farmers and the management members.

Creation of legitimacy (F7)

The agricultural development policies, as well as procedures used since the 1950s, are influenced by the policy direction of successive regimes. During the Imperial period, *tef* R&D focused on increasing the production and productivity of large-scale commercial farming, while the majority of smallholders were restricted from using technologies. Similarly, the research program passed through different phases since the 1950s at Jimma College of Agriculture, which only focused on breeding to enhance productivity (Cheng et al., 2017). The research system focused majorly on germplasm enhancement, genetic improvement and initiation of induced mutation

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techniques. The *Derg* administration launched an agrarian reform program in which all rural lands were declared as state property and the regime also controlled all economic domains including agriculture. During this period, the government attempted to discourage *tef* production because of its low yield but its high demand and adaptation to various environmental conditions sustained it (FAO, 2015). Furthermore, while the government declared land tenure, there was no access to research, extension and agrometeorological services for the majority of smallholders.

The EPRDF government implemented major policy reforms after overthrowing the preceding military government in 1991. The ADLI plan also prioritized the development of smallholder agriculture, hence, the crop was considered one of the major commodities to ensure food security. During this period, the policy document facilitated the discovery of suitable technologies from other countries as well as their use, but the strategy cannot be used for crops such as *tef* which major source is Ethiopia. Therefore, its technology development depends majorly on domestic research because adaptation strategy is not applicable. The government only focused on short-term usage and most of the technologies released by the research system were adapted.

Structural-functional analysis of *tef* innovation system

The systemic failures and weaknesses in the innovation system affected the development of innovation functions, such as technology development, technology diffusion, entrepreneurial activity, market formation, resource mobilization and creation of legitimacy. This indicates that the failures and weaknesses in structural elements of the system caused the slow development of *tef* innovation functions. Furthermore, absence or weakness in one of the functions has a significant impact on the others, thereby distorting the whole value chain. The systemic imperfections and malfunctioning in innovation functions constrained farm households from taking advantage of the improved technologies and economic benefits. The coupled structural-functional analysis result showed that the underdevelopment of *tef* R&D in Ethiopia was caused by the weaknesses in innovation functions and systemic imperfections/failures, such as limited and incompetent actors as well as institutional, interaction and partnership failures, as shown in Table 2.

Possible interventions to address systemic imperfections and functional failures

The structural-functional system analysis has facilitated a systemic study on the functions of *tef* innovation system, diagnosing the absence/ presence of weaknesses and capability of actors as well as determining interactions, institutions and infrastructure that can deliver these functions to support the innovation practices. Based on the systemic problems and weaknesses, some important possible interventions can be considered to strengthen the system.

Lack of technologies to address the problem of lodging, pre-harvest and post-harvest, acidity and waterlogging is one of the major constraints in the system. Furthermore, they are often caused by limited scientifically-trained human resources, inadequate facilities and insufficient financial resources. The weakness of research on technology development can be tackled by strengthening the research capacity, adaptation of advanced basic knowledge as well as the interaction and partnership among national and international actors/partners. The weaknesses of the system, which were identified as key contributor of innovation system problems was solved by (Jacobsson and Bergek, 2011) strengthening the existing platform for the smooth interaction, partnership and cooperation among actors along *tef* research system. The platform fostering the feedback loop must also be supported because it is very helpful while generating demand-driven technologies. This result is in line with Kebebe et al. (2015) and Negro et al. (2012) that the weaknesses in technology diffusion arises from weak public-private partnerships, limited interaction among key actors and limited enforcement of participatory approach. However, they can be tackled by establishing strong public-private partnerships, strengthening the existing multi-stakeholders platform as well as implementing PES to engage the end-users in technology diffusion. The weak interaction and partnership among actors create a mismatch between technology generation and the use of improved technologies when these problems are not solved. A similar finding was also obtained by Leta et al. (2017).

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Table 2. Systemic problems causing weaknesses or absence of the functions in *tef* innovation systems

System function	Weakness in innovation functions	Systemic failure (missing or weak)	Type of structural weakness
F1: Technology development	- Inadequate technology and knowledge - Insufficient knowledge on institutional arrangements - Limited *tef* research beyond breeding	- No private actors in the research system - Weak interactions and partnership among actors - Limited research capacity to develop breakthrough technologies - Lack of advanced molecular sciences	- Missing relevant actors - Capability failure - Hard and soft institution failures - Interaction failure
F2: Technology diffusion	- Limited engagement of public actors - Extension mainly focus on dissemination - Lack of adequate and quality inputs	- Main actors are engaged in multiple tasks (overloaded) - DAs lack guidelines to manage innovation system - Limited interactions among key actor	- Missing relevant actors - Interaction failure - Infrastructure failure
F3: Entrepreneurial activities	- Limited number of entrepreneurial activities - Subsistence farming - Medium size private entrepreneurs - Low aspiration, social constraints and cultural barriers	- Weak entrepreneurship skill and capacity - Limited advisory service - Weak public-private partnership to support entrepreneurship	- Limited actors - Demand articulation failure - Interaction failure - Physical infrastructure failure - Capability failure
F4: Guidance of the search	- No national extension strategy until 2017 - Continuous change in policy and implementation strategies	- Limited actors to increase protection of property rights - Weak enforcement of laws and property rights - Limited organizational capacity and human competence to protect property right of *tef* germplasm	- Hard and soft institution failures - Capability failure
F5: Market formation	- Supply of inputs dominated by public - Limited scope cooperatives - Markets are inefficient and poorly functioning	- Lack of coordination and partnership, which hinders the delivery of inputs - Poor infrastructure for the output markets - Limited private market actors for agricultural input	- Missing actors - Infrastructure failure - Interaction failure - Market failure
F6: Resource mobilization	- *Tef* R&D programs and projects are financed by public - Limited donors funding for *tef* R&D - Dire shortage of physical resources, facilities, modern laboratory equipment	- Inadequate funding - Lack of adequate physical facilities and competent human resources	- Physical infrastructure failure - Insufficient financial resources - Limited research and development capability
F7: Creation of legitimacy	- Weak interaction and partnership among professional association, policy makers and farmers' organizations - Lack of clear policies for endemic crops	- No strong legal framework for interactions and limited enforcement among relevant actors - Weak interaction and collaborations among relevant actors	- Missing actors - Interaction and partnership failure - Capability failure

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Limited numbers of entrepreneurs' activities in *tef* value system is majorly caused by the lack of entrepreneurial capability, limited public-private partnership and low aspiration due to social and cultural constraints. This problem can be addressed by strengthening the partnership and multi-stakeholder platforms among actors as well as enhancing the capability and aspiration of the entrepreneurs through capacity-building trainings. Furthermore, another problem faced is the weak enforcement and lack of clear/supportive hard and soft institutions for endemic crops, such as *tef* that is affected by the creation of legitimacy. These problems can be solved by increasing the protection and supporting the property right of these crops. Proper law enforcement must also be implemented to protect the germplasm. The problem of legitimacy creation can be solved by supporting and strengthening the existing professional associations, such as crop societies, academy of science and civic institutions. This result is in line with the previous research conducted by Negro et al. (2012); Wieczorek and Hekkert (2012); Kebebe et al. (2015).

CONCLUSIONS

Despite the systemic challenges of the sector, *tef* innovation system has made a significant contribution to the development of the crop in Ethiopia. This research investigated how the system has functioned to support *tef* R&D. It also determined the systemic constraints that were encountered in the process. Furthermore, the results showed that the limited capacity of existing actors, weak interaction among actors, weak enforcement of institutions and poor and inadequate infrastructure are the structural elements that are associated with the under-development of the innovation systems. These structural weaknesses have also influenced the development of system functions, such as technology development, diffusion, entrepreneurship, market formation, resource mobilization and legitimacy creation. This finding indicates that a weakness in one of the functions has a ripple effect on others, thereby leading to a dysfunctional innovation system. Therefore, there is no single/all-encompassing intervention that addresses the problems in *tef* innovation systems, but the sector can benefit from the current efforts aimed at enhancing systemic interaction in the AIS.

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