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ANALYSIS OF SORGHUM SOCIAL SEED NETWORK IN TIGRAY, NORTHERN ETHIOPIA

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ABSTRACT

Proper understanding of the nature of seed exchange among farming communities is fundamental to achieving a sustainable seed system and maintaining crop genetic resources. The objective of this study was to investigate sorghum (*Sorghum bicolor*) seed sources and analyse their network flow among farmers in Tigray in Northern Ethiopia. A survey was conducted using a semi-structured questionnaire, involving 153 sorghum household farmers selected randomly from six villages; namely Gezaadara, Medabe, Gezameker, Waekel, Munira and Gandostela. Farmers who plaid major roles in the sorghum seed exchange network were identified using social seed network analysis. Results showed that bartering and own-saved seeds were the dominant sources of sorghum seed for farmers throughout the study area; and sorghum seed flow was more confined within villages than beyond. Social capital such as cultural norms, trust and farmers' desire to increase sorghum production in the communities were the fundamental drivers for farmer sorghum seed exchange. Individuals distinguished as nodal farmers who had high bridging roles could also act as entry points for improved sorghum seed exchange interventions in Tigray.

Key Words: Bartering, social capital, *Sorghum bicolor*

RÉSUMÉ

Une bonne compréhension de la nature des échanges de semences entre les communautés agricoles est fondamentale pour parvenir à un système semencier durable et maintenir les ressources génétiques des cultures. L'objectif de cette étude était d'enquêter sur les sources de semences de sorgho (*Sorghum bicolor*) et d'analyser leur flux de réseau parmi les agriculteurs du Tigray, dans le Nord de l'Éthiopie. Une enquête a été menée à l'aide d'un questionnaire semi-structuré, impliquant 153 ménages producteurs de sorgho sélectionnés au hasard dans six villages ; à savoir Gezaadara, Medabe, Gezameker, Waekel, Munira et Gandostela. Les agriculteurs qui ont joué un rôle majeur dans le réseau d'échange de

semences de sorgho ont été identifiés à l'aide d'une analyse du réseau social de semences. Les résultats ont montré que le troc et les semences auto-conservées étaient les principales sources de semences de sorgho pour les agriculteurs dans toute la zone d'étude ; et le flux de semences de sorgho était plus confiné dans les villages qu'au-delà. Le capital social tel que les normes culturelles, la confiance et le désir des agriculteurs d'augmenter la production de sorgho dans les communautés ont été les moteurs fondamentaux de l'échange de semences de sorgho des agriculteurs. Les individus qualifiés d'agriculteurs nodaux qui avaient un rôle de relais élevé pourraient également servir de points d'entrée pour des interventions améliorées d'échange de semences de sorgho dans le Tigré.

Mots Clés : Troc, capital social, *Sorghum bicolor*

INTRODUCTION

Sorghum (*Sorghum bicolor*) is a staple crop in Ethiopia, grown over a range of altitudes, mainly beyond 400 meters above sea level (Teshome *et al*., 2007; Girma *et al*., 2020). Its inherent ability to yield reasonably in relatively low soil fertility and moisture-stressed areas makes it an excellent food security crop for smallholder farmers, especially in the arid and semi-arid tropics (Mundia *et al*., 2019).

Seed is considered as the most important element of the sorghum value chain in eastern Africa (McGuire and Sperling, 2016). Seed availability, access, affordability, adaptability and farmer-preferred crop varieties are determinants of the efficiency and productivity of associated technologies in increasing crop production. Unlimited farmer access to quality seed is key, not only to increase crop productivity, but also to conserve crop genetic resources (Okry *et al.,* 2011; Coomes *et al.,* 2015).

There are three types of seed systems through which farmers acquire seeds and other planting materials, namely, the formal, the informal and the integrated seed exchange system. The formal seed exchange system is distinguished by its clear-cut activities, starting with formal plant breeding, varieties release and regulations to maintain varietal identity and purity; as well as guarantee physical, physiological and sanitary quality (Atilaw *et al*., 2016). Seed marketing under this system takes place through officially recognised seed outlets, and by way of national agricultural research systems (Subedi *et al.,* 2013; Kansiime and Mastenbroek, 2016).

The informal type of seed system is also called a local seed system. By this system, the seeds are managed by farmers using their indigenous knowledge and capacity (Almekinders and Louwaars, 2002). Seed transactions are usually through barter, local markets, exchange, farmer's own-saved seeds, gifts and loans often in kind (McGuire, 2007). The informal seed system accounts for the largest share (>80%) of seed sources throughout the developing countries (Louwaars De Boef, 2012). In Ethiopia, about 95% of farmers' sorghum seed requirements are fulfilled mainly through the informal seed system (Adugna, 2014).

The integrated seed system is characterised by entrepreneurial farmers and farmer groups that produce and market crops that are not covered by the formal seed system (Subedi *et al*., 2013). The integrated seed system includes both formal and informal seed systems and receives high technical support from research, Non-government organisations (NGOs) and seed projects, and some regulatory oversight from the bureaus of agriculture (Sperling *et al*., 2013).

In the case of the informal seed system, farmers build unique social seed networks to access seed and related information, and thus, ensure availability of sufficient planting materials (Subedi *et al*., 2003; Abay *et al*., 2011). A social seed network refers to the interconnection of farmers to exchange seeds

and share seed-related experiences (Subedi *et al*., 2005).

The process of analysing the features and mechanisms involved in the networks is known as social seed network analysis (SSNA) (Poudel *et al*., 2015). It is a mathematical and graphical illustration of farmers' role in which the actors who play what and the links from where and to where can be easily justified (Poudel *et al*., 2015; Ricciardi, 2015). Using SSNA, it is possible to identify farmers who play major roles in the seed exchange network (Abay *et al*., 2011).

Unfortunately, information pertinent to social seed network analysis and the assets that could sustain local exchanges of sorghum seed is generally limited in Ethiopia. The objective of this study was to investigate sorghum (*Sorghum bicolor*) seed sources and their flow networks among farmers in Tigray, in Northern Ethiopia.

METHODOLOGY

Study sites. this study was carried out in two districts of Tigray, namely, Raya Azebo and Tahtay Adyabo, all in northern Ethiopia. Raya Azebo is located in the southern Zone of Tigray, while Tahtay Adyabo is found in the northwestern zone of Tigray (Fig. 1). The characteristic features of the two study areas are indicated in Table 1. The districts were selected purposely based on: (a) their status of high sorghum production; and (b) their possession of local seed flow and social seed networks. Three villages were subsequently selected from each district for the survey. From Raya Azebo, the villages included Waekel,

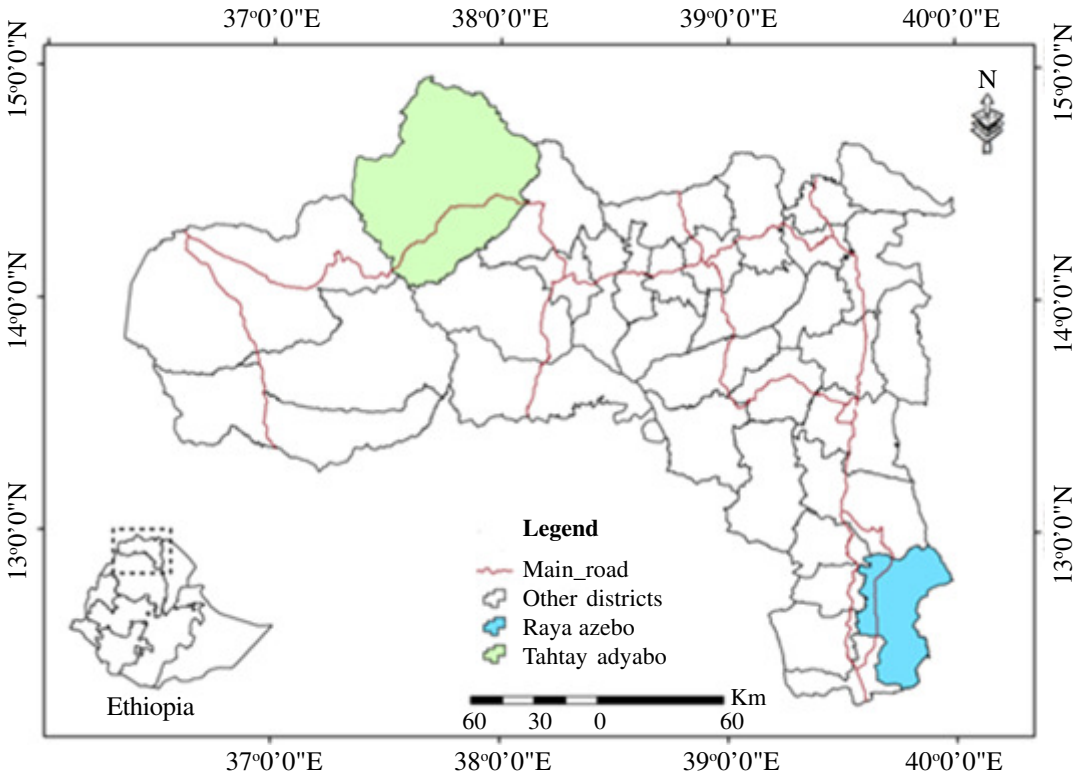

Figure 1. Location of the districts used in the study of sorghum seed exchange networks in Tigray, Northern Ethiopia.

TABLE 1. Characteristic features of the study sites used for sorghum social seed network analysis in Tigray, Northern Ethiopia

Characteristics	Raya Azebo	Tahtay Adyabo
Major crop grown	sorghum, teff, abaaro, kodom, zeriehadis, gano, dengle, gedalit, chibrak	Sorghum, sesame, millet, zeriegebru, dagnew, merowey, wediaker, chimroy, getsharas,
Major farmers' varieties of sorghum grown (local name)	jamuye	coden, shilquit, ganseber,
Altitude (m.a.s.l.)	1000-1660	700-1400
Mean temperature (^{O}C)	25-35	26.5-37
Mean annual rainfall (mm)	400-900	350-850
Main farming system	Subsistent farming	Subsistent farming

Gandostela and Munira; while from Tahtay Adyabo district, they included Gezameker, Medabe, and Gezaadre. A village is the smallest administrative unit in Ethiopia (Wubneh, 2017).

Survey process. This study was carried out from October 2018 to November 2019. A total of 153 household heads selected through a snowball sampling method, were interviewed using a semi-structured questionnaire, supplemented by a focus group discussions (FGDs). The snowball sampling method has been applauded as an effective approach to social network analysis (Subedi *et al*., 2003). The questionnaire was originally prepared in English and translated into Tigrigna (the main local language in Northern Ethiopia). Oral translators were also engaged to translate from Tigrigna to Kunama for the Kunama Ethnic group located in the Tahtay Adyabo district. Five individuals who spoke both languages fluently were used to ensure the correctness of the translations.

The survey followed three main steps; the first step was a reconnaissance survey coupled with discussion with eight agricultural experts, six community leaders, and ten elders. Discussion with these groups was done to gain background insights about sorghum cultivation in the study areas. In the second step, 36 sorghum farmers (50% females) were selected purposely. Based on the information obtained during the baseline survey, these farmers were technology adopters and expected to command a good sorghum production experience. Since these were the first participants to be engaged in the study, they acted as 'entry points' for the social network analysis for sorghum in Tigray; thus they were designated as first-batch farmers. Following the group discussion, an in-depth interview was done at the household level with the first-batch farmers, using the following criteria: (i) their source of sorghum seed used in the previous growing season, (ii) persons shared sorghum seed within the previous season, (iii) main seed sources for sharing seed, (iv), sorghum varieties exchanged, and (v) factors affecting the sorghum seed exchange process. These first-batch farmers listed at least 151 farmers as their seed exchange partners. Subsequently, we termed these 151 farmers as the "second-batch farmers", and subjected them to interviews using the same semi-structured questionnaire.

In the third step, 117 of the second-batch farmers were asked to name their seed exchange partners. The number of second-batch farmers was reduced from 151 to 117 because 20 farmers were already interviewed

during the first step and the rest (14 farmers) were not available due to various reasons. The second-batch farmers, in turn, listed 309 (third-batch) farmers as their seed exchange partners. The third batch of farmers were not interviewed due to resource limitations. However, they were included in the seed networks, seed sources and flow analysis based on the information obtained from the first and second-batch farmers, as they were seed exchange partners. For the data on the socioeconomics of farmers in the sorghum seed networks, and factors that influenced farmers to participate in the sorghum seed exchange sorghum, only the first and second-batch farmers' (a total of 153 farmers) were interviewed.

Socioeconomic characteristics of respondents. Land size per household ranged from 0.2 to 4.5 ha while mean age of the respondents was 54 years, with a minimum and maximum age of 31 and 89 years. Among the 153 households interviewed, 37 (11.1%) household heads were females. The majority of the respondents (76.5%) were illiterate as they did not have formal school; 19.6% attended elementary school; and 3.9% attended high school (Table 2).

Data analysis. Data obtained were triangulated and checked for consistency before analysis. The primary data collected were coded and entered into Microsoft Office Excel; before analysis using UCINET and Net draw software package (Borgatti *et al.,* 2002). While coding the data, farmers were considered as node data, whereas the seed exchange modes and the varieties under exchanged were used as tie data.

The role of the farmers in the network was computed using degree and betweenness centrality measures as described by Abay *et al*. (2011). A farmer with more direct connections with other persons in the network is called a nodal farmer (Abay *et al*., 2011), but there are no clear-cut standards for such a category (Poudel *et al*., 2015). Bridging farmers refers to those who can exchange seeds and information through their direct and indirect connections (Abay *et al*., 2011).

Descriptive statistics about the respondents' socioeconomic characteristics, seed exchange means, seed flow, sorghum

TABLE 2. Socioeconomic characteristics of the households involved in the study of sorghum seed exchange networks in Tigray, Northern Ethiopia

Characteristics	Level	N	%	P-value
Sex	Male	97	63.0	0.001
	Female	56	37.0	
Education status	Illiterate	117	76.5	0.001
	Elementary	30	19.6	
	≥High school	6	3.9	
Land size (ha)	<0.5	68	44.4	0.001
	0.5-1	44	28.8	
	1-2	28	18.3	
	>2	13	8.5	
Age (years)	<45	43	28.1	0.001
	45-60	75	49.0	
	>60	35	22.9	

varieties maintained per household, and motivations and discourage to exchange sorghum seed were analysed using the Statistical Package for Social Scientists version 20.0 (SPSS) software. Significant treatment mean differences were separated using the T-test and Chi-square test for the numerical and categorical data, respectively.

RESULTS

Sorghum seed flow and seed sources. Seed exchange with non-relatives was the most dominant seed source (47 %) among sorghum farmers in Tigray, followed by their own-saved seed (Table 3). Nevertheless, seed exchange with relatives and friends, gifts, local grain markets and seed loans played a pivotal role in the seed flow of sorghum seeds throughout the villages (Table 3).

Seed exchange events and flow of sorghum varieties. Most of the sorghum seed transactions in Tigray were within villages; whereas dismal seed transactions were outside the villages (Table 4). The distribution of

TABLE 3. Modes of sorghum farmers' seed sources in Tigray in Northern Ethiopia

Nature of seed sources	Tahtay Adyabo district					Raya Azebo district			
	GM	Me	GA	Un	Total (%)	WA	Gn	Mn	Total (%)
Own saved	3	9	8	0	20	10	13	11	34
Bartering with non-relatives	10	17	19	1	47	18	9	10	37
Bartering with relatives	2	6	3	0	11	3	2	1	6
Gift/friend	1	4	4	0	9	5	6	1	12
Local grain market	2	3	4	0	9	4	1	2	7
Seed loan	1	2	2	0	5	2	1	1	4
P value					0.00				0.00
Mode of exchanges seed exchanges within villages									
Bartering with non-relatives	12	20	25	0	57	28	13	12	53
Bartering with relatives	2	7	5	0	14	3	3	3	9
Gift/friend	2	6	7	0	15	8	10	2	20
Local market	2	2	4	0	8	6	2	3	11
Seed loan	1	2	3	0	6	3	2	2	7
P-value					0.00				0.00
Mode of exchanges seed exchanges outside villages									
Bartering with non-relatives	15	24	17	4	60	28	13	12	52
Bartering with relatives	5	7	1	0	13	3	3	2	8
Gift/friend	1	2	1	0	4	8	10	2	21
Local market	4	7	5	0	16	6	2	3	12
Seed loan	1	5	1	0	7	3	2	2	7
P-value					0.0				0.0

GM = Gezameker, Me = Medabe, GA = Gezaadra, WA = Waekel, Gn = Gandostela, Mn = Munira, uk = unknown village

farmer grown-varieties sorghum varied significantly across the villages under study (Table 5). Ten varieties were the most frequently exchanged of all the sorghum varieties presented by the respondents. In Raya Azebo district, the most popular varieties were abaaro, codem, zerihadis, dengle and jamuye; while in Tahtay Adyabo district, they included wediaker, zerigebru, dagnew, merowey and chimroy. In addition, there were significant variations ($P<0.05$) in the farmers' varieties among villages in each particular district. For instance, abaaro was the dominant variety in all the villages in Raya Azebo; while merowey and zeriegebru were the more popular varieties in Gezameker, Medabe and Gezaadre (Table 5).

TABLE 4. Sorghum seed exchange events (N) within and outside study villages in Tigray in Northern Ethiopia

Villages	Within village	Outside village	Total N	P value
Waekel	64 (85%)	11(15%)	75	
Gandestela	56(84%)	11(16%)	67	
Munira	44(86%)	7(14%)	51	
Gezameker	28(74%)	10 (26%)	38	0.00
Medabe	48(71%)	20(29%)	68	
Gezaadra	63(74%)	22(26%)	85	
Total	303 (79%)	81(21%)	384	

TABLE 5. Flow of sorghum varieties across the villages of Tigray, Northern Ethiopia

Village	Tahtay Adyabo					
Villages	Sorghum varieties (Local varieties)					
	Wediaker	Zerie Gebru	Dagnew	Merowey	Chimroy	Others
Gezameker	1	4	2	7	3	1
Medabe	2	13	8	7	9	2
Gezaadre	2	16	7	10	4	1
Total (%)	5	33	17	25	16	4
P value			<0.001			
District	Raya Azebo					
	Abaaro	Codem	Zerihadis	Dengle	Meshala	Others
Waekel	17	6	8	8	2	1
Gandestola	19	4	5	4	2	0
Munira	9	6	2	3	1	0
Total (%)	45	17	15	16	6	1
P value			<0.001			

Centrality measures. This is the degree of centrality and betweenness centrality of farmers who played active nodal, bridging and/or a combination of the roles (Table 6). The average degree centrality and betweenness centrality in Tahatay Adyabo district were 3.3 and 5.0, respectively, with a network centralisation of 1.2%. In Raya Azebo district, the average degree centrality and betweenness centrality were 2.6 and 3.5, respectively, with a network centralisation of 2.2%. There were 37 households in the sample, of whom 14 had both nodal and bridging roles, 12 had nodal roles, and 11 had bridging roles across the study districts (Table 6).

A farmer was considered nodal when he/she had direct connections with more than five farmers in the seed network. There were only eight females (23%) among the 37 nodal and/or bridging farmers in the sample (Table 6).

Seed exchange network maps. Maps generated for the degree centralities for sorghum seed flow networks across villages in the districts are presented in Figures 2 and 3, respectively. According to the network maps, in addition to the main networks of seed flow, there were sub-networks connected by nodal and bridging farmers. Isolated farmers were not part of the seed networks (Figs. 2 and 3). Many farmer-grown varieties were exchanged within the farmers' seed network.

Factors for sorghum seeds exchange. The main factors that motivated farmers to participate in the exchange of sorghum seeds included (i) ease of mutual farmer-farmer assistance (44%), (ii) replacement of non-performing varieties (23%), (iii) previous natural and manmade factors leading to loss of varieties (44%), (iv) ability to create and maintain friendship (33%), (v) adoption of new varieties (22%), (vi) for diverse culinary use (21%), and (vii) ease of information access from farmers (23%) (Table 7).

Several factors significantly ($P < 0.001$) motivated farmers to exchange sorghum seeds with other farmers. The major ones included (i) long-standing culture of seed exchange (87%), (ii) trust in the quality of farmer-saved seed (69%), and (iii) desire to increase productivity at the household and community level (65%) (Table 7). Other factors such as ease of mutual farmer-farmer assistance (44%), replacement of non-performing varieties (23%), previous natural and manmade factors leading to loss of varieties (44%), ability to create and maintain friendship (33%), adoption of new varieties (22%), for diverse culinary use (21%) and ease of information access from farmers (23%) also motivate farmers to exchange sorghum seeds in Tigray (Table 7).

The main challenges presented by respondents related to sorghum seed exchange in Tigray included (i) inferior quality seed in return (51%), (ii) increased farmer dependence on others for seed (46%), (iii) time required for seed exchange (39%), (iv) unwillingness of some farmers to share seeds (27%), (v) increased workload due to the seed exchange process (46%), (vi) lack of guarantee for seed quality (25%), and (vii) discrimination of some farmers during sharing seeds (6%) (Table 8).

DISCUSSION

Characteristics of sorghum seed sources and flows. It is clear from this study that the major means for acquisition of sorghum seeds in Tigray by farmers were through exchanging seeds of different varieties, barter-trade, as gifts, purchasing from local markets using cash, and seed loans (borrowing seeds for reimbursement after the next harvesting) (Table 3). All these characteristics could be due to the social and cultural customs of sharing seeds and the long history of cultivations of farmer-preferred local sorghum varieties, which in turn, implies that sorghum farmers in Tigray are over-reliant on the informal seed exchange system. The low adoption rate of improved varieties of sorghum in Tigray, which is only1-2% (Adugna, 2014) may also indicates the

TABLE 6. Nodal and bridging farmers present among sorghum seed networks across villages of Tigray in Northern Ethiopia

Farmer (node)	Villages	Centrality measures				
		Degree centralities	Out degree	In degree	Betweenness centralities	Position hold in the network
8	Gandostela				23	B
10	Gandostela	9	9	0		N
15	Gandostela	6	6	5		N
14	Gandostela	8	7	1		N
20	Gandostela	6	9	0		N
42	Gandostela	8	6	2	65	NB
152	Gandostela				38	B
29	Munira	8	7	1		N
30	Munira	8			38	B
24	Munira	9	7	2		N
1	Waekel	8	5	3	90	NB
2	Waekel	6	5	1	30	NB
3	Waekel	7	6	1	36	NB
33	Waekel	10	8	2	52	NB
35	Waekel				24	B
43	Waekel	7	6	1	24	B
47	Waekel	21	21	0		N
191	Medabe				28	NB
193	Medabe	6	5	1	20	NB
192	Medabe				21	B
195	Medabe	8	8	0		N
198	Medabe	9	8	1		N
211	Medabe	8	4	4	63	NB
224	Medabe				30	B
229	Medabe	6	3	3	39	NB
236	Medabe	6	5	1		N
184	Gezameker	6	3	3	51	NB
192	Gezameker				21	B
210	Gezameker				28	B
207	Gezameker				40	B
358	Gezameker	6	4	2	20	NB
359	Gezaadre	10	10	0		N
360	Gezaadre	7	4	3	30	NB
370	Gezaadre	9	8	1	34	NB
390	Gezaadre	13	12	1	23	NB
204	Gezaadre				36	B
385		7	1	6		N

N = a farmer with a nodal role; B = a farmer with a bridging role; NB = a farmer with both a nodal and bridging role in the seed network

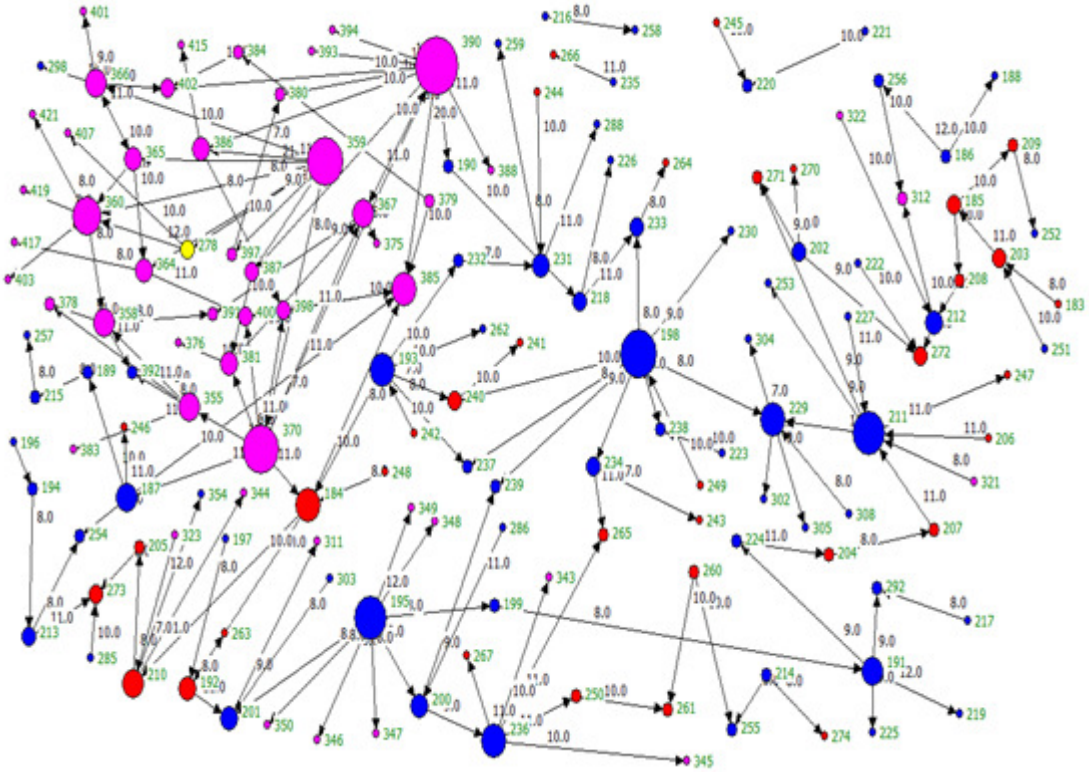

Figure 2. Farmers sorghum seed networks map for Tahtay Adyabo district in Tigray in Northern Ethiopia. Node size (dots) is an indication of the degree centrality of the households such that the larger the size of the node, the higher the centrality and the greater the number of direct connections with other households in the network. Arrows indicate the direction of the seed flow; while node colour indicates the location of the households (red = Medabe; blue = Gezaadra; pink = Gezameker; yellow = unknown village), the green numbers indicate the codes for the households and the black numbers indicates the variety type exchanged (7.0 = Wediaker; 8.0 = Zeriegebru; 9.0 = Dangew; 10.0 = Merowey; 11.0 = Chimroy; 12.0 = Other Varieties).

failure of the formal seed system to deliver farmer-preferred varieties. Besides, cases of better yields by landraces have been reported compared to improved varieties (Welderufael *et al.,* 2023). This emphasizes the need for careful attention to different seed intervention strategies in Tigray including promotion of farmer-preferred sorghum varieties through quality declared seed systems and integrating the local seed systems with the formal seed systems. Earlier reports have also underscored the significance of integrated seed systems in fulfilling the seed requirement of farmers (Sperling *et al*., 2013).

Bartering of sorghum seeds accounted for the largest share of sorghum seed source for the farmers in both the study districts (Table 3). Moreover, more respondents tended to barter sorghum seed with non-relatives (47%), particularly in Tahray Adyabo; compared to bartering seed with relatives. Similar reports exist elsewhere for seed exchange of a range of crops. For instance, Otieno *et al.* (2021) reported that east African farmers use informal seed system as a primary seed sources for crops such as sorghum, finger millet and beans.

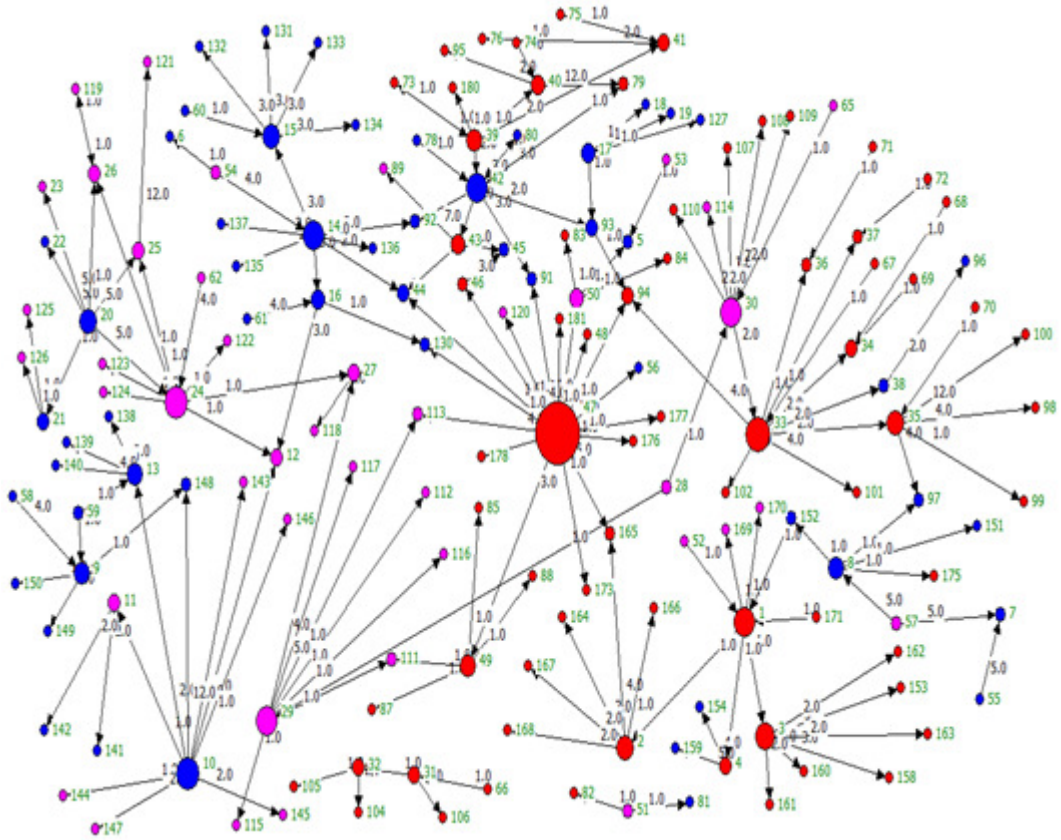

Figure 3. Farmers' sorghum seed network map for Raya Azebo district in Tigray in Northern Ethiopia. Node size is an indication of the degree of centrality of the households such that the larger the size of the node, the higher the centrality and the greater the number of direct connections with other households in the network. The node colour shows the villages of the households (red = Waekel; blue = Gandestola; pink = Munira). The arrows show the direction of the seed flow from one household to the other. The green numbers indicate the code for the households and the black colors show the type of sorghum varieties transacted (1.0 = abaaro; 2.0 = kodem; 3.0 = zeriehadis; 4.0 = meshalla; 5.0 = dengle; 12 = others)

Own saved seed was the second most important source of sorghum seeds for network exchange in both districts; accounting for 20 and 37% in Tahtay Adyabo and Raya Azebo, respectively (Table 3). Thijssen *et al*. (2008) similarly noted that Ethiopian farmers often saved own seeds for the next and other seasons. Farmers accessed sorghum seed from these sources because it was easily available in their own-stock and they were familiar with agronomic traits, cultivation and culinary purposes. It also saved their time spent on accessing seeds from neighbors or local markets. However, farmers isolated from other seed and information sources may resort to planting seeds of low quality grades. It is, therefore, important to capacitate farmers on seed selection, cleaning and storage as highlighted by Abay *et al*. (2011).

The barely important sources of sorghum seeds in the form of gifts, from local market and as seed loans in Tigray (Table 3) could be attributed to the over-reliance of Tigray sorghum farmers on the informal seed

TABLE 7. Reasons for motivation of farmers to exchange sorghum seeds in Tigray, Northern Ethiopia

Motivating reasons	Frequency	Percentages	P-value
To replace existing varieties	35	23	
To trace back lost varieties	67	44	
To increase productivity in the community	99	65	
Culture to exchange seed	133	87	<0.001
Helping each other	68	44	
Friendship	51	33	
To adopt new varieties	34	22	
Trusting farmers' seed	105	69	
For diverse culinary purposes	32	21	
Ease of information access	35	23	

TABLE 8. Factors that influenced sorghum seed exchange in Tigray, Northern Ethiopia

Challenges	Frequency	Percentages	P-value
Time-consuming	59	39	
Inferior quality seed in return	78	51	
Farmers' dependency	71	46	
Unwilling farmers to exchange seed	42	27	<0.001
Increase workload	46	30	
Lack of guarantee	39	25	
Discriminations	9	6	

systems. This emphasizes the need for the establishment of local seed businesses to support the local market to fulfill the sorghum seed requirements of farmers in Tigray. Thijssen *et al.* (2008) also reported similar finding.

Livelihood assets as drivers for sorghum seeds exchange. The main reason for sorghum seed exchange in Tigray was embedded in culture (Table 7). This was evidenced by the belief that "seed belongs to the earth and thus should not be denied to any farmer" (Rodier and Struik, 2018). Rodier and Struik (2018) contended that cultural norms were important social capital in sustaining seed exchange among farmers in Ethiopia. In the present study, respondents exchanged sorghum seeds with other farmers because they trusted the quality of their seeds (Table 7). Information on why farmers exchange sorghum seeds is crucial to uplifting the role of farmers in sustainable seed exchanges. This is also rooted in the strong belief that telling a lie about sorghum seed exchange is an act of disobedience to God. Cultural norms and trustworthiness are important motivating factors for sorghum seed exchange practices in Ethiopia. Social assets such as creating new and/or maintaining old friendships; the desire to help each other and increase production at the household and community also reportedly inspired many farmers to exchange sorghum seeds.

The farmers' awareness that seed exchange is important to boost sorghum production at the community level is a form of altruism, described as "the spirit of sharing

(Kiptot and Franzel, 2014). Respondents stated that beyond cultural norms and altruistic purposes, they were motivated to share seeds to help others as a risk-sharing mechanism that implied reciprocity. In line to this result, Rodier and Struik (2018) reported that a mix of personal and community interests that are deeply rooted in cultural norms motivate farmers to exchange sorghum seeds in northwestern Ethiopia. Investments in human, social, and financial capital are crucial to continuing farmers motivated (Kiptot and Franzel, 2014). Respondents on the contrary noted that in the process of seed exchange, they were often disadvantaged, because the seeds they in return got were of inferior quality to their seeds in terms of market value. To avoid the farmers' dependence on other farmers, they were unwilling to share their seeds with farmers who regularly asked them to barter seeds every year (Table 8). Another important issue mentioned by the respondents was selective seed donations by some farmers which was interpreted as discrimination.

Seed network for promoting seed dissemination. Data for farmers with nodal, bridging and a combination of nodal and bridging roles in sorghum seed exchange networks in Tigray are presented in Table 6. It is evident that the sorghum seed network in Tigray was fairly active and hyper-localised as the majority (79%) of the exchanges took place between farmers living in the same village. Specific roles of farmers in the seed network are important for sustainable seed transactions at the local level. Subedi *et al.* (2003) and Pautasso *et al*. (2013) pointed out that nodal farmers are important hotspots for effective seed provision and maintenance of crop genetic diversity in their environment; and have better experience and exposure to information. In the present study, bridging farmers who linked two or more sub-networks were important mediators of the sorghum seed network to continue functioning within and beyond the villages. Their role has been underscored as seed flow publicists in the informal seed system and more targeted for effective quality seed and information dissemination (Calvet-Mir *et al*., 2012). Therefore, one way of contributing to seed network efficiency is to stabilise the seed flows or support key farmers in the network. Such support could be given by providing training on seed production and management, by increasing access to genetic materials or by providing information (Abay *et al.,* 2011). Other measures could include awareness creation on the importance of local seed exchange among the key farmers and providing incentives in seed supply could significantly support to enhancing seed network efficiency (De Boef *et al*., 2010).

In contrast, farmers occupying the central position can be a point of disruption and affect the seed exchange network in case of their absence or turnover (Poudel, *et al*. 2015). Thus, as stated by Abay *et al.* (2011), to be most effective in disseminating quality seed and in meeting the demand for improved and local varieties, social seed network analysis needs to find the right balance in identifying nodal and connector farmers. Identifying farmers in key positions and designing a conducive approach to capacitate these farmers through training and feeding information, and awareness creation on the importance of local varieties (De Boef *et al*., 2010). Similar interventions were also advocated by several researchers (McGuire, 2007; Abay *et al*, 2011; Otieno *et al*., 2018) as robust strategies to strengthen informal seed exchanges.

CONCLUSION

Our study shows that farmers in Tigray predominantly access sorghum seeds through informal seed systems to fulfill their seed requirements. Bartering and own saved seeds are the main seed sources for farmers. This study underscores the significance of social network analysis in describing the complexity

of farmers' seed systems on-farm. Some farmers play a major role as nodal, bridging farmers, or a combination of activities within their seed network. The analysis is useful for designing interventions related to seed exchanges that is a leap to enhance the effectiveness of the informal seed network. The sorghum seed exchange network in Tigray is active and hyper-localised, as the majority of exchanges took place within their villages than beyond. Social, cultural, natural, human, and physical assets of the community are the most important driving assets for farmers to share seeds. Efforts such as training farmers on seed selection, promoting nodal and bridging farmers to share their seed management and seed sharing experience, and awareness creation on the significance of seed exchange to farmers and extension workers could have a significant positive impact to smooth the informal seed system of sorghum in Tigray.

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