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How social organization shapes crop diversity: an ecological anthropology approach among Tharaka farmers of Mount Kenya

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Abstract The conservation of in situ crop diversity is a key issue to ensure food security. Understanding the processes that shape it is crucial for efficiently managing such diversity. In most rural societies, crop diversity patterns are affected by farmers' practices of seed exchange, transmission, and selection, but the role of social organization in shaping those practices has been overlooked. This study proposes an ecological anthropology approach to investigate the relation between crop diversity patterns and the social organization of Tharaka farmers in Kenya. The Tharaka are organized in neighborhood-groups, clans, and age-sets. We quantified the influence of these three major social institutions on crop diversity patterns, for both crop species and sorghum landraces. General linear models were used to test the relations between crop species richness and each social factor, while the crop species and sorghum landraces compositions of cropping systems were compared separately through a between-class correspondence analysis. Crop species and sorghum landraces are not randomly distributed among farms, and neighborhood-groups constitute a significant factor organizing crop diversity at both specific and infraspecific levels. Adjacent neighborhood-groups present significantly different crop richness and composition. The results for species were consistent with those obtained for sorghum landraces, confirming that crop diversity was socially structured. The influence of social organization on seed networks and selection processes is discussed.

Keywords Agrobiodiversity · Sorghum · Social networks · Seed exchange · Farmers' selection · Crop domestication

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Introduction

Subsistence farming systems, which ensure food supplies for one-third of the world's population, are mostly based on mixed cropping. Crop diversity at specific and infraspecific levels ensures the resilience of smallholder farming systems in changing environments. Conservation of crop genetic resources is therefore a major issue for food security (Thrupp 2000).

To develop efficient in and ex situ conservation strategies, it is necessary to identify the mechanisms that shape crop diversity in situ. Indeed, the distribution of crop diversity is not random. Crop evolution, like that of wild plants, is driven by genetic drift, natural selection, and migration. However, crops are highly dependent on human selection and seed exchange practices. In most subsistence farming systems, farmers are involved in a social organization that shapes relationships and thus affects seed exchanges as well as knowledge and practices diffusion. Crop diversity in situ is not only shaped by environmental barriers, but also by social barriers. Indeed, the social relationships favor the diffusion of planting material, practices, and information between farmers. Contrarily, social barriers limit both the exchanges of seed and the transmission of knowledge and practices between farmers' communities, thereby affecting the distribution of crop genetic diversity in situ (Leclerc and Coppens d'Eeckenbrugge 2012). Seed migration depends on social networks of exchanges (McGuire 2008; Pautasso et al. 2013), while both vertical transmission of ethnobotanical knowledge and the limitation of horizontal transmission favor cultural differentiation (McElreath and Strimling 2008; Cavalli-Sforza and Feldman 1981). This latter social mechanism can explain the divergence of agricultural knowledge and practices between farmers' communities (Boster 1986). The limitation of seed exchanges, knowledge, and practices diffusion should thus lead to the differentiation of crop populations between communities. Perales et al. (2005) notably illustrated the influence of ethnolinguistic organization on maize diversity in Mexico by showing how the Tzotzil and Tzeltal farmers' communities, living in the same environment, have divergent selection practices. In northern Benin, Baco et al. (2008) showed that the differentiation of yam landraces was related to different ethnic groups. However, the influence of farmers' social organization on crop diversity remains insufficiently studied.

Ecological anthropology, which is defined by Orlove (1980) as the study of the relations among the population dynamics, social organization, and culture of human populations and the environments in which they live, provides theoretical and methodological insights for studying the relations between social organization and crop diversity. With this context we investigate the influence of rural communities' social organization on crop diversity patterns in situ. Among the Tharaka farming community, located in the southeastern slope of Mount Kenya, relationships are embedded within three major social institutions: neighborhood-groups, clans, and age-sets. The effect of each social institution on crop composition and species richness of households' cropping systems is quantified using ecology approaches. Results are then discussed regarding ethnographic observations and literature concerning Tharaka social relationship system. These results can be applied to the study and the conservation of crop genetic resources as they contribute to the global understanding of mechanisms that shape crop diversity in situ. The design and implementation of in situ conservation programs, as well as the collection and sampling of crop genetic resources for genetic studies and efficient ex situ conservation require a better understanding of the relation between the social organization of rural communities and the distribution of crop diversity. It is also essential in designing participatory research programs and ensuring the efficient diffusion of their results.

Conceptual framework

Leclerc and Coppens d'Eeckenbrugge (2012) proposed a multidisciplinary methodological framework combining social anthropology and crop population genetics. Through many examples, they illustrated that traditional knowledge as well as seed exchange systems are embedded into social structure, favoring vertical transmission of knowledge, practices, and plant genetic resources through a centripetal system. Thus, they consider that crop diversity patterns result not only from an interaction between genetic and environmental factors, G $\times$ E, but from a three-way interaction G $\times$ E $\times$ S, where "S" stands for the social differentiation factors. Following this framework, the present study investigates how Tharaka farmers' social organization contributes to shaping the diversity of their crops.

The Tharaka are one of the nine dialectal sub-groups composing the Meru group, which is part of the Bantu linguistic family (Moehlig et al. 1980). They settled about two centuries ago in the semi-arid plains on the eastern slope of Mount Kenya (Middleton 1953; Fadiman 1993) (Fig. 1). The economy of Tharaka smallholders is based on subsistence farming systems, involving a wide diversity of crop species and landraces. They carry out two cropping seasons, the first from October to December and the second from March to May. Their farmlands are frequently hit by drought, followed by severe food shortages, of which one of the most notable was described by Ambler (1988). Moreover, this semi-arid area is facing climate change, which severely affects the production (Downing 1992). Shift in rainfall seasonality and increasing temperatures cause changes of crop species and varieties, as some crops grown in the area are at their limit of adaptation (Mati 2000).

According to previous ethnographic studies, the Tharaka social organization is based on clan ties, neighborhood-groups, and age-sets (Lambert 1947; Middleton 1953). Children belong to the clan of their father and women adopt the clan of their husband when they get married. The clan identity determines social relations such as exchanges, cooperation, and marriage opportunities. Indeed, Tharaka clans are exogamous, prohibiting marriage between people belonging to the same clan. Affiliated clans live together within a neighborhood-group, called *ntora*. After marriage, women usually settle in the native ntora of their husbands. The residence is thus patrilocal and women frequently come from a different ntora or even a different territorial subdivision from that of their husbands (Peatrik 1999). Each household is thus included within a named ntora. The ntora constitutes the lowest level of political organization (Middleton 1953).

The age-set system is the third important Tharaka social institution described by Lambert (1947) and Middleton (1953), who defined it as the group of youths circumcised at the same time, irrespective of their clan or territorial affiliation. Tharaka are thus not only organized horizontally, with

Fig. 1 Study site location

differentiated clans and ntora, but also vertically with different age-sets, however the colonial administration considerably weakened this system (Peatrik 1999). The planting, selection, and trading of seeds are done by women. Men prepare the fields before the sowing, manage tobacco and some clonally reproduced crops such as yam, banana or sugar cane (Middleton 1953; authors' observations).

Our main hypothesis is that the social organization of the Tharaka influences the exchanges between farmers, including the diffusion of planting material, practices, and information. If ntora, clans or age-sets are social barriers limiting the flows of planting material and information between farmers, we expect the specific and the infraspecific portfolios to be different between ntora, or between clans, or between age-sets. Indeed, according to the three way interaction models, G × E × S, proposed by Leclerc and Coppens d'Eeckenbrugge (2012), these three social institutions (ntora, clan, and age) should structure the exchanges within the Tharaka society. However, the respective influence of each institution on the exchanges of planting material and information is unknown. In this paper, we thus investigate which of these three social institutions have a significant influence on crop diversity.

Methods

Crop diversity was measured through richness and composition of cropping systems, using quantitative approaches developed in ecology. We tested whether a relationship existed among the number of crop species cultivated per household (i.e., "species richness"), the household's crop species portfolio, which is the assemblage of crops that are cultivated together in the same household, (i.e., "crop composition"), and the ntora, clans, and age-sets of farmers. The results obtained at the interspecific level were compared with those obtained at the infraspecific level for sorghum (*Sorghum bicolor* (L.) Moench), which is the major crop of the Tharaka. The environmental factors were controlled in our field sampling strategy to avoid confusion in our inferential procedure.

Study site

Our study site was approximately 10 km^2. It was selected for its edaphic and topographic uniformity, with a constant altitude of 700 m above sea level (±50 m). The soils are also uniform across the study site. They are infertile, drained, deep, clayey, and powdery red ferrasols resulting from volcanic rock alteration (Jaetzold et al. 2007). The mean annual temperature is 22.9 °C and the mean annual rainfall is 600–700 mm (Camberlin et al. 2012; 2009).

Ninety-five households were randomly sampled on an aerial shot in order to represent around 40 % of the total population of the study area. In each household visited, women were preferentially interviewed (83 %) because agriculture is their field of competence. The households belonged to 11 ntora (Fig. 2) and 14 patrilinear and exogamous sub-clans. The five major ntora and the three main clans were retained for the analysis. Age categories between 20 and 50 years were equally represented in the sample and the mean age of the interviewed people was 42. Four age categories were constituted a priori for ease of analysis (15–30, 31–40, 41–50, 51–92).

The interviews were conducted with each farmer individually, and consisted of three sections. The first section dealt with social information concerning the household heads: their date and location of birth, their native clan, and the ntora they belonged to. The second section listed the crop species planted in the October 2010 cropping season according to the informant, and the third section reported

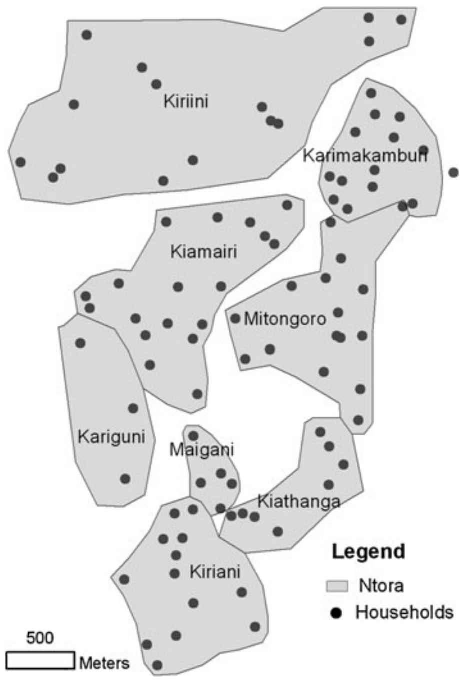

Fig. 2 Localization of the ntora

the inventory of sorghum landraces for the same season. We also surveyed the main source of each sorghum seed lot planted that season. We indicated whether they were own saved seed, purchased from market, or received from relatives. In the last case, the social link between the seed-provider and the informant was specified (belonging to the same ntora, the same clan, or the same age-set).

Data analysis

We performed statistical analyses to test the relationship among the social factors and the diversity of Tharaka cropping systems, at both specific and infraspecific levels. We tested whether the ntora, clans, and age categories (explanatory factors) explained crop diversity (response variable). The diversity of cropping systems was measured for each household by considering (1) their species and sorghum landraces richness and (2) their specific and sorghum infraspecific composition. All analyses were carried out with the R 2.13.0 software (R Development Core Team 2011).

Richness

Species richness is the number of different species (or sorghum landraces) inventoried in each household. The mean and cumulative richness were calculated for each ntora, clan or age category to compare them. The cumulative richness is the total number of distinct species (or sorghum landraces) inventoried in a population, and the mean richness is the sum of households' richness divided by the number of households in the population.

The relationship between crop species richness and each of the three social explanatory factors was assessed by a Poisson loglinear model, which is adequate for count data (Agresti 2007). For a single explanatory factor x, the Poisson model is

$$\log\mu = \alpha + \beta x,$$

where μ the mean (and the variance) of the explained variable (richness). Log-likelihood procedures determine the values of model parameters that maximize the probability of observing the empirical data. As the third and second order interactions were not significant, we studied the effect of each social factor without interaction. To assess whether the mean richness differed significantly between each social variable level (population), we used a Tukey's Honestly Significant Difference test, which compares the observed pairwise differences between populations' means to the distribution of expected pairwise differences under the null hypothesis (no differences between populations). The difference between two means is significant if it is higher than that observed in 95 % of the cases under the null hypothesis.

Composition

We established an exhaustive list of crop species and sorghum landraces cultivated in each household. The occurrence of each species and landrace was recorded in two separate matrix (one for the species and the other for the landraces), where the presence of a given species or landrace in a household was coded 1 and its absence was coded 0. Such a presence-absence matrix enables us to compute a distance between households based on their crop composition: the more similar is the crop composition of households, the shorter is the distance between them. The distance between households was measured using the Jaccard similarity index, computed for crop composition between pairs of households as follows:

$$dij = \frac{a}{a + b + c},$$

where dij is the Jaccard similarity between households i and j; a is the number of species present in both i and j households; b is the number of species present in the household i and absent in j; c is the number of species present in the household j and absent in i. A high number of common species between two households would result in a high similarity index, and vice versa. Pairwise similarity index of crop composition between households were computed separately for crop species and for sorghum landraces, and stored in separate matrix.

The composition of crop species and sorghum landraces was then compared among ntora, clans and age categories using a Between-Class correspondence analysis (Chessel et al. 2004; Doledec and Chessel 1989). The Between-Class analysis was performed on crop composition distance matrix, separately for crop species and sorghum landraces. This multivariate ordination analysis tests whether crop composition is more similar within groups (ntora, clans, or age categories) than between. Principal components are computed in order to maximize the variance between groups instead of maximizing the total variance, as correspondence analysis does. It is then possible to assess whether crop composition differs between groups using both graphical representation and Monte-Carlo test described thereafter. This constrained ordination method was developed in ecology to compare species composition between sites. An illustration of its application is given by Paillex et al. (2009) in ecology and by Baty et al. (2006) in genetics.

To test whether the crop specific and sorghum infra-specific compositions of households differed significantly between groups (ntora, clans, age categories), we used a Monte-Carlo permutation test (Manly 1997). This non-parametric test used 9999 permutations of the data to draw a random distribution of crops. It then tested whether the observed crop composition was more similar within groups than it would be under the null hypothesis, if crops were randomly distributed.

Results

Our survey confirmed previous ethnographic observations on the social organization of Tharaka, reporting that residence rule was patrilocal. Indeed, patrilocality (settlement within the ntora of the man's father) was observed in 70 % of the sampled households, and 84 % of the spouses originated from a different ntora other than their husbands' ntora. These observations are relevant for the understanding of seed, practices, and information diffusion pathways.

Patterns of richness and composition of cropping systems for crop species

Sixteen crop species were inventoried among the 95 households sampled, while each household cultivated, on average, between five and six species (mean: 5.3 ± 1.4, [1] min: 2; max: 9). Sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*), cowpea (*Vigna unguiculata*) and green grams (*Vigna radiata*) were grown by 80 % of the households. Forty percent of the households grew only those four crops, which are adapted to drought and form the basis of Tharaka cropping systems. Maize (*Zea mays)* and pigeon pea (*Cajanus cajan*) were cultivated by around 60 % of the households. Lastly, marginal species like pumpkins (*Cucurbita* sp.), cotton (*Gossypium* sp.), beans (*Phaseolus* sp.), cassava (*Manihot esculenta*), or dolichos (*Dolichos* sp.) were grown by less than 10 % of the households.

[1] Means are followed by their standard deviation.

Table 1 *p* value of Tukey's HSD pairwise comparisons for the mean specific richness between ntora

	Kiamairi	Kiriani	Kiriini	Mitongoro
Karimakamburi	0.999	0.128	0.494	0.002**
Kiamairi		0.543	0.309	<0.001***
Kiriani			0.936	0.726
Kiriini				0.227

Significance codes: *** 0.001; ** 0.01; * 0.1

The species richness did not differ significantly between clans and between age categories, whereas the species richness of a household depended significantly on the ntora it belonged to. The *p* values of the pairwise Tukey's HSD test (Table 1) were significant for the differences of mean species richness between ntora. The specific richness of households belonging to Kiamairi (4.5 ± 1.1 species) and Karimakamburi ntora (4.6 ± 1.4 species) were significantly lower ($p < 0.01$) than that of Mitongoro (6.5 ± 1.75 species). Despite their adjacency, households belonging to Mitongoro maintained more diversity than those of Karimakamburi (Fig. 3).

The Between-Class analysis according to ntora showed that crop species were not randomly distributed as there were significant differences of species composition between ntora. The ntora factor explained 9 % of the total variation of species composition, which is a significant proportion of between-group variation. The specific composition of the cropping systems of Mitongoro differed from that of Kiamairi and Karimakamburi (Fig. 4). We observed that the *p* value of the Monte-Carlo test for species composition differentiation was significant for ntora ($p = 0.0171$; Fig. 5), but not for clans ($p = 0.0977$) and age categories ($p = 0.7254$), meaning that species composition differed significantly between ntora, contrary to clans and age categories which were not significant explanatory factors for species composition.

Sorghum and millet were cultivated in every household. By contrast, the proportion of households growing maize varied between 35 % in Kiamairi to 87 % in Mitongoro, and from 35 to 81 % for pigeon pea in the same groups (Table 2). Fewer households in Karimakamburi were growing pigeon pea (43 %), maize (57 %), cowpea (79 %) and green gram (79 %) as compared to Mitongoro (100 % for cowpea and 94 % for green gram).

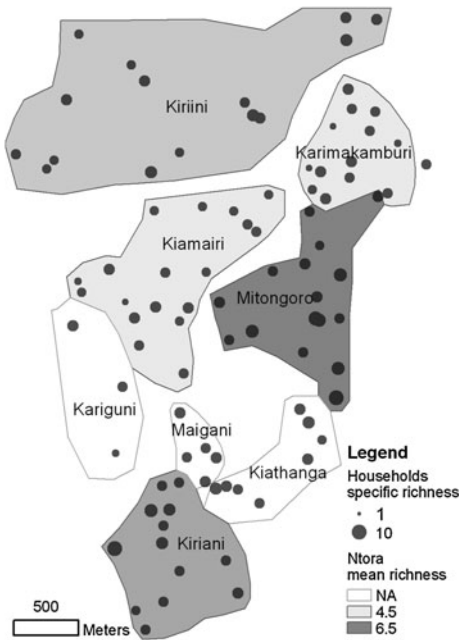

Fig. 3 Mean species richness of ntora and households' species richness

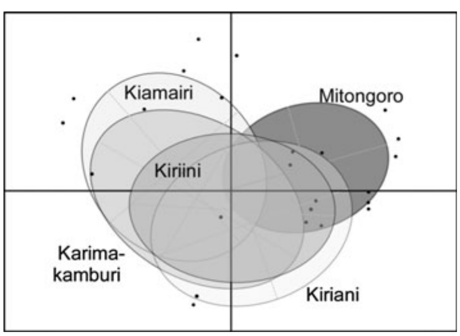

Fig. 4 Graphic display of the Between-Class analysis for crop species composition between ntora: projection of farms' portfolios similarity on axis 1 and 2 with ellipse and gravity centers of each ntora. The first and the second components of the Between-Class analysis represented respectively 66 and 14 % of the between-ntora variability

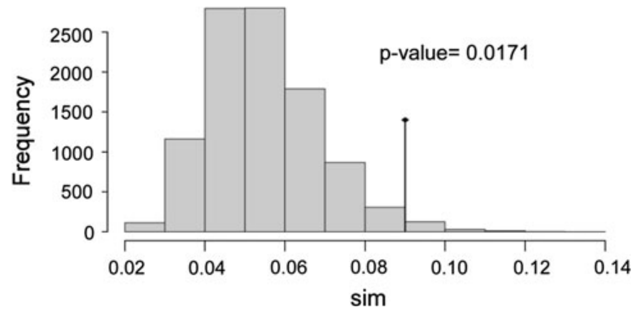

Fig. 5 Histogram of the 9999 simulated values of the Monte-Carlo test for the Between-Class analysis on crop species composition between ntora. The observed value is given by the vertical line

Patterns of richness and composition of cropping systems for sorghum landraces

While the Tharaka cultivated 21 different sorghum landraces on our study site, each household grew few of them (1.79 ± 0.74). The frequency distribution of sorghum landraces (Fig. 6) indicates that large differences in composition exist between households. *Mucarama* was the most common landrace, grown by 60 % of households; it was followed by *Kaguru* and *Mugeta*. The remaining 18 landraces were grown by less than 8 % of households, showing that each household separately cultivates only a small part of the whole infraspecific diversity of sorghum of the community.

Two-thirds of the sorghum landraces inventoried were local, which means that they have been grown within the household for at least one generation. Farmers produced a large proportion of their seed lots, thereby favoring their own local landraces. Seed source indicated that 77 % of seed lots sown in October 2010 were own seed or obtained from farmers belonging to the same ntora. On the other hand, the percentage of local landraces varied between ntora. Kiamairi had the highest percentage of local landraces, with 87 % of the October 2010 seed lots, while this percentage was 52 % in Karimakamburi, 58 % in Kiriini and 59 % in Mitongoro.

No significant relation was observed between the sorghum landraces richness and any of the three explanatory social variables (ntora, clans, age categories), but there were major differences of cumulative richness among ntora (Table 3). Table 3 shows that the cumulative richness was much lower in Karimakamburi (4 landraces) than in Kiriani (10 landraces) for a similar number of households visited.

The patterns of sorghum landraces composition were not random and the Between-Class analysis showed that there were significant differences in sorghum infraspecific composition among ntora. The ntora factor explained 11 % of the total variation in sorghum infraspecific composition. The sorghum landraces composition of Mitongoro differed from the compositions of Kiriani and Kiamairi, despite the spatial proximity between Kiamairi and Mitongoro (Fig. 7). The sorghum landraces composition of Karimakamburi also differed from that of Kiamairi. The Monte-Carlo test was significant ($p = 0.0010$; Fig. 8), confirming that sorghum landraces composition differed among ntora and that crop diversity was socially organized. By contrast, clans and age categories were not significant explanatory factors for sorghum infraspecific composition (Monte-Carlo $p = 0.6238$ between clans and $p = 0.3915$ between age categories).

Table 2 Percentage of households growing the major species in each ntora

	Number of farms	Sorghum	Millet	Cowpea	Green gram	Pigeon pea	Maize
Kiamairi	17	100	88	94	82	35	35
Mitongoro	16	100	94	100	94	87	81
Karimakamburi	14	100	100	79	79	43	57
Kiriini	14	100	93	93	100	50	71
Kiriani	13	100	100	100	100	54	77

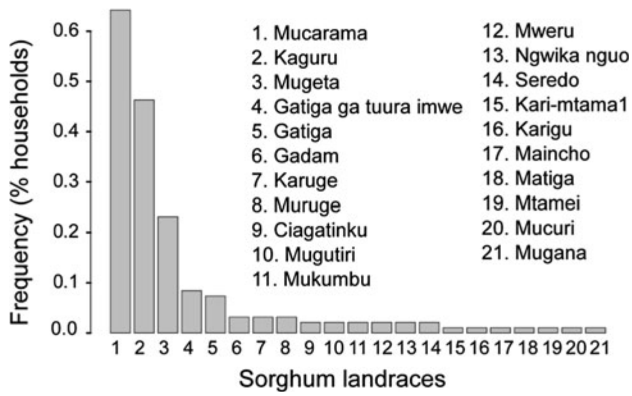

Fig. 6 Frequency of sorghum landraces (proportion of farms where each landrace is cultivated)

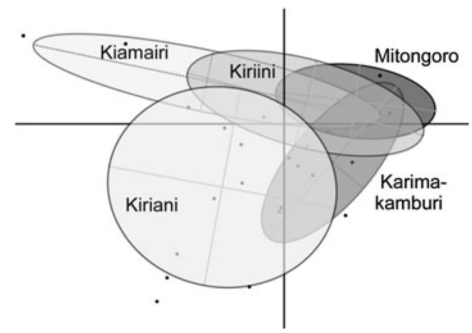

Fig. 7 Graphic display of the Between-Class analysis for sorghum infraspecific composition between ntora: projection of farms' portfolios similarity on axis 1 and 2 with ellipse and gravity centers of each ntora. The first and second projection axes represented respectively 53 and 23 % of the between-ntora variation

Table 3 Mean infraspecific richness (mean number of landraces cultivated per household within each ntora) and cumulative infraspecific richness (total number of distinct landraces cultivated in the ntora) of sorghum among the five main ntora

Neighborhood group	Number of farms	Mean richness	Cumulative richness
Karimakamburi	14	1.6	4
Kiriini	14	1.9	5
Mitongoro	16	1.7	7
Kiamairi	17	1.8	8
Kiriani	13	1.7	10
Total in the area	95	1.8	21

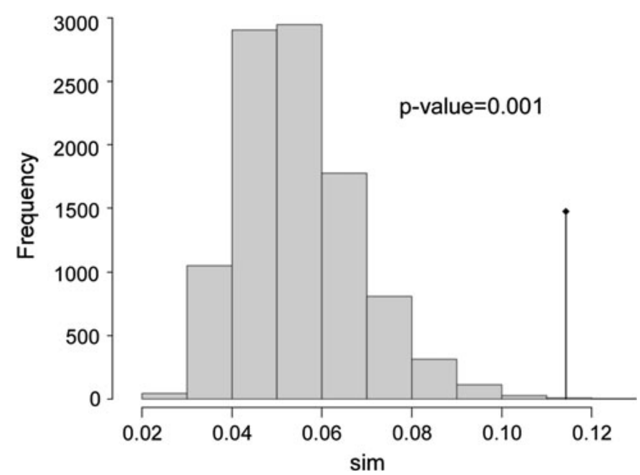

Fig. 8 Histograms of the 9999 simulated values of the Monte-Carlo test for the Between-Class analysis on sorghum infraspecific composition between ntora. The observed value is given by the vertical line

Discussion

This study highlighted linkages between Tharaka social organization and crop systems, for both crop species and crop landraces. Its aim was to quantify the effect of three major social institutions of the Tharaka, which are ntora (neighborhood-groups), clans, and age-sets, on the distribution of species and sorghum landraces diversity.

Our results showed that rural communities' social organization significantly influences crop diversity patterns in situ. The ntora organization contributed significantly to the diversity patterns of both crop species and sorghum landraces, while clan and age did not significantly influence the organization of specific and infraspecific diversity. On the contrary, no environmental effect was detected between the adjacent Mitongoro and Kiamairi ntora whose farms displayed significantly different crop richness and composition. Moreover, the proportion of local landraces differed between Mitongoro and Kiamairi. This latter group presented the highest proportion of local sorghum landraces and the lowest proportion of households growing maize, which was introduced in the 1960s.

Relation between crop diversity and the social organization

Leclerc and Coppens d'Eeckenbrugge (2012) explain that the social organization of human groups affects the differentiation of their crop germplasm. They propose that social anthropology can help to understand the differentiation mechanisms involved through the study of knowledge transmission, seed inheritance, and exchanges paths, together with marriage and residence rules.

Our results corroborate previous studies showing that farmer's behavior is strongly influenced by the behavior of others (Bandiera and Rasul 2006) and that social network plays a crucial role in the access to information (Van den Broeck and Dercon 2011) and seeds (David and Sperling 1999; Bellon 2004; McGuire 2008). The social network determines the access to seed sources as well as the opportunities to learn about crop species and varieties (Bellon 2004). The dependence of both information and seed exchanges on social organization can explain why such differences of crop diversity were found at both specific and infraspecific level between spatially close ntora. Ethnographic studies (Lambert 1947; Middleton 1953; Peatrik 1999) underlined the importance of the ntora in the social organization of the Tharaka and other Meru groups, it is thus likely that the exchanges of information and planting material take place mainly within it. Social barriers limit information and seed exchanges, and contribute to explain the differences of richness and composition we observed between ntora.

No relation between crop diversity and clan or age was established in this study, and little ethnographic information concerning these social institutions is available for the Tharaka. The complexity of clan and age-sets systems and the fact that they were considerably affected by the colonial administration (Brokensha and Glazier 1973; Peatrik 1999) could explain why their contribution to shaping seed and information exchanges appeared limited. Introduction of formal education and abandoning of indigenous cultures could also explain why their contribution is not significant.

Seed exchanges are limited by the social barriers

Among the Tharaka, the existence of social barriers is underpinned by the fact that most of the seed exchanges take place within the ntora, which corroborates the observation of Badstue et al. (2007) concerning the importance of trust in seed exchanges. It also supports the findings of McGuire (2008) who showed the importance of social networks in shaping seed networks. Centripetal seed exchanges, combined with vertical transmission customs, thus favor the differentiation of crop diversity between ntora (Leclerc and Coppens d'Eeckenbrugge 2012). At the same time, the Tharaka customary seed transmission pathway favors the maintenance of species and landraces within the ntora as ethnographic observations document that the mother-in-law provides her seeds to the newly married daughter-in-law who settles within the same ntora. On the other hand, one can argue that the proportion of seed lots coming from outside the ntora is potentially high and can lead to the homogenization of crops across ntora. The fact that this does not happen suggests that the social organization also contributes indirectly to restrict the exchanges of planting material through the limitation of information flows between farmers from different ntora.

Knowledge and practices are shaped by the social network

Several studies have shown that the social network is crucial for the adoption of new technologies and new planting material. They have suggested that it was more relevant to focus on small-scale social interaction (Conley and Udry 2001; Bandiera and Rasul 2006) and intensive exchanges of information between neighbors has been highlighted in several countries (Conley and Udry 2010; Van den Broeck and Dercon 2011). Knowledge transmission pathways affect cultural differentiation (Cavalli-Sforza and Feldman 1981), they are consequently involved in the divergence of farmers' practices. The vertical transmission of knowledge from parents or relatives to children favors cultural differentiation, contrary to the horizontal transmission between individuals belonging to the same age cohort that favors cultural uniformity. According to previous observations in another Meru group, the newly married spouses are trained to farming and household running by their mothers-in-law until the latter judge that the spouses are ready to manage their own household (Linsig personal communication). The knowledge transmission concerning crops thus follows the transmission of seeds from mothers-in-law to daughters-in-law. This vertical transmission pathway for agricultural practices favors their divergence between patrilinear families. In addition, horizontal knowledge exchanges between ntora appeared limited among the Tharaka. Indeed, we noticed that most mutual help and cooperation takes place within the neighborhood-groups, which is consistent with observations in other Meru groups (Peatrik 1999). It is therefore likely that both vertical transmission of knowledge from the mother-in-law to her daughter-in-law and horizontal transmission within the ntora favor the divergence of agricultural practices and thus the differentiation of crops between neighborhood-groups. For instance, it is striking that maize frequency is much lower and local sorghum landraces frequency is much higher in Kiamairi as compared to Mitongoro. This may result from a common reluctance to introduced crops in Kiamairi. Personal observations support this hypothesis as some Kiamairi farmers had a negative image of maize because it was not traditional. In addition, the fact that maize is not well adapted to the harsh climatic conditions of the area may explain why farmers' strategies concerning this particular species are different.

Last, the vertical knowledge transmission pathways may lead to the divergence of farmers' selection practices between neighborhood-groups, and thus contribute to infraspecific genetic diversity patterns. Indeed, the selection practices are culturally determined, as shown by Pressoir and Berthaud (2004) and Perales et al. (2005), who highlighted the divergence of maize selection practices among villages and ethnolinguistic groups in Mexico. Similar divergence between Aguaruna families was described by Boster (1986) for the identification of cassava cultivars, which is an activity closely related to selection. The divergence of selection practices can contribute to the observed infraspecific diversity pattern of sorghum, but a precise characterization of the agro-morphological diversity is necessary to assess the importance of this effect.

Perspectives

Our sampling strategy focused on ntora and enabled us to characterize the effect of this factor with sufficient statistical power. However, we lacked information concerning clans and age-sets. This strategy was therefore not optimal for studying the latter factors. Due to sample limitation, it was not possible to test interactions between ntora, clans, and age. Nonetheless, such interactions may exist. Each ntora is composed of major clans because of the patrilocality settlement custom, so it might be difficult to figure out which of the two factors is involved in diversity patterns. Moreover, clan identity plays a central role in alliances and exchanges. For instance, the prohibition of seed exchanges between clans related by the Gishiaro link suggests that this level of social organization may have an impact on crop diversity. Larger-scale studies are needed to address this issue. Due to the lack of information concerning age-set systems among Tharaka women, age categories were created a priori and without ethnographic bases. This choice may have affected our analysis. However, our own observations complemented by literature suggest that, since women initiation was abandoned at least 40 years ago, the age-set system has lost most of its significance (Peatrik 1999).

Uncontrolled environmental factors, such as the local edaphic variations (Bazile et al. 2008), the proximity to the local market or to an NGO, as well as the economic status of households (Rana et al. 2007), could have interfered with the ntora organization. Against this possible criticism, we would like to stress the consistency of our results for crop species and for sorghum landraces and the fact that adjacent ntora have different crop compositions. Moreover, these observations disagree with the hypothesis that the structure of information and seed exchange could result from geographical proximity.

Our study of sorghum diversity was based on local Tharaka nomenclature and we were not able to identify synonyms or homonyms as neither morphological nor genetic characterization were carried out. However, local names of sorghum landraces are indicators of cultural variations. This is illustrated by the work of Boster (1986), who showed that agreement between Aguaruna informants concerning the names of cassava cultivars is correlated to social distance between them. Common naming systems are indicators of cultural proximity and frequent exchanges between farmers. Studying rice cultivars names in Gambia, Nuijten and Almekinders (2008) observed that their uniformity reflects the intensity of seed exchange. When frequent seed exchanges of the same variety between two villages occur, that variety may obtain the same name in both villages. Farmers' variety names are exchanged as other language elements and thus can be used as a social differentiation index.

Applications for crop diversity study and conservation

As most rural populations retain their social organization, our demonstration is not limited to the Tharaka. The works of Perales et al. (2005), Pressoir and Berthaud (2004), and Baco et al. (2008) confirm that our findings among the Tharaka refer to more general mechanisms. In addition, their findings indicate that our approach could be generalized at different levels of social organization, from family units to ethnic or linguistic groups, as proposed recently (Leclerc and Coppens d'Eeckenbrugge 2012). Most studies dealing with crop diversity focus on the individual choices of farmers, emphasizing their dependence on environmental constraints (Lacy et al. 2006). They usually overlook the importance of social organization, neglecting that crops are reproduced, selected, and preferentially exchanged within socially defined groups. Bypassing the study of social organization may thus hamper the investigation of evolutionary processes involved in crop diversity patterns. We therefore recommend that research and conservation initiatives take more account of the social organization impact on crop diversity.

Our finding can be applied to conserve and sample genetic resource in situ more efficiently. Indeed, genetic resources collections generally neglect the sampling strategy at the local scale, targeting a limited number of accessible households. Furthermore, up to now, most crop collections have been based on geographic distance and agro-ecologic zonation, even though the link between crop diversity and climate is not always clear (Deu et al. 2008). While the cultural diversity and social structure of farmers has rarely been considered, our results show that it can have a strong impact on the spatial structure of diversity even at the local scale. They demonstrate that social anthropology surveys prior to inventories and sampling would help to capture crop diversity more efficiently.

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