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Expanding and intensifying rice production consequences on agrobiodiversity management and diet quality. A situated transdisciplinary gendered analysis in Senegal Middle Valley River.

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Abstract

After the extensive droughts of the mid70s in the Sahel, the construction of the Diama and Manantali dams materialized the will of the Senegalese State to develop the Senegal River Valley region. From 2010 the government accelerated the pace to economically valorize these investments by implementing an ambitious national program of rice self-sufficiency. However, that rapid irrigated rice expansion added to the drought and pushed back the natural floods, endangering the traditional culture system of flood recession in the main riverbed, the *Waalo*. But the traditional flood recession cropping system is low in inputs: not as labour-intensive as rice (direct planting) and rich in biodiversity, in particular for sorghum. The DIVA project, was conducted in Gu ed e-Chantier and 2 surrounding villages (Podor Department) and was carried out within the Halpulaar society, the majority in the middle valley. It aimed to comprehensively describe the consequences of these transformations for the agricultural, social, gender and nutritional dimensions. Considering that the convergence of academically distinguished research objects could be better achieved by associating research with various actors involved in local life, thanks to the mediation of the NGO Enda Pronat local peoples, the experimentation in the reality of transdisciplinary was also a scientific objective of the study discussed in this paper. So we applied a gendered transdisciplinary approach to consider three interconnected dimensions: social and family logics, agricultural management of biodiversity and diet quality. Results show that women's initiatives to improve and diversify their diet in response to rice pressure, essentially consisted of organic or non-organic collective irrigated gardeners, established with the help of NGOs but without any technical or financial support from the public policies. Nevertheless, we assessed that the current diet quality of the women was of concern, with an overconsumption of cereals (white rice) to the detriment of other plant-based foods and animal products. Simulations of the dietary changes that have occurred over the past 45 years showed that the diet quality has deteriorated with a significant decrease of nutrient intakes such as thiamin, vitamins B-6 and B-12, iron, potassium and zinc. We conclude that the rice intensification is increasing pressure on the flood recession system, which, by disappearing, increases food and environmental problems. Facing these deteriorations, the management of local agricultural biodiversity initiated by women is diverse and localized but limited and not so far supported by any governmental policy.

Keywords: Transdisciplinary; Sustainability Science; Nutrition-Sensitive Agriculture; Gender analysis; Biodiversity Management; Diet quality.

Introduction

Facing increasingly observed paradoxical situations showing disconnections between agricultural production and the different forms of malnutrition, especially in South Saharan Africa and Asia, a growing number of institutions around the world are committed to supporting nutrition-sensitive agriculture to achieve development goals. In a review about this topic, Ruel and Quisumbing (2018) identified six pathways through which agricultural intervention can impact nutrition and three of them relate to women: women's social status, health and workload. In another review, Carletto *et al.* (2017) recommend as a research priority, in particular for Africa, a better understanding of the transmission channels between crop choices, commercialization and nutritional outcomes through gendered approaches.

In the present situation the research gaps found their causes in agricultural development policies shaped by postcolonial and neoliberal policies that have privileged certain groups and neglected other issues, in particular women in agriculture, conservation of agrobiodiversity (Ravera *et al.* 2016; Zimmerer and de Haan, 2019) and diversity of food habits (Raschke and Cheema, 2008; Guétat-Bernard and Ndami, 2019). Nevertheless, a gender lens is essential because peasant seed selection and food functions are connected with African gender social norms and division of labor which impact food practices and activities (Westholm and Ostwald, 2020). This invisibility and underestimation of the crucial role of rural women in the use and conservation of seeds was pointed out in particular by Patricia Howard (2003). This book documented extensively that the knowledge and use of plant biodiversity is gender-differentiated everywhere. It defends the statement that gender perspective change our understanding of people-plant relationships in fundamental ways. In particular, when women select varieties for their fields or gardens, they consider not only agronomic characteristics, but also those related to processing, storage, consumption and the health needs of family members and domestic animals.

The present study was based on the hypothesis, which is at the basis of the DIVA research project, that changes in diet are linked to agricultural changes, and proposed to support this hypothesis by connecting surveys involving a transdisciplinary approach (between biotechnical and social sciences: agronomy, genetics, nutrition, socio-anthropology) through a gender analysis. In order to carry out the study in a collaborative way (Pohl and Hirsch Adorn, 2008; Lang *et al.*, 2012; Brandt *et al.*, 2013; Wolff *et al.*, 2019), various local stakeholders, outside academia, including the NGO Enda Pronat, the Senegalese Association of Farmers' Seeds (ASPS), were solicited as well as the contribution of Senegalese scientists working regularly in this region, particularly with women.

The study experimented with a transdisciplinary (TD) research as defined by Jaeger and Scheringer (1998) and Scholz and Steiner (2015): an approach in which the definition of the problem is independent of disciplinary considerations that are no longer able to cope with the increasing complexity of 'real-world' and contextualized problems. So, the originality and innovative nature of this project is threefold:

1. It was based on the definition of the research subject established in close collaboration with local NGOs, farmers' organizations and the civil society;
2. It was linked to the deep nature of the academic TD effort implemented where the combination of social sciences and biotechnical science presented difficulties, both theoretical and practical;

3. It was crossed by a gender analysis that is not only focused on gender relations in the family and community but also concerned technical agricultural observations on biodiversity management and nutritional records.

The primary aim of this article is to give a multidimensional and comprehensive (relational) view of the consequences of the recent evolution of agriculture in Middle Senegal Valley. The dimensions considered are the cultivated biodiversity, the female agricultural and culinary activities, gender relations within the family and the nutritional quality of family food. The second aim is methodological: as we consider the DIVA project as an experiment in TD research, we make a reflexive return to what is at stake in terms of conception of research, methods and results' analyses.

1 Methods

Knowledge integration in TD processes starts with updating specific contextual information drawn from direct consultations with various people involved in the life of the locality. Based on the model developed by Scholz and Steiner (2015), this fine contextualization is connected with the investigation protocols and, therefore, not outside the study's scope.

Contextualization

An agro-system historically built on the sorghum based flood recession agriculture

The study was conducted in the middle valley of the Senegal River, district of Podor in the North of Senegal. More specifically, our study area was located in three neighboring villages (Guédé-Chantier, Guédé-Village and Lérabé) situated on a branch of the river, the Doué (Fig. 1).

Two major ecosystems make up the landscape: the *Waaló*, composed of rich, clayey soil near the river and depressions, and the *Dieri*, composed of sandy dune-type soil. The traditional mid valley *halpulaar* territory, called '*Leydi*' (Fig. 2), is characterized by its geographical discontinuity and by movements of people and herds between the two areas (herds moving into the *Waaló* during the dry season for example). Floods structure the agricultural, pastoral and fishing activities; the recession cultivation in *Waaló* is imbricated with agro pastoralism in *Dieri* and with fishing activities in the river and semi permanent flood basins (Le Roy, 2008; Cesaro *et al.*, 2010; Garambois *et al.*, 2018). The queen recession plant species is sorghum (*Sorghum bicolor* L.), locally called *Samme*. Sorghum is sown as soon as the recession basins - called *Kolangal* consisting of a rich hydromorphic soil (*Hollaldé* type) - have dried out enough for direct seeding, which allows rapid sowing of large areas. Further, in these excellent agro-ecological conditions, recession sorghum has economic, social and nutritional advantages because it has high cultural and nutritional value and does not require monetary loan inputs, ploughing or complicated tools and productivity is high (Le Roy, 2007, 2008).

An expansion and intensification of rice cultivation disrupting the equilibriums

The agricultural system in the mid valley of Senegal River has undergone a major transformation since the climate crisis in the Sahel in the years 70-80s which has compromised hitherto durably rain fed crops and added uncertainties regarding traditional flood recession crops. In response, the Senegalese Government has since the 1950s strengthened the hydraulic installations (the Diama Dam downstream and the Manantali Dam upstream) in an attempt to develop irrigated crops (Seck, 1990). Hence, very visible transformations have taken place in the mid valley through the setting up of irrigated perimeters (locally called PIV), of which the Guédé-Chantier village is an emblematic place, that more and more transform the landscapes by replacing agro-pastoral and fishing systems, deeply anchored in a specific territory, by an intensive production system of irrigated

cultivation (90% rice). During the 1990s, dams allowed the tripling of the irrigated areas and rice production increased (Fig. S1 in Result S1 in Online Supplementary Material). The widespread use of irrigation and increased drought (rainfall is now stabilized at around max 250 mm /year instead of around 300 mm on average before 1970) considerably reducing the natural flooding of the river and jeopardizing the traditional farming system. Most inputs were therefore based on synthetic fertilizers, with consequences both to the rate of soil organic matter and to the dependence of families on input purchases and borrowing (Garambois *et al.*, 2018).

As a result of rising cereal prices, the 2008 global food crisis has hit Sahel countries hard and a new wave of an intensive rice program, began in 2010, planned to accelerate the pace of the movement towards the country's rice self-security. This plan called *Programme d'Accélération de la Cadence de l'Agriculture Sénégalaise* (PRACAS) is the main agricultural element of the economic 'Plan of Senegal Emergent'. The backbone of PRACAS consists in an extension of irrigated rice areas implemented by the national *Société d'aménagement et d'exploitation des terres du Delta et du Fleuve Senegal* (SAED) whose assignment by the State is essential since the State controls total irrigated land attribution which conditions the access to bank credit to buy seeds, inputs etc. for the rice cultivation campaign. This has led to such a great transformation in family life regarding food, health and social relations that most of those involved seriously question the ongoing situation.

Nutritional context

The inhabitants of the middle and lower valleys, which remained isolated rural areas until the end of 1990s, have since changed their food habits by eating more rice instead of local cereals. The World Food Program showed that food insecurity in the Podor department was of concern with only 65% of households considered as food secure while the national prevalence is 83% (WFP, 2017). In addition, it was shown that the diet in Northern Senegal is mainly composed of cereals, roots, vegetables oils and sugar and, to a lesser extent, vegetables, legumes and animal products (WFP, 2014). While this survey seems to indicate an unbalanced diet, accurate data about the food quantities consumed by the household and the individuals are lacking.

Intersectionality and social interaction of caste and gender

The majority of the population belongs to the *Halpulaar* ethnic group hierarchized in castes which define the powers (religious or over land ownership) and craft activities in the '*Leydi*' (Fig. 2). For example, the situation of interdependence of traditional craft trades resulted in exchanges of sorghum, milk and fish at the end of the rainy season (Boutillier and Schmitz, 1987; Boutillier, 1989). The system for allocating irrigated private land and the increase in (male) migration have had contradictory effects by favoring less strict caste hierarchies (Boutillier, 1989), and the maintenance of gender inequalities, in particular through the practice of virilocality (the spouses must settle in the place of residence of the husband's parents). The virilocality is certainly all the more strategic (Feldmann, 2013) in a context of irrigated agriculture where the demand for labor is increasing (Cordell *et al.*, 1996). Access to land is patrilineal and disproportionately favors men over women and high caste women over those at the bottom of the hierarchy (Sall and Thioune, 2012). This is particularly true for access to the most coveted land such as the *Waalo* and the *Falo* (on the river banks). Women's individual right to land not being recognized, they have, with the support of NGOs such as ENDA Pronat, recently negotiated access to shared gardens. But the land granted is often remote, not very fertile and not big enough to cover the needs and expectations of the women. Despite the heterogeneity of women's status according to their age, their entry into marriage

and their relationship to the head of the family, these gardens are often spaces of female solidarity.

Study design

Field research was conducted from April to June 2019 mainly by three female master students who lived and worked in the three villages jointly with three male Senegalese student-facilitators and translators from the local community of *Halpulaar*. An experimental (non-probabilistic) sample was established by local members of Enda Pronat to take advantage of their permanent presence in the area. This sample was constituted by nine families, three families in each village, involved in subsistence-oriented farming and with variations in socio-economic level and number of family members. Within these families, we have worked with 12 households (locally called *foyré*), considered as a set of people sharing the same meal. The *foyré* is also a socio-economic space of production and reproduction. This overlapping of status within the productive sphere and within the family explains the invisibility of women's work, especially as regards irrigated rice cultivation where it is considered as marginal and qualified by the women themselves as 'help'. Specific surveys related to three domains of research were jointly conducted on different members of the 12 households, as described in the following sections.

Agricultural system and biodiversity survey

All women and men from the 12 households were asked to provide information about the family functioning of agricultural systems, agricultural production and biodiversity management in semi-directive interviews. The individual interview guidelines were adapted to the respondent and the information collected took into account the differentiation between the fields cultivated by men and the areas cultivated by women. The interviews were analyzed in order to create a typology of farming areas and farmers' strategies (Rahmoun, 2018). In addition, a free listing method was used to obtain from women and men, from the 12 households but asked individually, a list of cultivated and/or known plants, present or formerly present, in order to investigate the most important ones in more detail.

Dietary survey and diet simulation

Women usually responsible for food preparation for the household were asked to provide information about foods and beverages consumed by household members during the previous year using a semi-quantitative Food Frequency Questionnaire (FFQ) co-developed for this study with local members of Enda Pronat (Gueye, 2018). Matching with relevant food composition database, energy and 21 nutrients intakes by household members were estimated. Then the adult male equivalents (AME) method was used to calculate the AME-predicted food and nutrient intakes of the women (Weisell and Dop, 2012) and the AME-predicted nutrient adequacy of the diet was assessed calculating the percentage of women not respecting the international nutrient recommendation (Joint WHO/FAO Expert Consultation, 2004). The complete method is detailed in Method S1 in Online Supplementary Material. Based on the main dietary changes identified through semi-directive interviews with men and women more than 65 years old from the 12 households about dietary changes that had occurred over the past 45 years, we simulated the effect of these changes by creating a simulated-past diet for each woman. SAS version 9.4 (SAS Institute) was used to perform the descriptive analyses of food and nutrient intakes and to conduct the simulations.

Comprehensive approach to the interaction between garden, yard and kitchen

To further understand the specific role of women in the local food system (agricultural production, biodiversity management, food preparation – ingredients and recipes – and sharing, food behavior), comprehensive and 'conversational interviews' (Olivier de Sardan,

1995) were conducted with all the women from the 12 households. The adoption of this socio-anthropological and geographical posture had the particularity of creating a ‘listening situation’, where the interview as interaction took place at home, in the concessions or in the fields. Benefiting from a presence of three months in the area and previous stays in Senegal, one of the master student investigators who were making the social geography inquiry (Gardien, 2018) had the possibility of coming back and renewing the ‘conversational interviews’. This investigator, a young unmarried woman (who had been assigned a role related to this status), also used a participative observatory perspective related to specific responsibilities of women such as field and kitchen work (preparation of food, cleaning the yard or the dishes). This research posture had for its ambition to analyze words and gestures, and to take an interest in places (the kitchen, the yard, and the garden) and the way they condition speech. In addition, using the geographical approach of territorialities and the meaning of spaces given by the actors according to their social positions, some landscape readings were conducted during walks.

Ways of working the transdisciplinary approach

In addition to the specific surveys of agricultural production and biodiversity, diet and role of women in the local food system, peripheral interviews were realized simultaneously with a panel of 17 key informants about these different topics. This panel covered a large range of socioeconomic positions.

Several formal meetings were organized in the study area in 2018 and 2019. An initial field meeting was held before the beginning of the study and involved 70 people (with Enda's employees, researcher from Africa Rice, teacher of the Eco-School of Guédé, responsible person from SAED, leader of women's organizations, peasant organization members ASPSP, medical nurse and traditional nurse ‘*badianogo*’) to mobilize, explain and discuss the issues at stake in the area.

Two workshops were then held during the supervising mission and involved the three student-investigators, the three student-facilitators, some Senegalese scientists and some members of the DIVA team (French academic researchers and local members of Enda Pronat).

Finally, a festive event called the ‘Diva Fest’ involving more than 75 people was held to share the results from the study with most of the women who were interviewed in the study, and collectively discuss these results. This event was also the opportunity to promote local biodiversity and culinary practices with collective meals.

2 Results and discussion

2.1 Multidimensional understanding of the consequences of the transformation of the agricultural system

The new agro-system organization, family food strategies and gendered work organization

The two years of the study allowed us to observe the complex design of the agro-system in relation to food strategies (Fig. 3), with the recession culture being absent during the first year and present during the second. The agro-system was geared mainly towards cultivation of irrigated Nerica-type rice varieties (‘New Rice for Africa’ from Africa Rice) and many local actors have mentioned that prioritization of irrigated rice cultivation had disorganized the whole production system so none of the surveyed families cultivated rice in the warm dry season (harvest in July) despite SAED recommendations. Nerica comes from crosses between *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) but nutritionally they are varieties of ‘white rice’ improved only to be productive under irrigation. The productive logic

in the system of the valley is to limit risks, first and foremost the risk of food shortage especially during the lean season. Another cash and food crop in the production system is the local purple variety of onion called '*Violet de Galmi*'. Onion was sold in a structured value chain, which generally helped to maintain a satisfactory selling price, and constituted the most regularly valuable agricultural production. According to families that can produce in the *Waaloo*, the capacity to produce onions (with a surplus from 2 to 15 tons according to the family) seemed decisive for building a cash inflow allowing for buying food and achieving food self-sufficiency in the absence of a recession culture. The last dominant crop in the production system was the Roma non-local variety of tomato, entirely given over to processing by the *Société de Conserves Alimentaires au Sénégal*, in Ross-Bethio (Senegal River delta).

As mentioned earlier, the productive logic in the system of the valley was, always intended to be, oriented mainly toward limiting risks to primarily achieving food self-sufficiency all through the year. The lean period is a constant preoccupation for women. The participatory survey revealed that in the *Waaloo* rice enters into land competition with the traditional flood-based organization and that this poses a real problem for families because of the attachment to traditional systems for technical, economic, food and cultural reasons, as other authors have found (Le Roy, 2007; Bruckmann, 2018). As typically in small family farming, the diversification of sources of income and food production is the main strategy of the families. The recession cultivation of sorghum fulfilled this function perfectly because it cost much less to grow (requiring less work and no inputs) and provided more money than rice that is sold by the kilo for twice the price. Nevertheless, such a strategy faced several limitations. Aiming for food security much more than for the achievement of good rice yields placed the families at odds with the demand of the public authorities transmitted by SAED which relates only to the objectives in terms of irrigated area and annual production: the rice production is expected to increase from 455,000 tons in 2018 to 875,000 tons in 2020. As a consequence of this mismatch between local and national objectives, families cannot but deplore the lack of technical and financial support from public authorities for the carrying out of diversification activities. Another important limitation was the land constraint, especially because the *Waaloo* lands prone to flood recession culture are never sold if not occupied by rice, tomato or onion (Bruckmann, 2018). According to the perception of being food secure, defined by families as being able to achieve self-sufficiency in rice and having extra assets from off-farm activities or expatriates, different strategies of production and limitations were described (Table 1).

While there were different strategies of diversification, a clear gendered organization of agricultural work was observed (Table 2). Globally, in irrigated plots of the *Waaloo*, under the responsibility of the men, almost exclusively owners of the land, the women were carrying out different strategic tasks (transplanting, weeding, guarding the cultivation against birds, harvesting) for the production of rice, onions and tomatoes. The new agro-system organization has created a novel female status, that of the 'woman who helps', which means she loses all family and social recognition. Even when migration kept young men absent and women were involved in many tasks, they very rarely gained recognition with strategic bodies (Top, 2014). When the lack of manpower made it necessary to make choices between crops in the irrigated *Waaloo* or flood basins, the family choice gave priority to irrigated plots and rice that became strategic for the families' food security and for earning money. The *Waaloo* has thus lost its place as a feeding ground to irrigated areas, and to rice, which is now the staple food of the peasants. Sorghum, on the other hand, was becoming a cash crop for some families, who preferred to sell it when they grew it because: '*The 50 kg bag is worth 30,000 FCFA for sorghum against 15,000 FCFA for rice. The women sell and the profits go to the husband but are shared in the family in the form of food*'.

By contrast, specific women (such as the wife of the head of the household after negotiation and agreement with the land owners of the noble caste (*Lawokobé*) were responsible for all the agricultural activities in the *Falo* (along the riverbanks), for six months of the year. The men, at their request, came to their aid. The products from the riverbanks could be used to enhance sauces and accompany dishes such as cowpea. Corn was eaten roasted, especially by children; sweet potatoes, grown on the lowest part of the banks, could be found in lunch dishes, served as a vegetable, as can squash or cherry tomato. The *Falo* has been gradually abandoned in favor of collective gardens; its cultivation was also more difficult due to the lack of flooding. In the *Dieri*, the involvement tended to be somewhat more balanced in the sense that both men and women worked in this area but on separate activities: men were more involved in tillage, plowing and weeding while women were more involved in harvesting. This pattern was slightly different depending on whether millet or colocynth and cowpea were cultivated (Table 2). Finally, there were specific areas in irrigated *Waaloo* recently gained by women for shared gardens dedicated to highly diversified productions such as hot pepper, cowpea, squash, cherry tomato, sorrel, eggplant, beetroot, onion, salad, cabbage and okra. Invariably, women were solely responsible for food processing whatever the cultivation and the area where the cultivation came from (Fig. S2 in Result S1 in Online Supplementary Material).

Knowledge on biodiversity and breeding in their agro-ecological context

While the cultivation of recession sorghum, cowpeas and corns has declined in favor of cultivation of irrigated Nerica-type rice varieties, this did not seem to have consequences for the knowledge of biodiversity or the breeding of traditional species varieties. Having such perennial knowledge was in sharp contrast to Nerica-type rice varieties, which were associated to no specific knowledge and generally known by the name ‘Nerica’ followed by a serial number.

When focusing on recession sorghum growing in the *Waaloo*, women listed up to 19 varieties whereas only 5 of them were still cultivated. The other varieties are still available locally, preserved by some families and sold in the bush markets; they are still present, too, in culinary memories. The women were able to accurately describe the characteristics of the grain and flour, the related agricultural practices (e.g. crop cycle, seasonality), the interests and disadvantages of cultivating the variety, and the management of seeds. This was explained by the fact that seed management and breeding were traditionally the responsibility of women. All these varieties were local or peasant. A summarized description of the 8 most cited recession sorghum varieties and photographs can be found in Tables S1 and Fig. S3 in Result S1 in Online Supplementary Material. Briefly, the 3 most frequently cited varieties were *Poordi* (which means brown, the color of the seed), *Mariam Sowdou* (from the name of the woman who introduced and spread it) and *Balieri* (which means white). Yellow variety (*Paaca*) was also mentioned. The choice of cultivating one or another variety was guided by the length of the crop cycle (e.g. the *Poordi* cycle was 20 days shorter than the *Balieri* cycle) and bird attacks (e.g. the *Balieri* was less sensitive compared to *Poordi*). As a result, the *Poordi* variety was the most cultivated while its bitter taste (a protective factor against bird attacks) was less and less appreciated by the families. Among the 19 other varieties mentioned, the cultivation of most of them has been abandoned due to longer cycles (e.g. *Bobo jamm* and *Samba Souké*). In addition, the decrease in flooding for several consecutive years has had consequences for the seed conservation of these different varieties. Because the maximum storage time is two years according to women involved in sorghum breeding, and because of the uncertainty of the next floods, women progressively stopped keeping seeds and preferred to buy them at the market or from neighbors. Nevertheless, some women did their best to save sorghum seeds.

In addition to the recession sorghum or cowpea cultivation in the *Waalo*, there was traditionally a large biodiversity of edible species allowing families to feed themselves during the year. Women listed varieties of squash and pumpkin (called *Déné Boudé*) with yellow flesh (called *Diayédjé*), maize, cornilla (called *niébé*), and black rice (called *Sarna* or *Maro Balléo*, which was cultivated before the Nerica rice), wild grasses with small edible seeds (known locally as *Pagguri*, locally considered similar to *fonio*), fruit of the water lily, seeds of *Nymphaea lotus* (called locally *Ndayri*), or bulb of *Gladiolus sp.* (*Iridaceae* locally called *Dayeedji*). However, the consumption of the previously mentioned species has decreased although some of them are still much appreciated foods, especially for their seeds (called *Podé*); they are available in the market. One woman explained: ‘*The disappearing crops means that people stop eating these foods. Because if you don't grow them anymore, you have to buy them, so you don't prefer to buy them, because before you could get them for free, apart from the trouble of growing them*’. *Podé* was one of the plants and associated dishes constantly evoked and considered as a culinary loss while it was alive in people’s memories. Cooking it is always a celebration: the choice to live in the villages, and sometimes in the concessions, made it possible to ask the families to cook the *podé* for us. This was an opportunity to measure the emotion involved in making this dish. Wild bush fruits such as *jujub* (desert date palm (*Balanites aegyptica*)) and *Fulani ngigili* (*Boscia Senegalensis*) have also become rare. The *Kelly* (*Zizyphus Mauritania*), a bush fruit resembling the *jujub* has completely disappeared (according to fieldwork, see also Boëtsch *et al.*, 2012).

Consequences of the new organization of the local agro-system on women’s diet

Another consequence of the new organization of the local agro-system concerns the quality of the diet of the families, and notably of the women. Data collected through the FFQ in 12 households were used to calculate AME-predicted food and the nutrient intake, over the previous year, of 43 women aged from 18 to 65 years. The current diet, described in Table 3, was mainly based on cereals, rice intake representing 61% of the total intake of cereals: wheat 18%, maize 8%, sorghum 8% and mil 5%. It also included modest intakes of fruits, vegetables and legumes mainly produced by the women in the shared gardens and the *Falo* (only 35% of the women followed the advice of consuming 400 g/d of fruits, vegetables and legumes (Joint WHO/FAO Expert Consultation, 2002) and very low intakes of animal products.

While the average energy intake of 2791 kcal/d might be relatively adequate as compared with the average energy requirement for women with active lifestyles, the current global nutrient adequacy of the diet was of concern (Table 4). Due to the predominance of refined cereals in the diet, more than half the women were unable to respect the recommendation of eleven nutrients, and a large portion of the sample did not meet the recommendation of two-thirds for iron (62.8%), vitamin A (55.8%), vitamin B-12 (48.8%), folate (46.5%), and riboflavin (39.5%) indicating a risk of nutrient inadequacies.

Based on interviews with adults older than 65 years, four main dietary changes that have occurred over the past 45 years were identified and we simulated the effect of these changes by creating a simulated-past diet for each women where i) the consumption of meat was raised to 20 g per day; ii) the current consumption of fish was multiplied by ten; iii) the current consumption of legumes was multiplied by two; iv) the associated increase of energy intake was compensated for by the decrease of consumption of cereals; and v) among the consumption of cereals, the consumption of rice and wheat was replaced by a caloric equivalent consumption of sorghum and mil. As a result, the simulated-past diet, richer in meat and fish, was found to be associated with higher average intake of most of the nutrients and a reduction of the prevalence of women not respecting the nutrient recommendation

(especially for thiamin, vitamins B-6 and B-12, iron, potassium and zinc). Nevertheless, this diet cannot be qualified as healthy due to a low consumption of fruits and vegetables.

While our estimations of both current and simulated-past diet might be prone to errors and bias, interviews with local actors about our results and comparison with literature about current and past diet in Sub-Saharan Africa indicated that our results were not too strongly affected by these errors and biases (see Method S1 in Online Supplementary Material for a more detailed discussion). Another question that arose in our work regarding diet has to be mentioned. While the kitchen space was clearly described by local women as a food space in continuity with the agricultural space where the sovereignty of women was exercised and where they expressed and improved a whole series of knowledge dishes (Fig. S4 in Result S1 in Online Supplementary Material), it would be desirable to continue investigations into the links between dishes and associated plants, all the more so since these are subjects that arouse great interest among women. We initiated this approach by starting with certain emblematic, such as preparations based on cowpeas or sorghum coucous (*niri*) whose consumption has fallen sharply due to lower production and higher purchase costs. Different preparations are associated with *niri*: *niri Kosam* (with milk), *niri bouna* (with dried fish) or *niri beref*. There are emblematic dishes, still prepared for certain occasions such as baptisms and weddings and associated with good health and culinary heritage. This study confirms, notably following Howard (2003), that culinary traditions are a major element in the preservation of wild and cultivated biodiversity. If culinary traditions are diminishing, the reasons for conserving these plants useful for food, as well as the knowledge associated with them (cultivation, processing, and storage) are also being lost. Thus, the work of women in the transmission of culinary knowledge is of great importance, and this makes the kitchen the primary place for maintaining biodiversity. In addition to being a place for conserving plants, the kitchen is also a place for creating emotions and memories. Thus, to evoke food and its evolution is also to evoke the memories associated with it by appealing to the senses.

2.2. The DIVA project as an experiment in transdisciplinary research

In this part, we stressed a reflexive return to the DIVA experiment of TD research. The study made it possible to confront academic research with a complex object and to observe certain difficulties and limitations in the reality but also the advantages that the TD approach presents. Firstly, complete interdisciplinarity, aiming for a combination of natural and social sciences, is inherently problematic both in its choice of objects and in its methods: the sciences of biology and health are governed by metrics and very delimited objects whereas the objects of socio-anthropology are not measured and the analysis of gender is by definition transverse. Secondly, the TD process, the participation of civil society in knowledge genesis, confronts the motives and values of people (ethics) which are generally different depending on the point of view. If the scientist is interested in producing knowledge that is as generalizable as possible, local actors are motivated by the desire for change or the resolution of a problem.

Theoretical foundation of our posture in TD and Sustainability Science

A research posture consisting in using all available resources (i.e. any form of knowledge and any way of accessing knowledge) does not represent a break with that which precedes it (tending always towards more specialization and technical progress) but an evolution linked to the profusion of knowledge and the improvement of access to all kinds of knowledge. In this respect, pragmatic philosophy, a philosophical theory of education developed by John Dewey (Dewey, 1925 [2012]; 2005) at the beginning of 20th century in the United States offers a particularly relevant framework to reflect on knowledge management for action science. In his theory of experience and education Dewey postulates that all knowledge

derives from experience and that new theories become established by and during empirical experiments. These concepts are at the basis of the sustainability science dealing with 'wicked' or real-world problems (Lang *et al.*, 2012; Wolff *et al.*, 2019). The theoretical framework of Sustainability Science is nowadays certainly of growing interest in the approach to societal demand in the face of the multifaceted environmental crisis that requires designing research processes in a flexible way in order not to be blinded by too focalized objectives (Brandt *et al.*, 2013). The Sustainability approach draws on concepts of research, such as eco-feminism (Mies and Shiva 1993; Guétat-Bernard, 2020), the French school of contemporary pragmatic sociology that provides important insights into the bounded multiplicity of nature's worth in political modernity (Latour 2005; Thevenot, 2007; Boltanski, 2009), political ecology for food sovereignty in the South and gender justice (Bezner-Kerr *et al.*, 2018; 2019). So, our approach has been situated accordingly and the fine contextualization was part of that. With the DIVA case study, considered as an empirical experiment bringing into play different types of knowledge, we attempted to collect information from diversified sources and to recombine results into a more global answer to the global question emerging from the consultations with local actors, men and women, about what is a more sustainable local food system. Based on this expectation, we emphasize how important it is to implement and share a 'comprehensive' understanding of the context in the broad sense (historical, political, geographic, spatiotemporal and cultural). Mutual understanding is only achievable if conditions that led to the observed situation are known to all and in that respect mediation organized by local members of Enda Pronat was instrumental.

Added value and limitations of the transdisciplinary research experiment

Our main finding concerning context was that cultural agricultural and ecological contexts were interlinked even if this interlinking was less visible today than 'before rice'. In this regard, Berkes and Folke (1998), Folke *et al.* (2003) and Hölling (2001) described coupled social-ecological systems as co-evolved, with mutually dependent and interacting social and ecological components. Understanding these interactions in our study was key to deciphering the status and positions of actors and investigating their embedded knowledge. For example, the 'DIVA Fest,' which was a festive event held to present the results, was one of several opportunities to interact with the community. All the participants (75 people, including most of the women who were interviewed in the study) continued to provide information enriching our own survey. During this event, women further described and discussed their attempts to experiment with a new cultural association of sorghum and cowpea under irrigation. They also took advantage of the event to report the death of seedling plants due to warmer and polluted water. The women farmers also appreciated the synthesis of the researchers' results: they felt that they were understood (the study correctly reflected their point of view), that their knowledge was valued and that their difficulties were publicly expressed in a symbolic place like the town hall.

While the dietary survey made it possible to describe the current diet of women as unbalanced in terms of a share of the different food groups and rice overconsumption, the TD approach allowed to go further when linking diet to local environment. This approach validated the intuition of local actors that the traditional dietary pattern based on sorghum and mil consumption was healthier than the current one. Furthermore, cross exchanges with actors allowed us to pose a strong hypothesis of the negative effect of the gradual disappearance of the recession system on transhumant pastoralism in the *Waaloo*. It was confirmed that this disappearance also affected fishing activities practiced in basins flooded during the recession and activities to maintain these basins for the reproduction of fishes, as anticipated by Boutillier and Schmitz (1987).

Another added value of the TD approach was observed when studying the local biodiversity through gendered interviews. Without information and feedback from local actors about our methods (i.e. design and revision of interview guide and ‘improvised’ women focus groups in the agro ecological planting places, kitchens, etc.), it would have been difficult to collect so precise a description of the varieties of plants like sorghum and cowpea, or the knowledge on the variety diversity of these plants.

3 Conclusion

The first goal of our research was, following Pohl and Hirsch Adorn (2008), to enlighten and promote what is perceived to be the common good by the actors, which relates to the value system shared by the Senegal Middle River people. To insure a correct instruction of the multi-dimensional inquiry considering the limited resources, the diverse participants in the DIVA study have endeavored to multiply interactions and mediation to primarily establish links of confidence, to be able to reliably put into perspective the case-specific knowledge gained. So the clear political outcome of our study was that the vision of irrigated rice cultivation, initially designed to ‘valorize’ the Senegal Middle River valley potential, operated a ‘flood marginalization’ far from the vision of all local actors, whether male or female. In this regard, pollution and food problems have already been anticipated for almost 20 years by a committee of researchers and local actors in this area (Adams, 2000; Bruckmann, 2018). However, the public authorities and donors have not taken these warnings into account by adopting an economic development approach where the river is disconnected from its flood and ignoring food traditions, cultural and agri-food function of floods. Our results, deeply locally situated, show the growing negative impacts on the expansion of irrigated intensive rice cultivation on biodiversity, traditional knowledge and nutrition. The ethical dimension of the TD and gendered DIVA study, despite its geographical limitations, consisted in giving value to the heritage and memory of local actors in their quest for food and cultural sovereignty. Women farmers of diverse status have expressed this attachment while at the same time stressing their concern for the disappearance of cultural, agriculture and food habits.

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Tables and Figures

Table 1. Farming strategies according to the level of self-sufficiency in rice

Self-sufficiency in rice	Objective	Barriers	Strategy
Families achieving self-sufficiency in rice (≥ 5 ares of rice and/or ≤ 20 persons in the family) with extra asset	Generate income and maintain food security	<ul style="list-style-type: none"> - All parcels are not exploitable under irrigation - Due to their family value, <i>Waalo</i> parcels are never sold 	<ul style="list-style-type: none"> - Combination of irrigated culture and <i>Waalo</i> culture - Money from emigration or extra-agricultural activity invested - Increase size of tomato plots
Families not achieving self-sufficiency in rice (large families with ≤ 5 ares of rice) and without extra asset	Achieve food security	<ul style="list-style-type: none"> - Plot of limited size - No possibility for financing for diversification projects 	<ul style="list-style-type: none"> - Income from cash crops for financing rice season - Combination of irrigated culture / <i>Waalo</i> culture / <i>Dieri</i> culture - Sale of goats and sheep (women) - Female gardening perimeters (for consumption and sale) - Sale of sorghum (if any) to buy rice (women and man)

Table 2. Division of agricultural activities between men and women by agricultural ecosystem.

Agricultural activities	<i>Waalo</i>		<i>Falo</i>		<i>Dieri</i>			
					Millet cultivation		Other cultivations ^a	
	Women	Man	Women	Man	Women	Man	Women	Man
Tillage, plowing	-	++++	+++	+	+	+++	+	+++
Sowing	++	++	++++	-	++	++	+++	++
Weeding	+	++++	+++	+	++	+++	+	+++
Guarding (against birds) ^b	+++	+			++++	+		
Harvesting	+	++++	++++	-	++++	+	++++	+
Threshing/ Winnowing	+	++++	++++	-	++++	+		
Processing	++++	-	++++	-	++++	-	++++	-

Share agricultural activities between men and women: “-” means 0%; “+” means 0 to 20%; “++” means 20 to 50%; “+++” means 50 to 80% and “++++” means 80 to 100 %. ^a Other cultivation in the *Dieri* were cowpea and colocynth. ^b Guarding against birds was also made by children (on a cycle of 90 days, they performed this work the last 50 days).

Table 3. AME-predicted food intake in grams and contribution to the total intake of solid foods in women from observed and simulated-past diet.

Food group	Observed diet			Simulated-past diet		
	Mean	SD	% of the total intake of solid foods	Mean	SD	% of the total intake of solid foods
Cereals	707	178	52.3	460	177	34.6
Vegetables	189	54	14.0	189	54	14.2
Fruits	63	33	4.6	63	33	4.7
Tubers	34	15	2.5	34	15	2.6
Legumes	94	60	7.0	189	120	14.2
Meat	4	7	0.3	20	0	1.5
Fish	13	10	0.9	126	98	9.5
Dairy	75	55	5.5	75	55	5.6
Oils	66	31	4.9	66	31	4.9
Sugar and sugar products	89	27	6.6	89	27	6.7
Miscellaneous	19	7	1.4	19	7	1.4
Beverages	178	50	0	178	50	0

Table 4. AME-predicted energy and nutrient intake in women from observed and simulated-past diet, and percentage of women not respecting the nutrient recommendation.

Nutrient	Reference value	Observed diet			Simulated-past diet		
		Mean	SD	Not respecting reference (%)	Mean	SD	Not respecting reference (%)
Energy (kcal)		2791	400		2791	400	
Protein (g)		63.8	14.3		100	20	
Protein (% EI)	10-15	9.13	1.49	46.5	14.4	2.9	51.2
Total fat (g)		102	27		122	30	
Total fat (% EI)	15-30	32.8	6.3	44.2	39.3	6.9	86.0
Available carbohydrates (g)		400	64		318	60	
Available carbohydrates (% EI)	55-75	57.5	5.9	18.6	45.5	8.5	79.1
Fiber (g)	30	28.4	10.1	46.5	38.9	9.0	20.9
Vitamin A (µg)	500	308	122	100	324	123	93.0
Vitamin E (mg)	7.5	20.5	5.3	0	24.0	6.3	0
Thiamin (mg)	1.1	1.08	0.33	46.5	1.46	0.37	7.0
Riboflavin (mg)	1.1	0.97	0.35	62.8	1.14	0.34	62.8
Niacin (mg)	16	22.1	7.4	11.6	34.7	7.77	0
Folate (µg)	400	265	70	72.1	329	106	72.1
Vitamin B-6 (mg)	1.3	1.25	0.43	53.5	2.69	0.71	0
Vitamin B-12 (µg)	2.4	1.78	0.67	86.0	11.5	7.4	0
Vitamin C (mg)	45	66.1	24.9	23.3	66.1	24.9	23.3
Calcium (mg)	750	667	242	62.8	776	234	62.8
Iron (mg)	29.4 ^a	16.4	5.7	88.4	27.2	6.0	4.7
Magnesium (mg)	220	550	212	0	938	224	0
Phosphorus (mg)	750	1184	351	4.7	1830	304	0
Potassium (mg)	3510	3423	990	67.4	4574	866	11.6
Sodium (mg)	2000	5523	2333	100	5055	2287	93.0
Zinc (mg)	9.8 ^a	8.58	2.18	69.8	12.7	2.3	0
Copper (mg)	1.5	1.68	0.50	23.3	2.28	0.54	0

EI, Energy intake; ^a Because the simulated-past diet contains more animal products, the recommendations for iron and zinc were selected with a moderate dietary bioavailability, resulting in a recommendation of 19.6 mg/d and 4.9 mg/d, respectively. In the simulation, the replacement of rice and wheat by the consumption of sorghum and mil explained 100% of the increase of fiber intake, 52% of the increase of thiamin intake, 38% of the increase of vitamin B-6 intake, 75% of the increase of iron intake, 55% of the increase of magnesium intake, 50% of the increase of phosphorus intake and 33% of the increase of potassium intake.

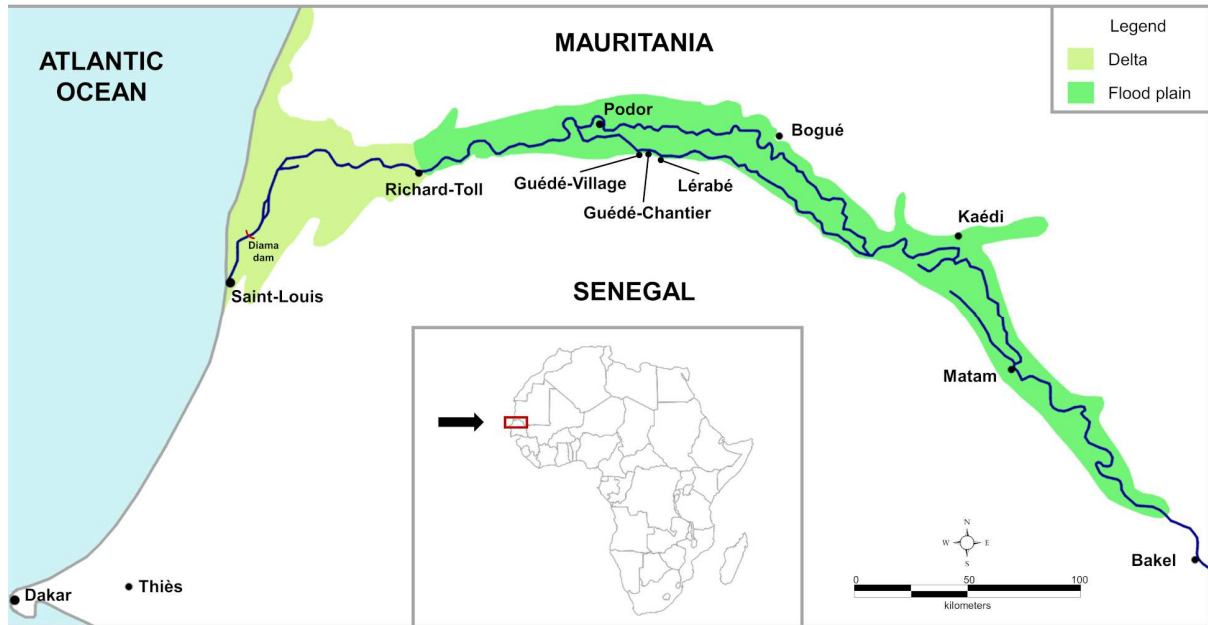


Fig. 1. Location map of the studies villages (Guédé-Chantier, Guédé-village and Lérabé) situated in the middle valley of the Senegal River, district of Podor in the North of Senegal.

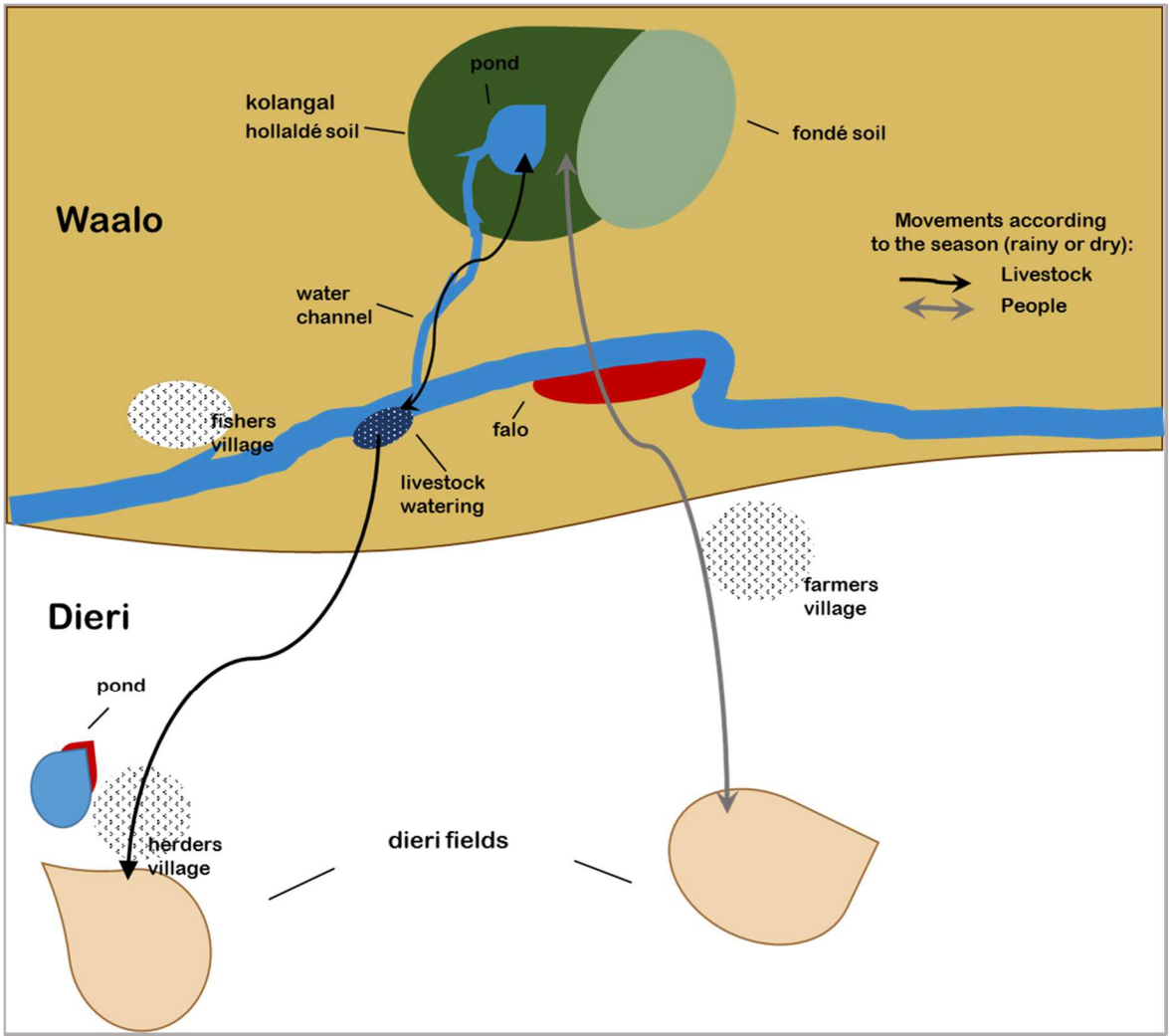


Fig. 2. Schematic representation of the 'Leydi', a traditional terroir characterized by its geographical discontinuity. Adapted from Boutillier and Schmitz (1987).

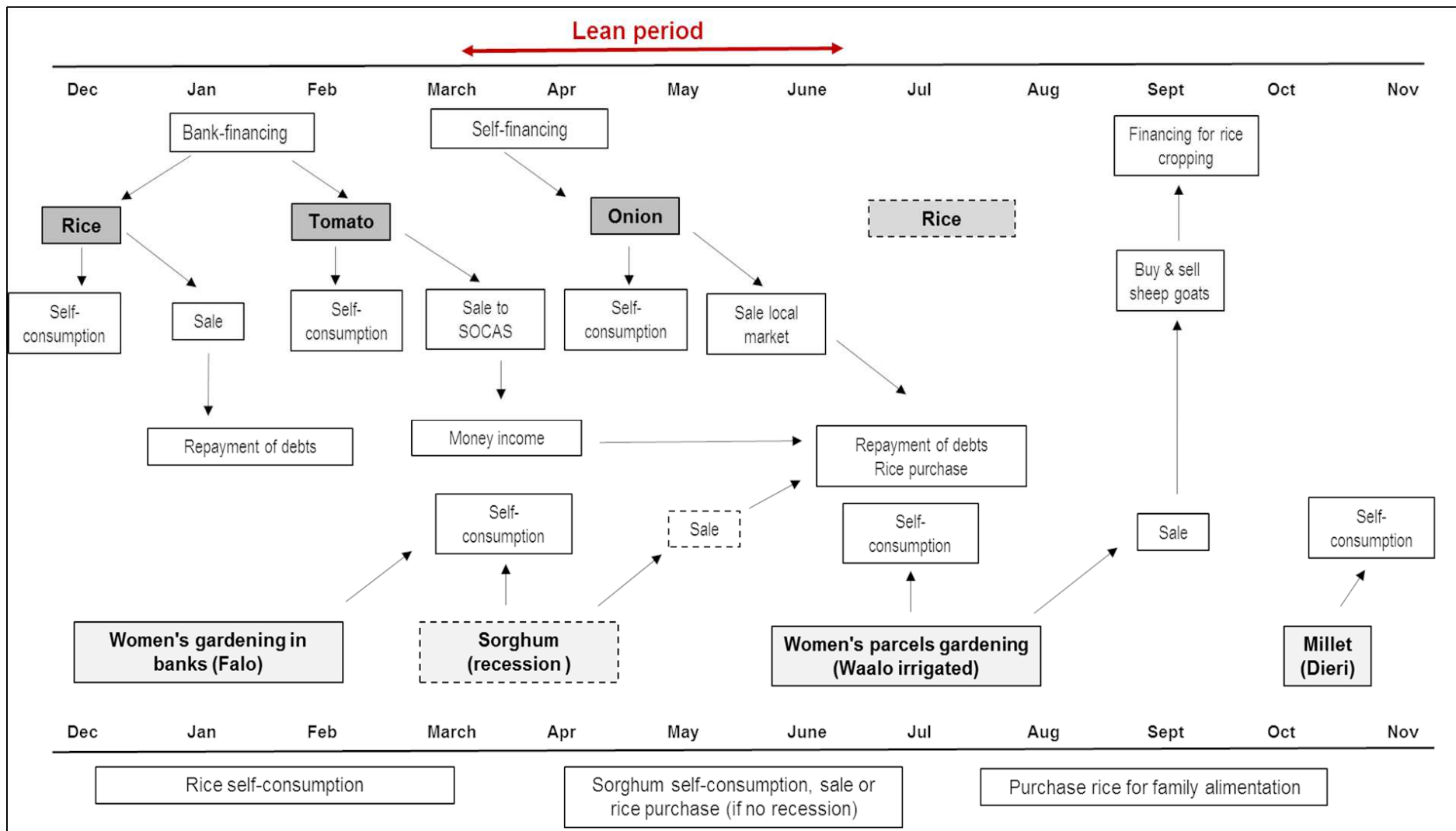


Fig. 3. Annual organization of agricultural production and food availability (case of single crop rice and the possibility to plant recession sorghum).