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Intensified rice production negatively impacts plant biodiversity, diet, lifestyle and quality of life: transdisciplinary and gendered research in the Middle Senegal River Valley

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Abstract

A major programme of irrigated rice extension in the Middle Senegal River Valley has further limited the river's natural flooding in the floodplain (Waalo), initially reduced by drought. We conducted a transdisciplinary (TD) and gendered study in the region to explore links between agricultural biodiversity and family diets using a social analysis of women's practices. The results showed how rice expansion impacts local agrobiodiversity, diet quality and the cultural way of life. Disappearance of the singular agropastoral and fishing system of the Senegal River Valley is profoundly modifying the landscape, limiting wooded riverine settings, and is undermining the traditional diversified flood-recession cropping system in the Waalo. This is causing an overconsumption of rice by reducing alternative food sources, such as sorghum, vegetables and animal products (fish, milk and meat). In particular, flood-recession sorghums are in danger of disappearing, yet they are more nutritious than rice and now sell for twice as much, or more. The way of life is being disrupted, notably sociabilities previously based on territorial complementarities, and women are disadvantaged in terms of recognition and added workload. Women's groups have launched collective irrigated gardens, organic or not, only supported by the local NGO, but any surplus is hardly ever sold on the weekly markets in the neighbourhood. Moreover, this diet imbalance increases nutritional risk factors for health, such as vitamin and iron deficiencies, especially for women, hypertension and diabetes. We argue that, firstly, gendered TD experiences are relevant for documenting women's activities in order for them to gain political support and, secondly, that targeting women's care tasks gives more value and impact to TD research results.

Keywords: Intensified rice, sorghum biodiversity, diet, lifestyle, gendered research, Senegal River Valley

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1 Introduction

Agricultural diversification contributes to diversified diets through both subsistence and income-generating pathways and may be an important strategy for improving diets and nutrition outcomes in low- and middle-income countries (Jones, 2017). This is especially true for African countries in the Sahel, where family farming is still dominant because these families have very little economic leeway to feed themselves. Some cases in sub-Saharan Africa in particular illustrate a dramatic disconnection between local increases in agricultural production and people's nutritional status (Dury and Bocoum 2012). In this respect, a recent review on Nutrition Sensitive Agriculture (NSA) identified six pathways by which agricultural intervention can positively influence nutrition (Ruel et al. 2018), three of which relate to women: women's social status, health, and workloads. In fact, calls for gender approaches, especially in the NSA field and agroecology, are generally becoming increasingly frequent in research (Howard et al. 2006, Carletto et al. 2017, Bezner-Kerr et al. 2019, Global Health 50/50, 2021) and among practitioners, such as the Alliance for Food Sovereignty in Africa (AFSA). Feminist theories denounce gender asymmetries and the downgrading of women's tasks. Being mainly outside the market, these activities are not considered as 'work' and suffer from a lack of economic recognition (Delphy 1970, Lagrave 1987). Women's work is indeed invisible because it is seen as the extension of their work at home and, as such, discredited. Qualified as 'social domestic reproduction' (Mies 1994, Federici 2016), as 'care' (Brugère 2011), or sometimes as 'subsistence' (Pruvost 2021), it is excluded from the economic sphere. Assigned to women, it is naturalized by the weight of the normative model in which men work for the market and women for use in the gender representations. That bias can be transferred to today's African farming women, because what is still called 'Agricultural Development for the South' has probably exacerbated gender power inequalities. Current agricultural modernisation programmes, derived from European post-colonial (patriarchal) rules and a post-war paradigm of agricultural intensification, value market-oriented activities and discredit subsistence activities. Thus, this process has privileged certain groups of crops or systems, while neglecting such issues as women in agriculture, conservation of agrobiodiversity (Ravera et al. 2019, Zimmerer and de Haan 2019) and diversity in food habits (Raschke and Cheema 2008, Guétat-Bernard and Ndami 2019). These issues are of crucial concern, because food provision is connected to gender norms relative to labour that have a great impact on women's workloads in particular (Westholm and Ostwald 2020).

However, it is not only food security that is affected by women's workloads, as women's management of agricultural biodiversity has also been underestimated. Patricia Howard was a pioneer in highlighting the critical role of rural women in managing agrobiodiversity, and in using and conserving a great variety of seeds (Howard 2003). Many gendered studies conducted in the global South have shown that the knowledge and use of plant biodiversity is gender-differentiated everywhere, especially in Africa (Howard 2003, 2006, Ravera et al. 2019). It is for these reasons that a gender perspective changes the understanding of people-plant relationships in fundamental ways: when women select varieties for their fields or gardens, they consider not only their agronomic characteristics, but also those related to processing, storage, consumption (including the quality and diversity of food) and the health

needs of family members and domestic animals (Howard 2006, Guetat and Saussey 2014). The promotion of agroecology in Africa, in particular by AFSA, highlights these women's knowledge of plants as regards their very diverse uses, especially for so-called 'Neglected and Under-utilised Species crops' (shortened to NUS), plants and trees, of which only women often retain the expertise (Bezner Kerr et al. 2019, Soler Montiel 2020). Consequently, innovative research bridging agricultural transformations, changes in biodiversity and the impact on local food cultures are called for by many development prescribers, particularly in regions under strong climate change pressures (FAO 2018). However, highlighting the interrelationships between the different aspects of NSA, such as physical and economic access to food, power and gender relations, access to land, nutritional knowledge, the state of natural resources (biodiversity, water), farm and non-farm income, needs to multiply transdisciplinary experiences. The research presented in this article is an attempt to address this gap in the context of the National Rice Self-Sufficiency Programme (PNAR) currently being implemented in the Senegal River Valley to reach national rice self-sufficiency. The project called DIVA (acronym for 'Relier la bioDIVERSité Agricole et la diversité alimentaire par l'analyse sociale des pratiques féminines et de l'alimentation') aims to analyse the impacts on family food security, diet and way of life of these massive efforts being made for irrigated rice expansion. The research question is: How is food security and the life of families impacted by the expansion of intensive rice cultivation in the Middle Senegal River Valley (MSV), a region at the heart of the intensification zone? We therefore experimented with an original transdisciplinary (TD) approach through a gender lens. The main disciplines considered in this study are agronomy to appreciate cultivated biodiversity and new agricultural system organisation, socio-anthropology to consider culinary activities and gender relations within the family, and nutrition to measure the quality of family and women's diets. In the discussion of this paper, we also address the methodological challenge of TD gendered research in dealing with the complexity of the links between agriculture, the environment and cultural well-being.

2 Approach and Methods

General approach

The study was based on the hypothesis that dietary changes in rural Africa (presumably damageable for health) are linked to agricultural changes, because there is little room for manoeuvre for feeding oneself beyond what is produced. It sought to support this hypothesis by taking a TD approach that embraced both biotechnical and social sciences, linking field surveys in agronomy, nutrition and socio-anthropology, and using a cross-cutting gendered analysis. TD research differs from interdisciplinary research, as a research question is defined independently of disciplinary considerations (Jaeger and Scheringer 1998), since these are no longer able to cope with the increasing complexity of the 'real world' and the high necessity for sustainability (Scholz and Steiner 2015). TD means conducting research in a collaborative way from the initial conception of the research issue, incorporating non-academic and traditional knowledge (Berkes and Folke 1998, Berkes et al. 2000, Pohl and Hadorn 2008). Thus, local non-academic stakeholders (women farmer groups, nurses, traditional healers, educators, the NGO Enda Pronat and the Senegalese Association of Farmer Seed Producers)

were brought into the process from the outset. An initial field meeting was held before the beginning of the study to mobilize, explain, and discuss the issues to be surveyed; it involved 70 people, including the Enda staff, a teacher from the Eco-School in Guédé, representatives from SAED (the state company that governs the irrigated rice intensification plan in the Senegal River Region), leaders of women's organizations, farmer organization members, a male medical nurse and traditional nurses (called '*badianogo*' in Senegal).

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

A festive event called the 'Diva Fest', involving more than 75 people, was held to share the study's findings with most of the women who had been interviewed in the study and to collectively discuss the findings.

The DIVA case study was conducted in the MSV, in Podor district, North Senegal. The study area covered three neighbouring villages (Guédé-Chantier, Guédé-Village and Lérabé) located on a branch of the river, the Doué (Fig.1). Three female Master's students living and working in the three villages conducted the major part of the field research from April to June 2019. The research team and Enda-Pronat together recruited three male Senegalese student-facilitators and native-language translators from the locality to assist the students. Local members of Enda Pronat, thanks to their longstanding and permanent presence in the area, were instrumental in establishing an experimental (non-probabilistic) sample, holding meetings and providing facilitation and day-to-day contacts. The core sample for the interdisciplinary study consisted of nine 'Halpulaar families', locally referred to as a *foyré*, consisting actually of 12 households, all involved in subsistence-oriented farming, but with differences in socio-economic level and family size (between 15 and 40 members). The *foyré* designates a set of people sharing the same meals and constitutes the socio-economic space where production and reproduction take place. The three students and their counterparts worked with the 12 core households. The size of a Halpulaar family can vary widely and can include as many as 50 people. Other groups or individuals outside the core sample were also interviewed, depending on the type of information sought: for example, individual women were interviewed on the local markets, but it was rather women's groups in the shared gardens or the co-wives of the *foyré* in their kitchen.

Agricultural system and biodiversity survey

Semi-structured questionnaires were used to gather information about the functioning and organization of the agricultural system, agricultural production and biodiversity management. The individual interview guidelines were tailored to the respondent's situation and took the gendered division of field labour into consideration. The interviews were analysed to create a typology of farmer strategies. A 'free listing' method was used to rapidly collect lists of plants known to individually interviewed women, men and children – about 80 people – inside and outside the core sample. The aim was to obtain lists of cultivated and/or known wild plants, present or formerly present, in order to investigate the most important ones (the most often cited and/or those that people put at the top of their lists) to explore them in more detail.

Dietary survey and diet simulation

The complete method is detailed in the Method-Online Supplementary Information. Briefly, the women usually responsible for food preparation for the household were asked to provide information about foods and beverages consumed by household members over the previous year, using a semi-quantitative Food Frequency Questionnaire (FFQ) co-developed for this study with local members of Enda Pronat. The energy and 21 nutrient contents of the different foods and beverages consumed by household members were mainly extracted from the Arican Food Composition Table (Barbara et al.2012). The adult male equivalents (AME) method was applied to the household data (Weisell and Dop 2012) to produce individualized estimates of food and nutrient intakes of each woman in the 12 households. The AME-predicted nutrient adequacy of the diet was assessed by calculating the percentage of women who did not meet the international nutrient recommendations (Joint WHO/FAO Expert Consultation, 2004). Based on semi-directive interviews with men and women over the age of 55 from the 12 households (about 30 people) about the main dietary changes that had occurred over the past 45 years, we created a simulated past diet for each woman and evaluated the differences with the current diet. SAS suite version 9.4 (SAS Institute) was used to perform a descriptive analysis of food and nutrient intakes and to perform the simulations.

Socio-anthropological survey to study the gender relation

The approach was centred on women's work in domestic and agricultural activities seeking to document women's practices and knowledge, and to clarify the impacts of agricultural changes on the nutritional quality of food. For the gender analysis we chose the ethics of care vision because it is transversal by definition and adapted to TD research, particularly for the issue generated by agroecological transition. The ethics of care indeed affirms the importance of continuous attention to others (Gilligan, [1982] 2008, Tronto [1994] 2009). Thus, to understand its ethical value, it must be observed in action, in the process of being accomplished. So, the 'kitchen' was considered as an essential space for observations, as it is the place where products enter to prepare meals and exit to feed the household.

Comprehensive 'conversational interviews' (Olivier de Sardan 1995) were conducted with all the women from the 12 households. The interview conversations also took place in homes, concessions, or fields, creating multiple opportunities of 'listening situations'. The Master's student in charge of this approach, a young single woman, took advantage of her three-month residence in the area to conduct 'conversational interviews' during domestic tasks in which she participated, the one allocated to young unmarried women in the community (marital status informs the group about her position in the local society). She was thus in a position to use a 'participant observation' approach to study the women's particular work responsibilities in field and home (food preparation, yard cleaning, washing dishes). The purpose of this research approach was to analyse words and gestures and to take into consideration the locations (kitchen, yard and garden) and contexts of the women's expressions.

3 Contextualisation

As assumed by TD Research, comprehensive contextualisation was conducted to understand the consequences of recent agricultural changes in the MSV. This represents part of the results because, by 'comprehensive' we mean highlighting the actor's discourses, the convergences

and the relationships between the observed phenomena relating the different aspects of the issue, namely agro-environmental, historical, social and cultural. To that end, we used not only bibliographical sources including grey literature, but also direct exchanges with actors and contributions from Senegalese scientists working regularly in this region. Mediation towards the local social actors provided by the long-standing stays of members of Enda Pronat was instrumental in enabling those interactions.

The MSV agro-system is historically built on sorghum-based flood-recession agriculture. Two major ecosystems make up the landscape: the floodplain called *Waal* is composed of rich, clayey soil near the river and in hollows, and the agropastoral zone called *Dieri* or *Jeeri* composed of bushy sandy dune soil. The traditional middle valley land system (Fig.2), referred to as *Leydi* in the Halpulaar (or Peul) language, is characterized by the discontinuity between these two areas and by movements of people and herds between the two (for example, herds moving into the *Waal* during the dry season). The river floods structure crop farming, grazing and fishing activities; flood-recession cropping in the *Waal* is interwoven with transhumant agropastoralism in the *Dieri* and with fishing in the river and the semi-permanent pools (Le Roy 2008, Cesaro et al. 2010, Garambois et al. 2018). The primary flood-recession crop is sorghum (*Sorghum bicolor* L.), locally called *samme*. Sorghum is sown as soon as the seasonally flooded hollows, called *Kolangal*, with their rich hydromorphic soils (called *hollaldé*), have dried out sufficiently. These are good conditions for direct seeding of local flood-recession sorghum varieties, because no nursery or inputs are needed and large areas can be quickly sown (Le Roy 2007, 2008). Historically, the agricultural system in the MSV has undergone a transformation since the climate crisis in the Sahel in 1970s-80s, and this has jeopardised the hitherto sustainable rain-fed crops and added uncertainties for traditional flood-recession crops. Small-scale irrigation had been practised since the 1950s. Then, in the 1980s, the Sahel States involved committed themselves to constructing the first dam in Diama, downstream (1986), and a second in Manantali (Mali) upstream (1988), in order to develop irrigated crops in response to drought and to produce electricity (Seck 1990). Since then, transformations have begun to be visible in the MSV with the establishment of village irrigation schemes (locally called PIV, *périmètres irrigués villageois*), of which the Guédé-Chantier village is emblematic. The landscapes have been increasingly transformed, with the agropastoral and fishing systems deeply anchored in a specific territory (Fig.2), within an intensive irrigated cropping system (see the drone photography provided in Fig.S1 in Online Supplementary Information). The irrigated areas of the valley, mostly in the *Waal*, now concern 116,000 ha mainly devoted to intensive rice farming (AFD, 2015) and a small area (less than 10%) to industrial tomato growing for the canning factory in the Delta. In the last ten years, the rapid increase in areas converted to irrigation and intensive rice farming has clearly been made at the expense of land formerly used for flood-recession cropping (Bruckmann 2018). As a result, most inputs are now synthetic fertilizers for growing a few genetically closely-related varieties. This has negative consequences for soil organic matter content and river pollution, and makes families dependent on bank loans to buy inputs (Garambois et al. 2018). In reaction to the 2008 food price crisis that deeply affected Sahel countries, the *Programme d'Accélération de la Cadence de l'Agriculture Sénégalaise* (PRACAS) was created in Senegal in 2010 to reach the goal of rice self-sufficiency by extending the area of irrigated rice monocultures. This rice

intensification programme was implemented by the State Company for the Development and Exploitation of the Lands of the Delta and the Senegal River Valley (*Société d'Aménagement et d'Exploitation des Terres du Delta et du Fleuve Sénégal*, SAED) in charge of allocating land for rice farming following a planned production objective. As rice is not traditionally grown in the MSV, this programme has led to a major transformation in family life in terms of food, health and social relations when compared to the old system based on a subtle balance between crop farming, stock grazing and fishing.

As for the nutritional context, the inhabitants of this region lived in a largely food self-sufficient manner. They have changed their food habits since the end of the 1990s, eating more rice in place of local cereals like sorghum and millet (Fig.3). The World Food Programme (WFP 2017) showed that food insecurity was of concern in the Podor department, with only 65% of households considered food secure compared to the national rate of 83%. Nonetheless, accurate data about the food quantities consumed by households and individuals are lacking. Only one survey seems to indicate an unbalanced diet in this region, with high intakes of cereals, roots, vegetable oils and sugar, and low intakes of vegetables, pulses and animal products (WFP 2014). Information gained during the initial meetings with local informants stressed diet-related health problems, particularly type 2 diabetes and hypertension, suspecting a link with the change in diet. From a socio-cultural and gender perspective, the majority of the population belongs to the Halpulaar ethnic group, whose caste system defines the hierarchies of power (religious, or over land ownership) and craft activities in the *Leydi*. An important feature of the traditional agricultural system is the interdependence between food activities, traditional craft trades and land functions resulting, for example, 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, favouring less strict caste hierarchies (Boutillier 1989). Access to land is patrilineal and disproportionately favours 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 lands such as the *Waaloo* and the *Falo* (riverbank fields). Women's individual rights to land are not recognized, but with the support of NGOs such as ENDA Pronat they have recently negotiated access to shared gardens. However, the land granted through this system is often remote, not very fertile, and too small in area to meet the women's needs and expectations. Despite the differences in women's status depending on age, marital status and relationship to the head of the family, these gardens are spaces of female solidarity.

4 Results: a multidimensional view of the consequences of agrifood system changes

Dimension 1: agrobiodiversity in the new system and consequences for women's work and their strategies for feeding their families

Due to the varying water flow owing to irregular rainfall and/or unpredictable reservoir management, the amplitude of the flood recession is unpredictable: it was practically absent in the first year of the study but was present in the second. In fact, in the second year, the *Waloo* floodplain was immediately exploited to plant flood-recession sorghum. This allowed us to observe the complex design of the agrosystem over two years and relate it to people's food

strategies (Fig.4). The farming system is now normalised by intensive rice cultivation and family food strategies depend on rice self-sufficiency. The rice system is based on growing irrigated high-yielding rice varieties provided by AfricaRice, which is part of the CGIAR International Rice Research Institute, IRRI, based in the Philippines. The AfricaRice research station located in the village of Ndiaye (in the delta) provides the varieties, which are selected pure lines of *Oryza sativa* (Group of Asian rice species) selected by IRRI and, in some places, of Nerica ('New Rice for Africa') lines that are very similar to *sativa* but come from initial crosses between *O. sativa* and *O. glaberrima* (group of African rice species). The breeding programme led by the local station is geared towards productivity under irrigation and does not include any taste or nutritional criteria (Africa Rice breeder, personal communication). All the local actors interviewed mentioned that prioritising irrigated rice farming has disorganized the entire production system, so that none of the families in the survey were growing rice in the warm dry season (harvest in July) despite SAED recommendations. The reason put forward was aversion to the bank loans for inputs that are inherent to the system; the cost, deducted from rice sales, is too high considering uncertainties about yield, payment lag times and workload. Consequently, the farmers preferred to diversify their activities, as they always did. This lack of interest in growing two rice cycles per year is expressed by the SAED local actors and matches the data on rice area and production in the region. According to the French Development Agency (AFD), one of the historical donors, the Podor Department accounts for 22,000 ha, i.e., about 20% of the total land area developed for irrigated rice in the valley, which is estimated to be stagnating at around 116,000 ha (AFD 2014). An important cash and food crop in the production system is the local purple onion variety called *Violet de Galmi*. The onions are sold via a structured product chain, which generally helps to maintain a satisfactory selling price. The people interviewed considered it a safer source of income than rice, but this highly depends on whether or not the Government allows imports from Europe. For families that can farm in the *Waaloo*, onion growing (with a surplus of 2 to 15 tons depending on the family) is critical for cash income, allowing families to buy food and achieve food self-sufficiency in the absence of a recession crop. Industrial tomato growing is also practised, but is decreasing because SOCAS, the main local processing company, has been experiencing profitability problems for several years. Producers use a single hybrid variety, RomaVF (TROPICASEM).

For women, limiting the risks of food insecurity throughout the year, particularly in the lean season (March to July, see Fig.4), is a constant concern, as revealed by the different kinds of meetings. Achieving food security involves much more than achieving good rice yields, a fact that puts farming families at odds with the public authorities' demands and pronouncements. Sorghum (and other crops, such cowpea and various vegetables) in the flood-recession farming system fulfilled this function perfectly, since it cost much less to grow (less work and no inputs) and brought in more money than rice. All interviewees said they sold sorghum at twice the price of rice. The analysis of the interviews identified different farming strategies designed to achieve this goal (Table 1). While there were different diversification strategies, a gendered organization of agricultural work was clearly observed (Table 2). Irrigated plots in the *Waaloo* are under the responsibility of men, traditionally 'owners' (in Senegal so far, the State is the only formal owner and lands are attributed to farmers). Women carry out various

strategic tasks for the production of rice, onions and tomatoes, including transplanting, weeding, guarding the crops against birds, and harvesting.

The *Waal* has thus lost its role in providing a diversity of food crops, and rice is now the farmers' staple food. However, sorghum has become a cash crop for some families, who prefer to sell rather than eat it, because 'a 50 kg bag is worth 30,000 CFA F for sorghum against 15,000 CFA F for rice. The women sell it and the profits go to the husband, but are shared within the family in the form of food'. In contrast to the *Waal*, the *Falo* (a narrow strip of land along the riverside) remains under the responsibility of certain women (such as the wife of the household head). These women, after negotiating with the landowners of the noble caste (*lawokobé*), are allowed to take charge of all agricultural activities there. The 'contract' is renewed every 6 months because this space is rich, but also small, and for this reason highly coveted. In general, the men help the women when asked. Plants produced from the riverbank (locally named 'condiments') can typically be used to enhance sauces and accompany dishes such as cowpea. Corn is eaten roasted, especially by children. Sweet potatoes, grown on the lowest part of the banks, are served as a vegetable in lunch dishes, as is squash and cherry tomato. The *Falo* is gradually being abandoned in favour of irrigated collective gardens, as its cultivation is now more difficult due to the lack of flooding. The pattern was found to vary slightly depending on whether millet, cowpea, or other crops, such as colocynth, were grown (Table 2). Finally, women have recently gained some specific areas in irrigated *Waal* land for shared irrigated gardens. The gardens are sometimes conducted in agroecology with the help of the NGO Enda Pronat, growing a wide range of crops, such as hot pepper, cowpea, squash, cherry tomato, sorrel, eggplant, beetroot, onion, salad, cabbage, and okra. The irrigation system requires a pump, at their own expense, as well as heavy ridging work (see Fig. S2 in Online Supplementary Information). Invariably, women are solely responsible for food processing, whatever the crop and whichever area it comes from.

Dimension 2: Women's knowledge on plants and on their uses

While flood-recession farming has declined, it does not seem to have had an impact on local knowledge of biodiversity yet, or of the breeding of traditional crop varieties. In the interviewees' responses, such perennial knowledge was in sharp contrast to their scant knowledge about rice varieties. They have no specific knowledge of these rice varieties and generally just know them by the name 'Nerica' or 'Sahel' followed by a serial number. As regards *Waal* flood-recession sorghum specifically, women listed up to 19 varieties, although only 5 are still cultivated. The other varieties are still available locally, conserved by some families and sold on the bush markets; they are still present, too, in culinary memories. The women accurately describe the characteristics of the grain and flour, the related agricultural practices (e.g., crop cycle, seasonality), the advantages and disadvantages of growing the variety, and management of its seeds. This knowledge is clearly gendered, since seed management and breeding were traditionally the responsibility of women. All these varieties were obtained locally, by farmer selection. A summary description of the 8 most cited flood-recession sorghum varieties, with photographs, can be found in Tables S1 and Fig.S3 (Online Supplementary Information-Results). Briefly, the 3 most frequently cited varieties were *Poordi* (which means brown, the colour of the seed), *Mariam Sowdou* (from the name of the woman who introduced and disseminated it), and *Balieri* (which means

white). A yellow variety, *Paaca*, was also mentioned. The choice of growing one or other variety is guided by the length of the crop cycle (e.g., the *Poordi* cycle is 20 days shorter than the *Baliéri* cycle) and bird attacks (e.g., the *Baliéri* is less sensitive compared to *Poordi*). As a result, the *Poordi* variety is the most widely grown, although its bitter taste (a protective factor against bird attacks) is less and less appreciated by families. Among the 19 other varieties mentioned, some have been abandoned because their cycles are longer (e.g., *Bobo jamm* and *Samba Souké*). In addition, the decrease in flooding over several consecutive years has had consequences for seed conservation of these different varieties. According to women involved in sorghum breeding, owing to the uncertainty of the next season's floods, they have gradually stopped storing seeds and prefer to buy them at market or from neighbours.

Nevertheless, some women were doing their best to save sorghum seeds.

In addition to flood-recession sorghum or cowpea growing in the *Waalo*, there has traditionally been a wide biodiversity of edible species, allowing families to feed themselves throughout the year. Women listed varieties of squash and pumpkin (called *Déné Boudé*) with yellow flesh (called *Diayédjé*), maize, cowpea (or *niébé*), and black rice (called *Sarna* or *Maro Balléo*, which was cultivated before the new rice arrived), wild grasses with small edible seeds (known locally as *Pagguri*, and locally considered similar to fonio), the fruit of the water lily, seeds of *Nymphaea lotus* (locally called *Ndayri*), and bulbs of *Gladiolus* sp. (Iridaceae, locally *Dayeedji*). While consumption of these species has decreased, some of them are still much prized foods and seeds continue to be available on the market, like pumpkin seeds to make a very appreciated paste called *podé*. One woman explained: 'The disappearance of crops means that people stop eating these foods. Because if you don't grow them anymore, you have to buy them, so you prefer not to buy them because, before, you could get them for free, apart from the trouble of growing them'. *Podé* was one of the plant-based foods constantly mentioned as a culinary loss, though still alive in people's memories. Cooking is always a celebration. As the researchers were living in the villages, or sometimes in the concessions, they were able to ask the families to cook *podé* for them and thereby appreciate the emotion associated with making this dish (see Fig.S4, Online Supplementary Information). Wild bush fruits, such as jujube (*Zizyphus mauritiana*), desert date palm (*Balanites aegyptiaca*) and Fulani nigigili (*Boscia senegalensis*) have also become rare.

Dimension 3: effects of the new agrosystem on women's diets

Another consequence of the newly organized local agrosystem concerns the quality of family diets and, notably, for women. Women are more susceptible than men to various nutritional deficiencies (calcium, vitamin D, B, iron) to maintain bone health and prevent anaemia, notably during childbearing periods. For this reason, dietary assessments are generally made on women, especially when they concern rural societies in the South. Data from 12 households collected through the FFQ were used to calculate AME-predicted food and the nutrient intake over the previous year of 43 women aged from 18 to 65. The women's current diet, described in Table 3, was mainly based on cereals (52% of the total intake of solid foods), with rice amounting to 61% of total cereal intake, along with wheat (18%), maize (8%), sorghum (8%) and millet (5%). It also included modest intakes of fruit, vegetables and pulses, mainly produced by the women in the shared gardens and the *Falo*. Only 35% of the women followed the recommendation of consuming 400 g/day of fruits, vegetables and pulses

(Joint WHO/FAO Expert Consultation, 2002). Lastly, the diet included very low intakes of animal products.

While the women's average energy intake of 2,791 kcal/d might be relatively adequate compared to the average energy requirement for women with active lifestyles, nutrient content was of concern (for details see Table S2, Online Supplemental Information). Due to the predominance of white rice and wheat (both refined cereals) in the diet, more than half the women were unable to meet the recommendation of eleven nutrients. Furthermore, a high proportion of the sample did not meet two-thirds of the reference values for iron (62.8%), vitamin A (55.8%), vitamin B-12 (48.8%), folate (46.5%), and riboflavin (39.5%), indicating a risk of micronutrient deficiency.

Based on interviews with adults over 55 years old, four main dietary changes over the past 45 years were identified. To understand whether these dietary changes were associated with a decrease in the nutrient adequacy of the diet, we created a simulated past diet for each woman, as follows: i) meat consumption was raised to 20 g per day; ii) fish consumption was multiplied by ten; iii) consumption of pulses was doubled; iv) the resulting increase in energy intake was compensated for by a decreased consumption of cereals; and v) the consumption of rice and wheat was replaced by a calorically equivalent consumption of sorghum and millet. The simulated past diet was found to provide a higher average intake of most micronutrients and a reduction in the proportion of women failing to meet nutrient recommendations, especially for thiamin, vitamins B-6 and B-12, iron, potassium, and zinc (Table 3). The replacement of rice and wheat by the consumption of sorghum and millet explained 100% of the increase in fibre intake. This replacement explained 33 to 75% of the improvement in thiamin, vitamin B-6, iron and potassium intake i.e., 52% of the increase in thiamin intake, 38% of the increase in vitamin B-6 intake, 75% of the increase in iron intake, 55% of the increase in magnesium intake, 50% of the increase in phosphorus intake and 33% of the increase in potassium intake (for more details see Table S2, Online Supplemental Information). Nevertheless, the simulated past diet cannot be called healthy, because it still included small amounts of fruits and vegetables compared to FAO recommendations (Joint WHO/FAO Expert Consultation, 2002).

5 Discussion

This discussion is divided into two parts: the first discusses the results structured according to the three preceding dimensions analysed above and the second proposes a methodological extrapolation that we think is of interest beyond this case study.

Discussion part 1: New agrosystem organisation and consequences for women's activities

This section discusses **dimension 1** relating to how the new organisation of the agrosystem impacts family strategies for food security and women's workloads. The gradual abandonment of flood-recession agriculture during the dry season is a major loss in terms of self-sufficiency because of its inherent and irreplaceable advantages: reduced labour, few tools, no inputs and high biodiversity (Lericollais and schmitz 1984). Recession sorghum is particularly valued because of its excellent agroecological characteristics, due to its high adaptability to low-input farming systems and its nutritional composition. Flood-recession

sorghum is also appreciated by women and men – the share of cultivation tasks is traditionally balanced (quasi-ritualised) between them – for its ease of cultivation and because it does not involve inputs or excessive work. Indeed, fertilization is ‘natural’: at the end of the rainy season, the river's overflow area gradually recedes, the waterlogged soil dries out and an intense microbial life is triggered that degrades organic matter to the benefit of the crop (Le Roy 2007, 2008).

Today's strategies now clearly depend on the level of self-sufficiency in rice and, albeit in an unpredictable and exceptional way, on the river floods that render possible not only the recession crops but also transhumant pastoralism and fishing. Pastoralism and fishing were not specifically studied, but according to the testimonies of the actors, in the *Walo* rice is accused of deteriorating the quality and quantity of pastures and water. The *Walo* lands suitable for flood-recession farming are traditionally allocated and never actually sold (Bruckmann 2018). Natural flooding favoured the lending of fields or various other self-help practices between families and castes (Haby Ba, Enda-Pronat, Guédé, personal communication). Since the river water is now highly dependent on dam management upstream, which is a cross-border political issue that is not at all transparent, these social practices are declining as flood-recession crops disappear.

Hence, this centrality of irrigated rice monocultures has exacerbated the invisibility of women's work. This has created a novel female status, which the women themselves refer to as 'the woman who helps' and which means they lose the family and social recognition they had with the past system based on their knowledge of traditional crop biodiversity management and associated recipes. The Senegal River valley is historically an area of high emigration (internal and international), especially of young men, including married men, and the management of migratory income is actually a characteristic of that region and continues to be so (Top 2014). This results in a feminization of agriculture, as women make up an increasing proportion of the agricultural labour force, but this is not matched by any recognition of land rights, or recognition in family and collective decision-making bodies (Thioune and Sall, 2012, Top 2014). In addition, gender inequalities are favoured by the persistence of the practice of virilocality (wives must move into the husband's parents' place of residence), which is of even greater strategic importance (Feldmann 2013) in the context of irrigated agriculture, where the demand for labour is greater than in the old system (Cordell et al. 1996). This is clearly an additional pressure for women when considering that providing food security for the family is clearly acknowledged to be their responsibility.

Some issues on feminine skills expressed in our work on diet are worth noting in relation to **dimension 2** about women's knowledge. Women clearly described the kitchen space as a food space in continuity with the agricultural space, where the women exercised their sovereignty and where they expressed and improved a whole series of culinary skills. The links between dishes and their associated plants should be further investigated, particularly as these subjects aroused great interest among the women participants. We began to address this, starting with preparations based on certain emblematic species such as cowpea and sorghum. For example, consumption of sorghum couscous (*niri*) has fallen sharply due to less production and higher purchasing costs. Different preparations are associated with *niri*: *niri kosam* (with milk), *niri bouna* (with dried fish), or *niri beref* (with pumpkin, *Citrullus lanatus*). These are emblematic dishes, still prepared on such occasions as baptisms and weddings, and associated with good

health and culinary heritage. This study confirms the finding by Howard (2003) that culinary traditions are a major element in the conservation of wild and cultivated biodiversity. If culinary traditions decline, the reasons for conserving these food plants, and the knowledge of how to grow, process and store them, are also lost. Thus, women's work in transmitting culinary knowledge is of great importance, and this makes the kitchen the primary place for maintaining biodiversity. As well as playing a vital role in plant conservation, the kitchen is also a place where emotions and memories are created. To talk about food and its evolution is also to evoke the memories associated with it by appealing to the senses.

Other more traditional women's knowledge on the natural environment is at risk, specifically that on surrounding trees that are very important in the fight against desertification in the Sahel region. Regarding the disappearance of trees and shrubs, such as *Zizyphus* sp., or *Balanites aegyptiaca*, reported by the women, it should be noted that a belt of trees generally surrounds (or surrounded) most African villages, and like all tree and shrub species in the Sahel, these trees have a great variety of uses (Boëtsch et al. 2012). *Zizyphus mauritanus* and related species like the locally named *Kelly* are known for their highly vitaminised red berries, the medicinal properties of the leaves (diabetes and postpartum) and use of the bark for dyeing (Kaligarine and Koné 2011). The women have a great interest in maintaining and taking care of these species, because the close proximity helps them with firewood for cooking and because they have knowledge of the different transformation processes and products that they could sell on the local market. If many of these trees have almost disappeared, it is not only because of demography, drought and firewood, as is generally claimed, but also because of their devalued status as 'women's plants' ('plantes de femmes' in French) in comparison with the great national ambition of self-sufficiency in rice. In our case, the women said that these trees had disappeared as the fields were restructured by the construction of irrigation systems.

The lack of financial and technical support for these women's activities, where they could express their gender-specific knowledge, with potential to generate new ones, has never been addressed by the public authorities, especially for sustaining women's gardening activities. This has been deplored for many years, indeed right from the outset of irrigated rice cultivation in the Delta (Nation 2010).

This section relates to how the new organization of the agrosystem impacts women's diets (**dimension 3**). The dietary survey was much needed, as it described the women's current diet as unhealthy due to overconsumption of white rice to the detriment of other food groups like vegetables, pulses and animal products, but thanks to the TD approach it was possible to go further and make the link between that diet and the local environment. The intuition of local actors (not limited to the women's groups) that the traditional dietary pattern based on sorghum and millet consumption was healthier than the current one was confirmed by the data. The exchanges with actors also allowed them to put forward their views on the negative effects of the gradual disappearance of the flood recession system (i) on transhumant pastoralism in the *Waalo* and (ii) on the decrease in fishing in temporary ponds during flood recession, as anticipated by Boutillier and Schmitz (1987). During the study, we came across a publication by Duboz et al. (2017) that reported a high rate of type 2 diabetes in the nearby rural *Ferlo* region (Great Green Wall region). The article noted that, for the first time, this was

a rural area, as such an increase was already recognised in many African urban areas (Duboz et al. 2017).

Discussion part 2: the methodological challenge

The DIVA case study is an experiment in transdisciplinary (TD) research.

TD research is recurrently claimed by research prescribers: for example, to achieve the so-called *nexus* between climate change adaptation, biodiversity and food security, agroecological transition, as well as to think and implement the One Health strategy. TD derives from the theories of action research within Sustainability Science (Kates et al. 2001, Lang et al. 2012). It aims to reflect upon and propose a new way of acquiring scientific knowledge aimed at linking, at least in the mid-term, research, social transformation and public action. The combination of natural and social sciences is inherently problematic, both in its choice of objects and in its methods. Secondly, the participation of civil society in knowledge generation is confronted with individuals' motives and values (ethics), which generally differ depending on their point of view. While the scientist wants to produce knowledge that is as widely applicable as possible, local actors are motivated by the desire for change, or the resolution of a local problem.

In our case, and from the local actor's point of view, the issue can be summarized by: What is, in the local context, the most desirable and sustainable agricultural and food system for achieving food security and a balanced diet throughout the year? However, this is proving extremely difficult for academic science to address. The main difficulty is that the research question necessarily calls upon several different scientific disciplines, epistemologies and methods. Each scientist must therefore renounce certain standardized measurements, or adapt them, making it less central to their own disciplinary field of investigation. Other academic limitations relate to the management of observations, which must very often remain qualitative because interactions cannot be quantified by existing standardized measurement scales. This is due to the way modern science has developed historically, especially in the 20th and 21st centuries, moving towards ever-greater specialization, with research in each discipline conducted in isolation. As a result, TD research is inherently problematic, both in its choice of objects and in its methods. The sciences of biology and health are governed by standardized metrics applied to discrete objects, whereas the objects of socio-anthropology are, by nature, never discrete and therefore unquantifiable. This set of paradoxical requirements constitutes a paradigm shift and therefore requires profound changes in the forms, strategies and epistemologies of research modalities that imply collaboration between science and society. All this explains why TD is moving ahead slowly, on concrete cases (Brandt et al. 2013, Isgren et al. 2019).

Notwithstanding these difficulties, we postulate that some conceptual difficulties inherent to TD can be overcome by implementing highly contextualized, localized approaches using diverse sources of information and systematic consultations with stakeholders. We think that connecting and synergising observations from different academic fields and including non-academic knowledge from the early stage of the reflection, is at the same time the challenge, but also the condition for reaching the social utility of the research being conducted.

The ethics of care is an indispensable enrichment to properly answer complex research questions on food matters.

The TD exercise presents certain particularities and advantages when working with rural African women, whose activities are numerous and diverse at all stages of the family food security system. In other words, and with regard to the local food system, particularly in the global South, gendering TD research is a necessity.

The evolution of food and cooking practices over time reflects an environment that is both ecological (itself affected by the consequences of productive choices), cultural (what is permitted or prohibited) and political. These practices also translate the strategies of individuals in their context, particularly the more vulnerable (Guétat-Bernard and Saussey 2014). On the other hand, the economic invisibilisation of women's work in a society that overvalues so-called productive (i.e., economic) work was developed by the sociologist Christine Delphy (1970). Following this author, feminist intellectuals (Gilligan 2008, Tronto [1993] 2009, Laugier 2015) have shown that women's 'different voice' is not so much that of women alone, but that of all people who carry out care activities. Globally, the ethics of the care notion affirm the importance of continuous care and attention to others. This explains why the status of the 'woman who helps' is actually a devalued status, which seems to be perceived as such by the women themselves, including by some of them during this study. From the observation of care practices in the particular situation of our study, we can infer powerfully internalized knowledge of the dependencies and interdependencies between humans and their environment. We discovered, during the second year of our research, when recession cultivation was allowed by good rainfall conditions, the deep cultural attachment to sorghum as a festive plant associated with rituals and exchanges and the predominant place of women in conserving seeds and the memory of uses.

Given that the field of domestic care is mainly feminine everywhere, and particularly in the rural South, it is not surprising that the field of agroecology, which values the links between production, food and health and their local sustainability, constitutes the daily life of women and is sometimes claimed as feminist (Pruvost 2021, Soler Montiel 2020).

Thus, as consideration of the fact that gender justice would drive more balanced and healthier diets remains too infrequent in scientific studies (Global Health Report 50/50 2021), our methodological ambition was to propose a double framework: TD research complemented by an ethical vision of care. This is demanding in terms of a paradigm shift, but necessary for responding to the urgent need to multiply research results of use for equitable agroecological transition and food security in the South. Such a framework would allow coverage of a large number of empirical situations, and has the advantage of being flexible enough to be adapted to the available human resources, both in terms of social actors and in terms of academic research and development actors.

6 Conclusion

The DIVA study was conducted as an empirical experiment incorporating different types of knowledge to provide a more comprehensive answer to the questions of food security and quality of life emerging from consultations with local actors, both men and women, of the MSV. To fully investigate this question in terms of agricultural and dietary practices and

cultural habits, a gendered transdisciplinary inquiry was conducted whose originality and novelty can be summarized as follows:

1. From the outset, the research topic was defined in close collaboration with local NGOs, farmer organizations and civil society, and particularly women.
2. The study attempted to combine three main dimensions – agricultural management of biodiversity, intra-family relations (division of labour) and household dietary intakes – i.e., social science and biotechnical science. This is rarely done, because of the practical and theoretical difficulties involved.
3. The TD approach was combined with a gendered stance derived from the feminist theory of the ethics of care and we discussed the possibility of performing TD gendered research in a wide range of situations of food insecurity, especially in the global South.

We must also emphasize how important it is to implement and share a ‘comprehensive’ understanding of the historical, political, geographical, spatio-temporal and cultural context. Mutual understanding is only achievable if the conditions that led to the observed situation are known to all the research actors and also discussed repeatedly with participants.

With regard to the specific results of the case study, we conclude that the local people's initial perception that the extension of irrigated rice farming is causing disruptions and disturbances of various kinds has a sound basis; when traditional farming and fishing are disrupted, biodiversity and the environment are altered, and so is the local cultural lifestyle and food culture. The political vision of irrigated rice cultivation, designed to optimise the economic potential of the MSV, has marginalised flood-recession cultivation, which is far from the aspirations of local people, men and women alike. Almost 20 years ago, a committee of researchers and local actors already foresaw pollution and food problems in the area (Adams 2000). However, the public authorities and donors did not consider these warnings and have adopted an economic development approach that sees no connection between the river and its floods, and entirely ignores dietary traditions and the cultural and nutritional functions of the floods. The ethical dimension of the DIVA study gives value to the heritage and memory of local actors in their quest to maintain their traditional farming system, their biodiversity, seeds and food culture, all of which are intertwined elements constituting their cultural identity. Women farmers of various statuses have particularly expressed this deep attachment and stressed their concern about its disappearance. It remains difficult for civil society to influence rural policy, but conventional research alone without society will be powerless (Rocha et al. 2012). Thus, research has a role to play in making women’s roles and situations visible, in order to protect their knowledge, and to mediate and facilitate their initiatives for healthy diets within family agriculture.

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Titles of Tables and Figures*

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

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

Table 3. AME-predicted food intake (in grams), and contribution to total solid food intake (%), for women, obtained from the observed diet (FFQ) and simulated-past diet

Fig.1 Location map of the study villages (Guédé-Chantier, Guédé-Village and Lérabé) in the Middle Senegal River Valley, district of Podor, North Senegal

Fig.2 Diagram of a *Leydi*, the traditional territory type of the Senegal River Valley (Haalpular people) characterized by geographical discontinuity (adapted from Boutillier and Schmitz,1987)

Fig.3 Evolution of cereal consumption in the Senegal Middle Valley, diagram elaborated from Babacar Ba data (2008)

Fig.4 Diagram of the annual organization of agricultural production and food availability (case of a single rice crop per year with possibility of planting flood-recession sorghum)

* See also Tables S1 and S2 and Fig.S1, Fig.S2, Fig.S3, Fig.S4 provided in Online Supplementary Information-Result when referred to in the text.