Management of Rice Seed During Insurgency: a case study in Sierra Leone

Gelejimah Alfred Mokuwa

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Thesis

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Abstract

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In large parts of West Africa small scale farmers rely upon the cultivation of upland rice under low input conditions in a great diversity of micro-environments. It has been suggested that formal research should consider the context within which farmers address their food security issues. But these contexts need further clarification for poor and marginalized farm households facing many challenges, including dislocations associated with political and social unrest, and civil war. The research presented in this thesis builds on earlier findings concerning farmer management of rice genetic resources under farmer low-resource conditions. It starts with a regional focus, drawing on methods from the social and biological sciences, concerning the human, environmental and technical factors shaping the character and composition of rice varieties grown by small-scale farmers in coastal West Africa (seven countries from Senegal to Togo) and then focuses on specific in-depth field studies undertaken in Sierra Leone.

Findings show that farmer rice genetic resources were persistently and enduringly adapted to local agro-ecologies via strong selection processes and local adaptation strategies, and that these adaptive processes were largely unaffected by the temporary contingencies of civil war. It is also shown that even under extreme (war-time) conditions success indicators in farmers' local seed channels remain robust. Farmers continue to select and adapt their seed types to local contingencies, and war served as yet one more stimulus to further adaptation. This persistent human selective activity continues to make a significant contribution to the food security of poor and marginalized farm households in the region.

The major finding of this thesis is that selection for robustness among varieties of the local staple, rice, helped to protect Sierra Leonean farmers against some of the worst effects of war-induced food insecurity. In this sense, therefore, war may have served to strengthen and prolong farmer preferences for robustness, but it was not the cause of this preference. The marked diversity farmers maintain in their rice varieties is understood to be part of a longer-term risk-spreading strategy that also facilitates successful and often serendipitous variety innovations. In a world facing major climatic changes this local capacity for seed selection and innovation ought to be a valued resource for technological change. The present study provides a starting point for thinking about the improved effectiveness of institutional innovation strategies for farmer participatory innovation activities.

Keywords: Technography, *Oryza glaberrima*, *Oryza sativa*, farmer hybrids, sub-optimal agriculture, farmer adaptive management, plant genetic resources, peace and extreme (wartime) conditions, local seed channels, selection for robustness, Sierra Leone, West Africa.

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Gelejimah Alfred Mokuwa

September 2015

Wageningen, the Netherlands

kids.

Dedication

To my beloved Mother Madam Kumba Bona.

Please see these pages as a result of your sacrifice and commitment to the education of your kids.

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CHAPTER ONE

Introduction

Alfred Mokuwa

Abstract

In large parts of West Africa small scale farmers rely upon the cultivation of upland rice under low input conditions in a great diversity of micro-environments. It has been suggested that formal research should consider the context within which farmers address their food security issues. But these contexts need further clarification for poor and marginalized farm households facing many challenges, including dislocations associated with political and social unrest, and civil war. The research presented in this thesis builds on earlier findings concerning farmer management of rice genetic resources under farmer low-resource conditions. It starts with a regional focus, drawing on methods from the social and biological sciences, concerning the human, environmental and technical factors shaping the character and composition of rice varieties grown by small-scale farmers in coastal West Africa (seven countries from Senegal to Togo) and then focuses on specific in-depth field studies undertaken in Sierra Leone.

Findings show that farmer rice genetic resources were persistently and enduringly adapted to local agro-ecologies via strong selection processes and local adaptation strategies, and that these adaptive processes were largely unaffected by the temporary contingencies of civil war. It is also shown that even under extreme (war-time) conditions success indicators in farmers' local seed channels remain robust. Farmers continue to select and adapt their seed types to local contingencies, and war served as yet one more stimulus to further adaptation. This persistent human selective activity continues to make a significant contribution to the food security of poor and marginalized farm households in the region.

The major finding of this thesis is that selection for robustness among varieties of the local staples, rice, helped to protect Sierra Leonean farmers against some of the worst effects of war-induced food insecurity. In this sense, therefore, war may have served to strengthen and prolong farmer preferences for robustness, but it was not the cause of this preference. The marked diversity farmers maintain in their rice varieties is understood to be part of a longer-term risk-spreading strategy that also facilitates successful and often serendipitous variety innovations. In a world facing major climatic changes this local capacity for seed selection and innovation ought to be a valued resource for technological change. The present study provides a starting point for thinking about the improved effectiveness of institutional innovation strategies for farmer participatory innovation activities.

Keywords: Technography, Oryza glaberrima, Oryza sativa, farmer Hybrids, sub-optimal agriculture, Famer adaptive management, plant genetic resources, Peace and extreme (wartime) conditions, local seed channels, selection for robustness, Sierra Leone, West Africa

Introduction

This thesis is part of a larger programme in which a group of researchers drawing on methods from the social and biological sciences has enquired into the human, environmental and technical factors shaping the character and composition of rice varieties grown by small-scale farmers in coastal West Africa (seven countries from Senegal to Togo). Rice is primarily an in-breeder, and it has been widely reported in the literature that farmer selection on morphological features serves to maintain distinct varieties in farmers' fields (for review see Jusu 1999). But there is also some small degree of natural outcrossing in rice in and between farmers' fields (Nuijten and Richards 2013) and this serves to ensure a degree of genetic diversity in local collections of planting materials. As a result, farmers keep a keen eye open for unusual off-types in their seed stocks, and sometimes consciously experiment with this material l (Richards 1986, 1990).

West Africa is an interesting case for the researcher interested in farmer selection of rice, since it is the only region where two domesticated species of rice - *Oryza glaberrima* (African rice) and *O. sativa* (Asian rice) - are planted in close proximity, raising the issue of whether there has been any gene flow between the two species. It was once widely assumed that such gene flow was prevented by a sterility barrier. More recent work has shown that this barrier could be overcome by scientific techniques (Jones et al. 1997). At about the same time Jusu (1999) presented morphological evidence for supposing that some farmer varieties of rice in Sierra Leone had an inter-specific hybrid composition.

The joint papers emerging from the present work programme (three of which are included in this thesis) provide stronger molecular and morphological evidence supporting Jusu's tentative conclusion. The data are now drawn from samples of farmer rice varieties from across the region, and show that hybrid-derived farmer material is especially frequent in two countries - Sierra Leone and Guinea Bissau. Both countries were likely early entry points for Asian rice, diffused towards coastal West Africa by early Portuguese oceanic trade. In both countries African and Asian rice types are still grown in close proximity. In Ghana and Togo, by contrast the two species are planted in distinct locations, for cultural and topographical reasons, and farmer hybrid material is rare or absent.

The overall dynamic supporting farmer rice selection in West Africa is shown to be the need to adapt to a wide variety of adverse conditions (see Chapter 5, below). Experimental data reveal that farmer varieties are often exceptionally robust and many have superior performance in farmer low-input conditions. This robustness is shown to be a product of a mixture of natural outcrossing and intense farmer selection and dissemination. In a sense, therefore, robustness of the seed types is a product of the robustness of the farmer seed selection system. The present thesis makes this topic the specific focus of attention. What kind of shocks can the system withstand while still producing useful, adapted planting material? Are present farmer varieties the products of historical or current capacities? To what extent are farmers capable to renew their own varieties to adapt to new challenges, including market demands and climate change?

As noted, Sierra Leone is a country in which farmer rice seed innovation is especially marked. It is the most rice-dependent country in the region, the crop being the source of about 50% of all calories consumed by the population. Furthermore, the country presents a kind of natural experiment, since it was hit by a damaging civil war (the rebellion of the Revolutionary United Front). This was a rural-based insurgency lasting for over a decade (1991-2002) and disrupted all but the most basic aspects of economic production. Was the farmer seed system for rice robust enough to survive even this kind of violent dislocation?

Many development and humanitarian agencies assumed that the chaos was total and they prepared to offer farmers seeds-and-tools packages to re-start their lives once peace returned (Richards et al. 2004). There is little doubt these inputs helped speed up the pace of recovery. But evidence (mainly farmer reports, some baselined by pre-war data) will be presented below (Chapters 2 and 3) to suggest that the war did little to damage the overall effectiveness of the farmer seed system.

For example, there was no sudden war-induced drop in seed varieties available, or abrupt shift in post-war patterns of seed usage, despite the fact that humanitarian agencies mainly distributed exotic or improved seed material. This supports a conclusion that the farmer seed system for rice in Sierra Leone remains robustly capable of generating and disseminating adapted seed types. The system should be allowed space to continue, for the benefit of the many farm households dependent on producing the rice they consume under family farming conditions.

From the 1960s, considerable efforts have been made on introduction and promotion of improved crop varieties based on their performance under optimal conditions (Amanor, 2011). For rice, this was based on the assumption that the agro-ecology of rice farming can be readily remodelled in the direction of optimality. But it has more recently begun to be realized that the promoted exotic varieties did not address farmers' conditions, because prevailing environmental and socio-economic as well as cultural requirements were underestimated. Improved varieties were not well adapted to sub-optimal farming conditions (Sall et al. 1998). Continuities in farmer seed selection and use despite extensive socio-economic disruption imposed by the war in Sierra Leone suggest a different approach. In a world facing major climatic changes local capacity for agro-ecological innovation ought to be the starting point for technological change.

Problem statement

Farmers who hid in isolated areas in central-northern Sierra Leone during the civil war from 1991 to 2002 were, in many cases, denied access to international humanitarian aid, and had no option than to continue farming to provide food security. Farmer seed selections, and especially varieties of African rice (*Oryza glaberrima*) proved adaptable in these conditions. These local seed selections were, and remain, important to farmers as food-security crops. The present study evaluates the management of these farmer seed selections by vulnerable or marginal farmers in central-northern Sierra Leone, in order to throw light on the scope of indigenous capacity for food security by "the poorest of the poor".

The research seeks to understand what processes or mechanisms underpin robustness in conflict-affected farmer seed systems for rice, in order to inform formal scientific institutions and humanitarian agencies. The study pursues an interdisciplinary approach combining biological and anthropological investigations to uncover interactions between socio-economic variables and phenotypic and genetic diversity of African Rice. It is intended that the present study will contribute to the improved effectiveness of institutional innovation strategies and farmer participatory innovation activities.

Research objectives

The research reported in this thesis seeks to better understand farmer adaptation of (African) Rice as a means to food security under extreme circumstances (war and lack of access to humanitarian inputs), and to explore the relevance of these adaptations to the post-war food security of marginalized and isolated groups, with particular focus on women and youth with weak land rights. The research is part of a larger programme in which a group of researchers drawing on methods from the social and biological sciences starts with a regional focus in seven coastal West African countries on farmers' varietal diversity and zooms in on specific field work based case studies on Sierra Leone in order to explore the context of farmers' seed choices and investigate the assumption that war in Sierra Leone caused a reduction in farmer rice seed genetic diversity.

The research specifically aims to:

1. Examine if and how a low-intensity insurgency affected farmer rice seed selection
2. Explore informal seed system dynamics with a view to throwing light on further options for linking local knowledge of local food security adaptation and formal institutions
3. Examine war-time food security adaptations, and to assess to what extent such analysis contributes to the long-term food security of poor and marginalized farm households in the region
4. Explore farmers' varietal diversity across coastal West Africa in order to depict the diversity represented by farmers' varieties in the region
5. Analyse the morphological characteristics of typical farmer varieties under different sub-optimal conditions across West Africa in order to evaluate their robustness and coping strategies
6. To explain how farmer practices have combined with environmental pressures to shape rice diversity in the case study countries to better understand region specific morphological traits in order to depict the scope of the interplay of artificial and natural selection in crop adaptation in low-input farming systems in West Africa and to assess to what extent such analysis contributes to multiple pathways for natural and artificial (farmer) selection in order to depict how closely related are the differences at the molecular level relate to the differences at the morphological level (see Nuijten et al., 2009).

Research questions

The research questions addressed in this thesis are as follows:

1. How did populations cut off from humanitarian inputs (enclave populations) adapt to food insecurity during the war in Sierra Leone, and why, and how, were these adaptations effective?
2. How were seed materials for rice (and other food security crops) obtained in extreme conditions? What survives of this war-time food security crop adaptation under conditions of post-war recovery, and why?

3. What diversity exists in farmers' fields in coastal West Africa? What did African rice (*O. glaberrima*) and other hardy farmer seed selections contribute to food-security adaptation under extreme conditions and war-time enclave conditions?
4. What relevance do answers to the above questions have for future food security of impoverished and marginalized rural groups in the West African rice-growing region?
5. What scientific principles underlie these extreme conditions and war-time food security adaptations, and to what extent can such analysis contribute to the long-term food security of poor and marginalized farmers in the region?
6. . How do farmer varieties perform across a wide range of environments? What are the implications of the robustness of farmer varieties for the formal system of crop development?
7. . How farmer practices in combination with environmental pressures have shaped the phenotypic diversity of rice in the West African rice-growing region? To which extent can such differences at the morphological level relate to differences at the molecular level as well as to the specific regions where these varieties were collected?

Research design and methods

This research seeks to examine the claim that while war had many destructive side-effects, and disrupted farming, farmer seed systems were robust. Seed systems in this context are defined as social arrangements for distributing seeds among farmers across both space and time. In this regard, seeds and varieties are deemed socio-technological facts. They are embedded within both social and biological-agronomic (technical) relations of production. The research specifically examines seed management modalities. It is thus, above all, evaluation research, in which objectives are to be attained by exploring the context of farmers' seed choices, distribution modalities, local management of rice diversity, and related institutional practices of variety development and conservation as socio-technical programmes. Such programmes (Okry, 2011) are characterized by distinctive modes of operation, regulations, and aims through which achievement of goals is reached.

Different research designs have been proposed as suitable for evaluation research. The proposed study was carried out using a methodology known as technography (Richards 2003). Technography (the description and analysis of technological activity as a systematically related set of material and sociological processes) assumes the existence of real (if deeply embedded) causal mechanisms of both a material/biological and sociological nature, to be identified and elucidated by research. Technography is thus located within a philosophical framework of critical realism (Pawson and Tilley 1997). Under the technographic rubric social and biological variables are assigned an equivalent epistemological status and treated within an integrated framework.

A range of methods was used to realise the proposed technographic research design, oriented on farmer adaptive management of plant genetic resources in extreme conditions. These include:

- Identification, collection, genetic/morphological characterization and agronomic assessment of relevant rice seed materials across Coastal West Africa in order to depict the diversity represented by farmers' seed choices
- Direct observation of actual farmer management practices
- Farming systems description and analysis
- Ethnographic observation and analysis
- Use of survey-based based instruments to access sociological, agro-ecological, economic and political/institutional variables
- In-depth interviewing of key informants about the war, histories of displacement and enclavisation, food security and adaptive experimentation.

Research area, sampling, data collection and units of analysis

The study design selected a number of previously war-enclaved communities along a north-south transect through four districts of central-northern Sierra Leone (Moyamba, Tonkolili, Bombali and Kambia Districts) for detailed field investigation, and identified a small group of more accessible localities for comparative purposes.

In establishing and contextualising these field sites use was made, where possible, of earlier base-line data sets for war-affected rural communities in central-northern Sierra Leone. These included a detailed pre-war survey of rice farming in Mogbuama (Richards 1986) and randomised data sets covering social backgrounds of enclaved farmers (on-road, off-road villages), seed losses, seed choices of rehabilitating farmers, as supplied by the humanitarian agency CARE from c. 2000, plus a range of socio-economic and socio-political indicators, village histories of displacement and enclavisation, and information on social and political organization and village institutions compiled by Richards et al. (2004).

The present author took part in the CARE baseline surveys as a field data collector, so has good knowledge of the scope and reliability of this data source. This and other pre-research baseline data sources (to be specified below) allow a regional picture of differences between wartime enclaved and accessible communities to be formed, and field sites were chosen to provide detailed focus within this larger picture.

Previous work had shown the importance of careful categorization by gender, age and class fraction ("children of the chief", commoners and clients, strangers), in order to understand systematic variations in orientation towards food security adaptation (Archibald & Richards 2002; 2002b). It was an objective of the current study further to determine which groups had been active in harnessing the potential of African rice and other hardy rice types, how they had gone about this, and how well the information had been shared.

The research established data sets on a standard set of topics, including land quality, labour availability, seed exchange, seed loss, access to seed, field size, variety names, number of varieties per household/work unit, land access, and other factors related to variety management. Sampled farmers were also asked to provide seed and plant samples for each variety encountered during the survey to correctly identify varieties and provide molecular evidence using marker probes as well as morphological data on grain and plant types.

The present researcher also took charge, on behalf of the larger research team, of field management of observation trials (at Fala Junction, Kowa Chiefdom) to measure robustness and strategies of adaptation within a large set of farmer varieties collected from across costal West Africa (see Chapter 5 below). A fire in the thatched building rented for temporary storage of trial materials was disruptive but not disastrous.

The prime units of analysis were dryland rice growing households. It should be noted that the farms studied are not the units of analysis, but the whole set of upland rice farms found in the villages during the fieldwork period (2007-2008). A reason for this time-demanding approach was to try and capture intra-village, and more specifically inter-farm, dynamic aspects of variety choice, seed exchange and genetic erosion resulting from natural and/or social factors. This allowed some probing into the impact of different seed distribution modalities to sustain conclusions drawn from Chapter 2.

The argument and analysis of war impacts on seed systems is covered in Chapters 2 and 3. The collective Chapters 4-6, based on data generated by the larger project, provide technical background to understanding the detailed arguments in Chapters 2 and 3.

The key data sources for Chapters 2-3 include:

- Six chiefdom-level ethnographic war accounts obtained between 2007 and 2010, reflecting 117 focus groups and 1352 farmers from Biriwa, Bramaia, Kholifa Rowalla, Magbema and Tonko Limba chiefdoms (Northern Province) and Kamajei chiefdom (Southern Province).
- A core analysis of seed system dynamics (discussed in Chapter 3 below) based on all upland rice farms (n = 287, 100% sample) surveyed in the 2007 season in six settlements selected from four chiefdoms (Biriwa, Magbema, Kholifa Rowalla [Northern Province], and Kamajei [Southern Province]).
- Preliminary interviews helped to understand the general context of the research.
- Use was also made of base line data sets mentioned above (and further described in Chapters 2 and 3 below). Some additional facts concerning war impacts were derived from village war history sheets prepared as part of the CARE base-line studies. Use was also made of material derived from the countrywide conflict mapping report prepared for the Special Court for War Crimes in Sierra Leone (Smith and Longley 2004).

For the general coastal West African study investigation methods used included:

Methods from natural sciences:

- Comparative field trials.
- Laboratory analysis of field materials.
- Experiments on adaptive plasticity/robustness of farmer rice varieties, as discussed in detail below, Chapters 4-6.
- Molecular analysis: AFLP marker probes were used to characterize farmer rice varieties collected across seven countries in coastal West Africa.
- Observations in farmers' fields of e.g. germination, seed rate and seed mixture.

Methods from social sciences:

- Participant observation was used to gain closer understanding of the farming reality under study, to unravel strategies of seed management, to understand local variety development and conservation, and to explore the context of farmers' seed choices and distribution modalities.
- Formal questionnaires were used to assess seed acquisition and distribution patterns and modalities, and data relating to such matters as labour sources, farm areas seeded, and seed rates.
- Key informant interviews were used to collect information on food security and farmer adaptive experimentation.

A more detailed account of data collection and analysis is provided in the methodology section of each chapter.

Thesis outline

This thesis is organized in seven chapters.

CHAPTER 1 provides an overview of the argument and brief summary of the research approach and methods used.

CHAPTER 2 focuses on describing the impact on rice farming of the civil war in the case-study areas. The civil war in Sierra Leone was largely a rural insurgency, and its impacts were highly varied from place to place. The chapter compares a southern group of villages where the rebel impact was quite short-lived, and where farmers resettled after a matter of months, under the protection of their own civil defence fighters, and a northern region in which rebel occupation was longer. One of the chiefdoms sampled (Kholifa Rhowalla) was a major centre for RUF activity (the movement's leader came from this area). Here, farming took place under conditions of considerable insecurity over several seasons, and cut off from any international humanitarian support. The implications of these different histories of occupation are explored.

CHAPTER 3 looks at the impact of war on farmer seed choices and on the functioning of the farmer seed system. It is a retrospective study based on farmer recalls at three periods (before, during and after the war). These perceived tendencies are analyzed graphically. Human memory is selective, and is shaped by current social conditions. It is possible, therefore, that farmer recalls have been shaped by more recent events. Considerable effort is made in the chapter, therefore, to "ground" these memory data. Two approaches are applied. One is to compare farmer recalls concerning rice varieties grown in the post-war period with actual measured data based on farm surveys and collections undertaken in 2007-8. The second is to link the relevant subset of the recall data on the pre-war period to base-line data available for one specific settlement surveyed in 1983 and 1987. The 1983 data involved a complete inventory and collection of rice types (Richards 1986). In both cases the consistency and reliability of farmer recall is judged to be good, suggesting that the perceived "trends" are not unduly biased by recent events. The conclusions of the analysis are that the farmer seed system is dynamic, and follows a trajectory of its own. There is little or no evidence that large deviations were imposed by wartime dislocations. The farmer seed system in Sierra Leone appears robust to the kinds of shocks administered by war.

CHAPTER 4 analyzes the molecular composition of a set of 315 farmer rice varieties collected in seven countries of coastal West Africa using AFLP markers. The results are presented as an unrooted tree with four main features. Three clusters represent the main botanical groups (*O. glaberrima*, and *O. sativa spp*. indica, and *O. sativa spp*. japonica). A fourth cluster, divided into two sub-clusters, is recognized as a group of farmer varieties of hybrid inter-specific (*O. glaberrima* x *O. sativa spp*. indica) derivation. Evidence is presented to suggest that these 'farmer hybrids" have some considerable historical depth. A possible mechanism for in-field hybridization under conditions of farmer selection is outlined.

CHAPTER 5 offers evidence of the robustness of farmer rice varieties in coastal West Africa. Experiments in five countries showed that farmer varieties were tolerant of sub-optimal conditions, but employed a range of strategies to cope with stress. Varieties of *O. glaberrima* were the most successful in adapting to a range of adverse conditions. Other varieties did well in a range of conditions, but some varieties (especially from *O. sativa spp*. japonica) were limited to specific niches. The data contradict the rather common belief that farmer varieties are only of local value. Unfortunately, the experiment was designed before results of molecular analysis identified a set of farmer varieties of inter-specific hybrid derivation, and (by chance) none of the farmer hybrids was included in the design. It should be a priority for further work to remedy this omission.

CHAPTER 6 assesses the interplay of artificial (farmer) and natural selection in rice adaptation in low-input farming systems in six countries of coastal West Africa using 20 morphological traits and 176 molecular markers for 182 farmer varieties. Farmer varieties of

O. sativa exhibit considerable genetic and morphological diversity, reflecting complex development pathways. In *O. glaberrima* recent farmer usage seems to have restricted genetic diversity, but the species continues to play an important role in rice genetic diversity by contributing to the formation of farmer hybrid-derived selections. It is concluded that farmer varieties of rice in coastal West Africa are the product of long and complex selection processes involving genotype x natural environment x social selection factors.

CHAPTER 7 comprises a short summary and overview, with some consideration given to the findings of the thesis both for rice research in West Africa and for national rice research policy. A plea is made for more attention to be paid to supporting farmer seed innovation systems, e.g. through farmer-to-farmer learning.

CHAPTER TWO

Farmer rice variety choices in war and peace

Alfred Mokuwa

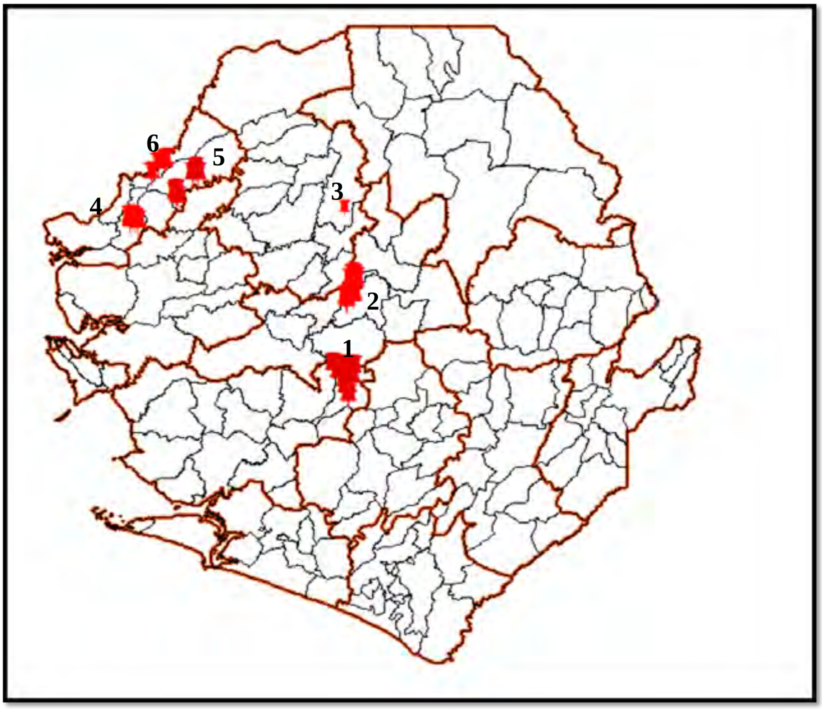
Abstract

Adversities take many different forms. It is widely assumed by protagonists that incidents of atrocity crippled the entire crop production sector and farmer seed choices in Sierra Leone. This chapter seeks to investigate this assumption. The objective of this chapter is to examine if and how insurgency in Sierra Leone affected the agricultural population. The main factors examined include the timing of the adversity and its duration and frequency. The methodology adopted is to document and assess what impact war had in particular on rice farming. Extensive ethnographic data were collected in six chiefdoms from north-central Sierra Leone were chosen to include four distinct ethno-linguistic communities (Limba, Mende, Susu and Temne). Data were collected from head of households for all upland rice farms in each village. Participatory Rural Appraisal (PRA) Tools was adapted, described by pre-defined questions for general discussion sessions aimed at obtaining ethnographic data on war damage that comparatively disrupted farming activity in the rural economy, administered to focus groups of elders, women and male youths for the villages surveyed in 2007-2010. In all six chiefdoms, a total of 1352 farmers were involved. Basic data source used is the countrywide conflict mapping report prepared for the Special Court for War Crimes in Sierra Leone during the period March 1991-January 2002. This chapter concludes that while the war may have depressed rice productivity, incidents of atrocity were not very frequent for the agricultural populations as a whole. This chapter does not explicitly argue this claim but in later chapters of this thesis the social and biological bases for robustness in rice variety choice will be analysed.

Key words: Adversity, Duration, Frequency, Farmer seed choice, Sierra Leone, War.

Introduction

The objective of this chapter is to examine if and how a low-intensity insurgency in Sierra Leone affected farmer rice seed selection. It has been widely assumed that such effects exist and that they are negative. This chapter seeks to test this assumption, and is divided into two parts, the first focusing on the war, the second on seeds. The methodology adopted is to document the impact of insurgency in six chiefdoms in central and northern Sierra Leone (Part 1; see Map), and to examine farmer seed selection processes across three periods (pre-war, during the war and post-war) to see what if any effect war had on the availability of seed



***Map**: Geographic overview of the Sierra Leone map. Pushpins along central to-north-west transect locating the villages, the chiefdoms in the study area.*

1	Kamajei Chiefdom, Moyamba District (central-South)
2	Kholifa Rowalla Chiefdom, Tonkolili District (central-North)
3	Biriwa Chiefdom, Bombali District (North)
4	Magbema Chiefdom, Kambia District (North-west)
5	Tonko Limba Chiefdom, Kambia District (North-west)
6	Bramaia Chiefdom, Kambia District (North-west)

types and on the logic of farmer choices (Part 2). It will be shown that the war did not have any major or permanent negative effect on farmer seed selection dynamics. There was little or no war-induced loss of varieties, and no major break in selection dynamic during the war. Farmer selection for robustness in a challenging environment was maintained across all three periods. Seemingly, selection for robustness protected Sierra Leonean rice farmers against some of the worst effects of the war crisis. This leads in later chapters to a more extended examination of the social and biological bases for robustness in rice seed systems in Sierra Leone, and West Africa more widely.

Rice seeds in Sierra Leone

Sierra Leone is an agrarian economy and the majority of the labour force is found in the agriculture sector. Rice is the most important staple, and is nearly all grown by small-scale (peasant) farmers, most of whom cultivate in the first place to supply household needs (Richards, 1986; Steady, 1985). Farming communities in Sierra Leone are materially poor, and attach great social and cultural importance to rice cultivation. Much of this cultivation occurs on rain-fed drylands. Dryland (or upland) rice cultivation represents a way of life in which important traditional values are embedded (Beoku-Betts, 1990). These embedded values strongly affect exchange, gifts, trade and marriage (Okry, 2011; Richards, 1986). Maintaining dryland rice seed agro-diversity is a key to ensuring household yield stability, food security, and (ultimately) the reproduction of social and cultural values. It is an assumption of this study that these social and cultural values have been important in the survival and recovery of rural communities in Sierra Leone from traumatic events associated with the recent civil war.

Seed variety plays an important part in small-scale rice farming systems in Sierra Leone. Anthropological field work by Richards (1986) established that a significant portion of the food security of low-resource rice farmers in one community in central Sierra Leone (Mogbuama) came from maintaining a portfolio of rice types adapted to different soils types, and that this minimized labour burdens in field management of dryland rice. More generally, it has been argued it is an important socio-technical objective in poor and marginal farming communities to maintain and strengthen local seed systems through in situ agro-biodiversity conservation (Okry, 2011; Wood and Lenné, 1999).

Rotational bush fallowing (shifting cultivation) is the main means for producing rice on uplands in Sierra Leone. There has been long-term debate about the sustainability of the system (literature summarized in Richards 1985). It can be argued that these debates have tended to ignore the adaptive contributions of farmers in devising ways to extend the viability of this mode of cultivation under increased demographic pressures. In this thesis attention will be focused on the contribution made by seed variety selection. In this regard the study builds on a general approach advocated by Almekinders and De Boef (2000)that the foundation for farmer adaptive potential is to be found in maintaining high level of agrobiodiversity. Specifically, it will be shown seed selection and experiment by farmers, in the face of difficult and sometimes rapidly changing conditions, has under-appreciated adaptive potential.

Advocates of this position worry that war destroys or undermines agro-biodiversity (Jacobs and Schloeder, 2001; Kalpers, 2001; McNeely, 2000 ; Martin and Szuter, 1999; Richards, 1998; Richards et al.,1997). In regard to Sierra Leone, where civil war crippled ‘the entire crop production sector' (Chakanda, 2009), there were strong expectations that the war must have caused major damage to seed systems. For instance, agricultural technicians from the Sierra Leone Agricultural Research Institute (SLARI) predicted high levels of genetic erosion, because so many farming communities were displaced in refugee camps, without opportunity to grow rice for a number of years (personal communication, 2007).

Concerns over rice agrodiversity were also fuelled by the activity of humanitarian agencies, in setting up emergency seed supply systems for displaced farmers. The agencies concentrated on distributing a few reputedly high-yield varieties to replace the numerous farmer varieties presumed be lost. This emphasis was partly a matter of logistics; bulk seed suppliers (either locally, or in neighbouring countries) only or mainly produced "modern" varieties. But agencies also had the perception that farmer varieties had failed under stress of war-time conditions. The problem with distributing mainly or only "modern" varieties is that it potentially threatens to reduce the number of farmer varieties in circulation, and thus undermine agro-diversity.

This chapter investigates the assumption that war in Sierra Leone caused a reduction in farmer seed diversity. The reason for the investigation is both practical as well as scientific. The scientific objective is to gain a better understanding of the principles underlying farmer seed selection. Which kinds of seeds are selected, and how is varietal diversity maintained (or lost) under a range of operational conditions, including extreme events such as war? The practical concerns relate to seed development and supply considerations in humanitarian crises. As will be shown, the study creates space for a rather different technological agenda for humanitarian agencies, to be discussed in the concluding chapter (Sperling, 2002; Scowcroft, 1996) while also strengthening rice seed systems and agro-biodiversity conservation in ways supportive of local food security and poverty alleviation (Okry, 2011; Monde and Richards, 1992).

The research design analyzes the effects of insurgency on rice seed biodiversity through paying close attention to farming communities in six chiefdoms (Tables 1 and 2). Distribution of rice varieties in these communities is assessed at pre-war, during-war and post-war periods from farmer recall data. The accuracy of farmer recall evidence is estimated by comparing post-war recall data with field survey collection data for all upland rice farms in the four case-study communities in 2007-8. Farmer recall data are found to be reliable (see below). Doubtless, memory lapses introduced some "noise" into the older recall data sets (for the pre-war and during-war periods), but this was not excessive for the one case where pre-war baseline data were available. This was a comprehensive collection of rice varieties for the village of Mogbuama, studied by Richards in 1983 and 1987 (Richards 1986, 1995, 1997).

Questions of variation in war damage are also assessed for the six chiefdom. The basic data source used is the countrywide conflict mapping report prepared for the opening of the Special Court for war crimes in Sierra Leone, entitled *Conflict Mapping in Sierra Leone* (Smith, Gambette and Longley 2004). The work contains records of about 5500 separate incidents of wartime violence during the period March 1991-January 2002. Each incident is identified by location, date and faction involved. Testimony was supplied by 401 residents in 146 chiefdoms incidents took place.

Further detail is available from war impact questionnaires administered to focus groups of elders, women and male youths in villages in Kamajei chiefdom in 2002, a location for several of the villages surveyed in 2007-8. This war-impact study was designed by Steve Archibald and Paul Richards for the development agency CARE (Archibald and Richards 2002; 2002b; Richards, 1997). The present author took part in the administration of the survey. The war damage data sets are compared with data on reported farmer rice variety changes.

After a brief discussion of data collection methods, Part 1 offers an analysis of war impacts in the six selected chiefdoms. Details are summarized in six text boxes. Impacts vary from moderate to serious, and vary a great deal in terms of local details. The Sierra Leone civil war was a low-level insurgency, and despite widespread publicity in international media, the conflict was neither continuous nor total. Periods of attack were often very short, followed by retreat of fighters and long periods of relative calm. Much farming was carried out in these quieter periods, even if under modified conditions due to lack of security.

Part 2 considers changes in farmer and farming community portfolios of upland rice types, before, during and after the war. Results are mainly presented in the form of tables and figures summing up changes over time. The data show significant changes over a period of about 30 years in use of rice varieties (some apparent extinctions, some adoption of novelties, resulting both from farmer selection and formal research, over a period from c. 1980 up to 2007-8 (the date of fieldwork for this study) but few changes can be directly and unambiguously linked to the war. Not many, if any, varieties were lost. Varieties introduced as a direct consequence of the war (e.g. those favoured by humanitarian agencies for resettling war-displaced farmers) show up in the survey data, but have served to diversify rather than displace local choices.

Data collection - strategy and issues

The six selected chiefdoms run in an arc from the centre of the country (Kamajei chiefdom, Mende-speaking) through north-central Sierra Leone (two chiefdoms - Temne-speaking Kholifa-Rowalla chiefdom and Limba-speaking Biriwa chiefdom) to three chiefdoms situated close to the north-western international borders of Sierra Leone with the Republic of Guinea (Magbema chiefdom - Temne-speaking, Tonko Limba chiefdom - Limba speaking, and Bramaia chiefdom - Susu-speaking). The chiefdoms were chosen to reflect a variety of environmental conditions (a gradient from forest to savannah) and to include four distinct ethno-linguistic communities (Mende, Temne, Limba and Susu). The first three are the largest of Sierra Leone's 17 ethno-linguistic communities.

The actual villages studied in each of chiefdoms are listed in Table 2.Data were collected from head of households for all upland rice farms in each village. The upland rice farm is the main source of family feeding, and is controlled by the head of the household. Most heads of household are male. Widows and unmarried women with dependents occasionally also have upland rice farms (since they are heads of their households). Women are also farmers. But most married women carry out specific tasks on the upland rice farm, such as weeding, and/or grow non-rice crops such as groundnuts or plant rice in seasonal wetlands, so are excluded by the study's focus on varieties associated with upland rice farms.

Primary data were collected, in all, from over 200 household heads. The questionnaire administered to farmers gathered information on seed sown at various periods, means of seed acquisition, seed sources, and the relationship of the supplier to the recipient. In addition, all 200 farms were visited, and all rice varieties planted that season (either 2007 or 2008) were identified, and many were collected for further analysis (see chapters on molecular composition and morphology, this thesis).

For clarification, materials planted by farmers during the fieldwork period are actual measured data concerning plots and plot sizes. These data are used as controls for the information supplied by farmers on historical changes, since there should be a good fit between field measurements and variety portfolios reported for the most recent (post-war) period. This is further discussed below (Part 2). The (reported) data allow us to track changes over time in use of varieties, and to track losses.

On the issue of the losses it needs to be made clear that these are reports of loss of a particular variety by a specific farmer. Any temptation simply to aggregate these figures to arrive at a measure of genetic erosion should be resisted. All the aggregate data show is the rate of turnover for that particular village. High rates of turnover could be associated with genetic erosion. But equally, they could also be an index of the enthusiasm of farmers to experiment among varieties. The data require to be further analysed to bring out whether abandonment rates match adoption rates for given settlements. But even this would not prove erosion, since inter-village effects (not analysed in this research design) would have to be included. Varieties may shift among villages in response to environmental change; they may be abandoned in places where they are becoming less well suited to conditions, only to be adopted in other villages where they are becoming better suited.

It should also be noted, farms studied are not samples, but the total number of upland rice farms found in each survey village during the fieldwork period (2007-8). A reason for this exhaustive and time-demanding approach was to capture inter-farm dynamic aspects of seed choice and seed exchange resulting from community environmental or social factors.

Age and gender for farmer-informants are reported, and related to data on farmer-to-farmer seeds exchanges. These data shed light on various actors and institutions involved in strengthening rice seed systems and agro-biodiversity during the war (1991-2001) and in early post-war period (2002-2007/8). These data allow some probing into the impact of different seed distribution modalities - such as farmer-to-farmer exchange and distribution by humanitarian agencies.

Some sampling biases should be taken into account. Respondents encountered were mainly middle-aged or older male farmers with vast knowledge of the local environment and indigenous upland rice management practices. Many will have been members of the counter-insurgency Civil Defence Force (CDF). Women, youth and those who fought with other factions in the war are under-represented by reason of the focus on upland farms and heads of households.

This could have implications for the picture presented below concerning rice seed exchange networks. Women are assiduous collectors and experimenters with rice, and have their own gendered networks of seed exchange. The rebel Revolutionary United Front faced problems of food supply, and organised its own system of collective farms (Peters and Richards 2011). Like women, re-settled ex-combatant farmers from the rebel side in the war may have their own seed exchange networks, and different varieties may have been selected and circulated. They will have been missed in this study, since it focuses on farmers who were settled in situ before, during and after the war.

A final issue worth mentioning relates to the reliance of the study on recall data. All memory fades over time. We have to make some allowance for that. Presumably, pre-war recollections cannot be as accurate as later recollections. Equally, we have to take into account that memory is actively kept alive or reconstructed by subsequent experiences and current concerns. The study seeks to ground truth recent recalls with measured data, but the present study has no data to reveal what filters and biases may selectively operate on the memories of older male heads of household over longer periods of time.

An overall outline of the war

The civil war in Sierra Leone was begun when a small group of armed dissidents, with support from the Libyan leader Col. Gaddafi, attacked two border districts of eastern and southern Sierra Leone in March-April 1991. The Revolutionary United Front (RUF) aimed to depose the one-party regime of President Momoh. Some of the movement's leaders had gained guerrilla experience fighting with the rebel forces of Charles Taylor in Liberia, and some of Taylor's fighters helped the RUF enter Sierra Leone. The rebels initially gained some support from among disaffected groups in Pujehun and Kailahun Districts, but atrocities, many committed by the Liberians, quickly alienated local populations. The weak national army lacked counter-insurgency capacity, however, and the war spread in border districts.

Further RUF advance was halted when Guinean and Nigerian troops secured river crossing points at Daru, east of Kenema and Gondama, south of Bo.

The Momoh regime was then deposed by an army coup, and new regime of young officers (the National Provisional Ruling Council, NPRC) oppose took power (1992), promising to oppose the rebels with renewed vigour. Taylor's troops had by now withdrawn, and a weakened RUF was pushed back towards Liberia in 1993, at which point the NPRC government of Chairman Strasser declared a unilateral cease fire. Meanwhile, the rebels abandoned its vehicles and heavy weapons, and opted instead for a "jungle" campaign based on camps located in forest reserves dotted across the country. From 1994 its pin-prick raids spread terror and confusion to all parts of the country, and even to the outskirts of the capital, Freetown, where the government was forced to re-think its strategy.

Mercenary forces (international private security companies) were now hired to stem the rebel advance. One British-based group using Gurkha veterans was ambushed with many casualties and withdrew. A second (British-South African) group - Executive Outcomes - was more successful, both in securing mining sites in Kono and Moyamba, and then in training army and civil defence volunteer units in counter-insurgency. Executive Outcomes, with support from Nigerian peacekeepers, attacked several RUF forest camps from the air, and the RUF began to engage in a peace process sponsored by the government of Cote d'Ivoire.

At this point public and international pressure forced the army out of power, and elections were held, ushering in the civilian regime of President Kabbah. The Kabbah government continued the Ivorian peace process, but further raids by Executive Outcomes-backed civil defence forces on RUF positions undermined rebel confidence in the negotiations. The RUF signed a peace deal on 30th November 1996, but perhaps only because it specified that Executive Outcomes would leave the country within 90 days.

In May 1997 army elements still loyal to President Momoh deposed President Kabbah and installed a military junta. The junta then offered peace and a power-sharing agreement to the RUF. RUF fighters left their jungle bases and entered Freetown. The new regime drew some support from Momoh-loyalists among civilian elements. But the international community was utterly opposed to the junta. Nigerian peacekeepers (based at the international airport at Lungi) mounted an operation to drive junta forces and the RUF from, the capital in February 1998 and the civilian president was restored. The countryside was now divided between areas (mainly in the south and east) controlled by the civil defence militia forces loyal to President Kabbah and the north of the country, mainly controlled by junta elements (ex-army groups or RUF units, depending on region).

Mid-1998, rogue international mining interests and arms suppliers re-trained and re-equipped junta and RUF forces on the Liberian border. These re-armed dissident groups attacked the eastern diamond mining districts in December 1998 and marched on Freetown, intent on avenging the deaths of 23 junta army officers shot by the government for treason in October, and on releasing RUF leader, Foday Sankoh, held on death row pending execution. The junta forces attacked eastern and central Freetown on January 6th. 1999, causing many casualties among civilians and the deaths of up to one thousand Nigerian peace-keeping troops.

It was only with difficulty that the Nigerian army regained control of the city. The rebels retreated into the interior along secondary roads and tracks, causing havoc wherever they went. This was the period when amputations, and other mutilations and atrocities, reached a peak, especially in the north of the country, where local civil defence forces were less strong. Rural civilians in remote farming districts of the north and north-west were among those hardest hit by this rebel violence.

An elected president in Nigeria announced that the Nigerian peace-keepers planned to withdraw from Sierra Leone. Lacking a national army, the government sued for peace, and signed a deal with the RUF in Togo that provided it a place in a new civilian-led power-sharing regime. The international community objected to the deal, and took steps to restrict the RUF's role in the regime. Things came to a head at the hand over from the Nigerians to a new UN peacekeeping force, UNAMSIL, in May 2000, when a UN source first announced that the rebels were once more marching on Freetown, causing widespread panic, and then promptly withdrew the report as incorrect. Meanwhile, the British government had committed troops to Freetown to supervise an international evacuation, and to impose a security corridor around Freetown, pending full UN deployment.

Almost the entire Freetown-based leadership of the new RUF political party allowed under the Lome agreement (some 400 detainees) was detained as the British arrived. They remained in jail for six years, and the movement's political will was broken. Banditry by a dissident army splinter group - the West Side Boys - was ended by British army operation in August 2000. The Abuja accords of 2000-2001 then offered disarmament and reintegration packages to fighters of all factions still in the bush. Most accepted the terms. The anarchic violence widely predicted for the post-war period never materialized. President Kabbah declared the war to be ended in February 2002.

Variable war impacts

By the mid-1990s war had affected nearly all parts of the country. The effects were often severe close to the Liberian border where the war took root and lasted longest (e.g. in parts of Kailahun District controlled by the RUF from 1991 to 2001), in mining districts, where the different factions repeatedly fought for diamonds and other valuable assets, and in remote rural areas close to RUF camps, where civilians were regularly raided for food supplies, and forced into what amounted to slave labour to grow food and carry supplies for the rebels. But these severe effects were not long-lasting in all districts.

In some parts, the war reached late. For example, it only affected Freetown and surrounding districts from 1999. In other districts (much of the south and parts of the east) the war ended early (c. 1996). Mass mobilization of almost all able-bodied men into the civil defence forces (CDF) in 1995-6, drove out the rebels in these districts, and displaced villagers were able to return home and resume farming from late 1996 or early 1997. In these re-populated areas farmers tended to abandon export cash crops such as coffee and cacao and focus solely on subsistence farming. This served to boost the local rice economy.

Other areas, however, experienced repeated, or irregular but recurrent, war activity, and some villages were uprooted and resettled on a number of different occasions. Thus there is no single picture of war damage for the rural economy of Sierra Leone as a whole. Everything must be related to location, time and context. Tables 2-9 and Figures 1-6, based on farmer interview materials for 47 villages in six chiefdoms (n = 1352), supplemented by data from the Archibald-Richards survey of 16 villages in Kamajei chiefdom, offer a picture of the ebb and flow of war for the villages studied in this thesis. In all, 39 separate attacks are reported (Table 2) peaking in 1996 (32.5% of all attacks).

More than 80% of all attacks were experienced in the four years 1995-98. The majority of attacks (36 of 39) were attributed to the RUF (Table 3). This may represent a sample bias, since many villagers farming throughout the war were CDF supporters or members. Farmers reported significant proportions of foreigners (mainly Liberians) in the attacking forces (Table 4). Most Liberians within the RUF were withdrawn in 1992, but many of the foundation cadres of the RUF had spent time as exiles in Liberia, or had been recruited from among cross-border populations.

Information on main attacking groups (Table 3) and the ethno-linguistic identity on attackers (Table 9), taken together, makes an important point about the nature of the war. Farmers identified the main protagonist as the RUF, but also report encountering speakers of 12 of the 17 distinct ethno-linguistic groups in Sierra Leone among these attacking forces, thus confirming claims (see Richards 1998) that there was little or no ethnic element to the Sierra Leonean rebellion. One or two Liberian languages were also reported, e.g. Gbande, though it should be noted that this language is also spoken in one or two villages in Kailahun District in Sierra Leone, though not normally reckoned among the country's 'official' languages. The 'missing' five are all small minority languages.

Data on abductions of villagers by rebel forces are also highly relevant, since upland rice agriculture in Sierra Leone is limited by problems of (gendered) labour supply. Active young men are needed to clear farms of bush. Women are a necessary part of the labour force for planting and weeding. Table 7 shows the number of abduction events reported by farmers, classified by size and gender. Thirty-one abduction events were reported involving men and twenty-two abduction events were reported involving women. Numbers per event were often quite small (half of all events reported for men involved less than 5 abductees per event, and more than half of all events for women involved less than 4 abductees per event). But in villages of on average 250-300 people the loss of even a handful of active young men and women would significantly increase labour supply problems. Abductees were stigmatised by their enforced induction into the rebel movement, as fighters or 'bush wives' (Coulter 2009) and among those surviving the war few have ever returned and successfully resettled to a farming way of life (Richards et al. 2004).

Among the 1352 farmers interviewed, displacement peaked in 1996, and early return peaked in 1997-8 (Figs. 1-4). This information is important, because it shows that the period of maximum dislocation of agriculture due to the war was restricted to a remarkably short period. Farms were mainly abandoned in 1996 but much agriculture was resumed in 1997-8, whereas the general picture of the war painted by media and scholarly sources is of a devastating conflict stretching over a decade from 1991, and intensifying over the second half of this decade. This is because the war came to the capital late (in 1999). The data in Figs. 1-4 suggest that for the case study farmers, at least, a war beginning in 1996 was largely over by 1998.

Although the six chiefdoms cover a substantial transect from centre to extreme north-west of the country caution should be exercised in extending this generalization to all 149 chiefdoms in Sierra Leone. As already noted, the war was variable and patchy in its impact, and larger, randomised chiefdom sample will be needed to extend this finding across the country. But it is highly relevant to understanding the apparent rather low impact of the war on rice farming in the six sample chiefdoms, to be discussed below.

The conflict mapping report in places significantly adds to the picture just painted for the sampled villages and farmers. Not all attacks were the work of rebel forces. Sometimes violence continued after the RUF had withdrawn because the war had re-opened old wounds.

A specific example is the cease-fire period accompanying the negotiation of the Abidjan peace (April-November 1996). The conflict mapping report describes most areas as quiet during this period, but skirmishing was still common in the northern part of Moyamba District (including Kamajei chiefdom). Some of this was banditry along the main road from Bo to Freetown, passing through Moyamba Junction, a noted trouble spot. But other violence (burning of villages in Fakunya chiefdom, for example) reflected inter-communal tensions over land and other grievances. Informants mostly reference these actions to the RUF, but some were probably incidents between rival civil defence groups.

For further information on local war impacts on the six chiefdoms the reader is referred to the six text boxes below (one for each chiefdom). Specific locations of incidents and agriculturally significant information are highlighted. Some points relevant to the detailed analysis of seed changes in Chapter 3 are now discussed. This discussion concludes the chapter.

Discussion of war impacts on agriculture

The different periods and durations of direct war disturbance are apparent in the data for the six different locations. Any direct attack generally resulted in the displacement of farming people, though this might only be for a short duration, especially if there were civil defence fighters around, trusted by the villagers.

Farming was badly disrupted when people were displaced. Even if absence was only temporary, those fleeing for their lives might find their crops ruined by birds or weeds when they returned. Fighting also directly affected farming through loss of labour, especially when farm household members were killed or abducted. Those abducted were often strong young men, taken by the RUF as carriers or potential fighters. This robbed upland rice farming, always short of labour, with resources to cope with bottlenecks during busy periods.

The numbers of abductees - perhaps 4-5 young adult men and women per village - might not seem large, but this might amount to as much as 10-20% of the total age cohort for a typical village of 250-300 people. The general mobilization of the most active males for civil defence duties also had a temporary depressive effect on labour availability for farming.

Despite the fact that the effects of the war often remained severe for an intense period perhaps lasting several months, location, time and context is important. Those farmers who did not flee either from rebel or government forces were able to harvest much of what they had sown. Among those who did flee, but who ultimately returned, the majority lost one or two sowing seasons.

The short duration of the direct effect of the war in the six case-study chiefdoms (as noted in the boxes below) makes the Sierra Leone conflict different from other rural wars in sub-Saharan Africa (e.g. DRC and Liberia). The relative stability of the population for lengthy periods rendered the research design for this study feasible. Among those farmers interviewed in 2007-2008, over 80% had previously been farming in their communities and knew the micro-ecology well, including suitable seeds to sow.

Time spent away from the farmstead is also a direct indicator of agricultural disruption. This also varied by location and context. The effect of this was that more elder farmers and more women had to the work normally done by energetic young men and women. Astonishingly, when set against dramatic media images of people on the run, was that 67.5% (Table 2) of those still farming in the six chiefdoms during the peak period of the war (1996) had not been displaced at all.

This figure implies considerable household stability, and has substantial implications for varietal stability, since those who never moved never families lost control of their seed stocks. This means that returnees met a substantial population able to help them resettle by gifting or loaning them a good portion of seed.

Other more indirect effects can also be inferred. When villages were burnt, seed for the season might be lost in an instant. Time would also have to be diverted to basic concerns, such as providing temporary shelter. The basic farm tool (the cutlass) was a tool of war for the under-supplied rebel forces, and many will have been looted during attacks. Security check points on roads implies that obtaining basic supplies of bare essentials (such as salt and oil for lamps) must have become more difficult and expensive, thus undermining the capacity of farmers to care for themselves or to feed cooperative farming work gangs.

Other indirect effects are harder to assess, such as the impact on farming of terror tactics, including amputation, initially intended to deter voting in the 1996 election, from which the rebels were excluded. Amputation seems to have become a way of forcing compliance from villagers otherwise unwilling to support junta or rebel forces, especially after the retreat to the bush by AFRC forces ejected from Freetown in 1999.

It can be concluded from the conflict mapping report that Incidents of atrocity were not very frequent for the agricultural populations as a whole (atrocities are reported for less than a quarter of all chiefdoms), but the deterrent "shock" effect must have spread far and wide. Fear of being caught alone in the bush in a rebel ambush, and of becoming the victim such a hideous attack, perhaps carried out with the farmer's own cutlass, surely undermined confidence among villagers when setting off to the farm every day. Villagers reported that they limited their farming operations to areas close to their settlement. Unsurprisingly, many opted for the relative safety of the displaced camps.

Others, however, we caught by the rebels and put to work growing food for the RUF. In Gondama, Kamajei chiefdom, for example, some farmers had to abandon their farms to birds and rebels, and abductees from Mongere and more distant areas were asked by RUF forces to take over a few farms, while the rebels ensured their security. Early returnees from camps after the CDF drove out the rebels embarked on seed recovery from burnt debris on the foundations (*pehbimbei*) of mud houses, as in Mogbuama, Yoni, and other localities. They also harvested varieties rattooning on rice plots abandoned by fleeing rebels.

In all areas farmers tended to abandon export cash crops and focus solely on subsistence farming. Subsequent returnees regularly acquired seeds from distant kin and friends in towns or more fully resettled village, as well as from IDP camps run by humanitarian agencies at secure locations in government-controlled areas.

Those who stayed, or returned to their villages early, sometimes were vulnerable to further attacks and/or persecution (as presumed rebel sympathisers) by government forces or CDF. Irrespective of these risks, some farmers returned to their communities as soon as they could.

These were the real peasants, who valued their land above all other assets and livelihood opportunities.

Variation in direct and indirect effects can also be noted. A major issue is whether the location lay in the direct path of "food finding missions" by the RUF (or other militia groups). Several villages in the northern part of Kamajei chiefdom - an area of rice surplus - had the misfortune to attract an apparent steady stream of "food finding missions" from the notorious Kangari Hills RUF base, Camp Bokoh, in 1996-7, but were spared after that camp was emptied by the junta power-sharing call in May 1997. Later, it was the villages in the more populous but less rice-rich southern part of the chiefdom that found themselves menaced by predatory kamajoisia road blocks, not to mention the appalling "revenge" attack by four civil defence fighters on a school teacher between Mokonde and Pelewahun, right on the boundary of Njala University, as reported in the conflict mapping document (see Box below).

These local variations in direct and indirect effects are significant for later analysis. Biriwa chiefdom is a case in point. Most of the RUF activity centred on a rebel camp at Kamabai, on the main road to Kabala. It seems apparent (see relevant box) that the RUF wanted the large cattle herds of the Mabole Valley, and residents of Kamabai town seem to have been plagued by demands for hospitality. It was probably dangerous to refuse such requests.

Bumban, by contrast, though no more than a few kilometres from Kamabai in a blind valley surrounded by the high and rocky Gbengbe hills, seems to have been relatively free of "food finding missions" and the violent disruptions to seasonal farming activity these missions caused for farmers in northern Kamajei chiefdom, for example. This is reflected, it will be shown, in the continuity of seed selection processes in Bumban.

Bumban did not escape entirely, however. Reports of the burning of some houses in this settlement suggest that home-stored seed meant for the planting season must have been lost. On the other hand, farmers were often quite skilful at protecting seeds under war-zone conditions. Some farmers hid their seeds for multiplication and on-farm cultivation in unusual locations. Others, who had lost their whole stock, relied on seed diffusion in war-zone conditions through informal seed networks. Seeds supplied in this way were often heavily mixed. Farmers planted everything and then started the business of sorting and selecting. The most common varieties - Ronko, Saharie, DC, Kebdeh/kebleh, Gbalikintha, Gbakuthamitha-painday, and Samba - were among farmers' preference under fragile conditions.

Under enclave conditions farmers were also ingenious in not drawing attention to rebels on food finding missions, e.g. by suppressing smoke from cooking fires or by doing their farm work undercover. Swamps in Bumban were dug and puddled at night, for instance. All these adaptations helped to keep farm work going even under rebel 'occupation'. Other effects are less clear. In Biriwa chiefdom there is a long history of farmer-pastoralist conflict. Cattle reduce farmer seed stocks by grazing their farms when not properly controlled by herders. Possibly cattle theft by the RUF reduced some of this pressure? On the other hand, some of the violence attributed to the rebels may actually have been score settling for cattle damage cases.

In Bramaia for example some farmers protected preferred seeds in trenches from getting eroded away during the conflict. Although few farmers who were able to harvest after an attack also escaped with their (rice) seeds for domestication, before relocation back into their communities. If anything, this also served to boost the local seed (rice) biodiversity under extreme conditions. It is apparent also some farmers acquired seeds from relatives and colleague farmers for cultivation during refuge across the international borders into Guinea, while others acquired seeds through trans-border seed exchange networks and through trans-border weekly market outlets. A porous border contributed to seed diffusion both at before, during and after the war, between Maritime Guinea and Sierra Leone. The variety Saidou Gbélie/Kiamp (Pa) /Samando diffused across parts of the country during this period. Susu and Limba rice farmers maintained its origin is from Maritime Guinea. Nowadays, a strong preference seems to exist over modern ‘elite’ varieties. About 6 to 7 Km west of Bassia is Bokarriah Tassin, in Maritime Guinea lives a 50 year old Ma Dama who deals in seeds rice along the border with Sierra Leone, over 20 years, who confirmed that seed exchange and purchase among Susu people is not only common practice but also continue to boost the local rice industry. This seed network existed before and during conflict in the Susu cross border lands of Guinea and Sierra Leone, as noted by Okry (2011). At the barrie in Senthai, Magbema chiefdom, farmers noted their ancestors once benefited from seeds abandoned by fleeing Susu who left behind seeds stock after a defeating battle by Temne warriors.

During focus groups discussion, a good number of farmers remarked the looting and pilfering and mistreatment was terrible and became the order of the day, but then continued ‘pilfering was nothing new. Although farming activity was affected during the conflict, but burning for the most times was restricted because the fighting forces themselves rely greatly on exploiting farmers for food in the jungle. Chickens and cattle were also consumed voraciously and extensively by fighters.

Table 1a: *Chiefdom & number of villages studied**

Chiefdom **(n=1352)**	no. villages studied
Biriwa	1
Bramaia	6
Kamajei	16
Kholifa Rowalla	12
Magbema	6
Tonko Limba	6
Total	47

***Table 1b**: Villages studied per chiefdom*

#	Region	District	Chiefdom	Village
1	North-west	Kambia	Bramaia	Bassia
2				Gbolon
3				Kwie
4				Sabouya
5				Salaamu
6				Shakaia
7			Magbema	Kamba
8				Kayorkneh
9				Magbema
10				Mathoraneh
11				Rogbon
12				Senthai
13			Tonko Limba	Kafanta
14				Kathantineh
15				Katherie
16				Mafafilah
17				Masunthu
18				Yibaya
19	North	Bombali	Biriwa	Bumban
20	central-North	Tonkolili	Kholifa Rowalla	Gbondayma
21				Mabai
22				Mabomina
23				Magbontho
24				Makump
25				Mamayllah

* continued on the following page

***Table 1b** (continued): Villages studied per chiefdom*

#	Region	District	Chiefdom	Village
26	central-North			Mapaythor
27				Marunka
28				Matham
29				Mayemberrie
30				Rogbesseh
31				(upper) Mayatha
32	central-South	Moyamba	Kamajei	Bontiwo
33				Foya
34				Gondama
35				Jabaama
36				Jagbeima
37				Katéma
38				Ketuma
39				Kowama
40				Léibéma
41				Mblama
42				Mobai
43				Mogbuama
44				Tendihun
45				Yandu
46				Yéssan
47				Yoni

***Table 2**: Periods of first attack experienced by case-study farmers**

Year (n=1352)	Frequency	Per cent
1993	2	5.0
1994	3	7.5
1995	10	25.0
1996	13	32.5
1997	4	10.0
1998	6	15.0
1999	1	2.5
Total	**39**	**100.0**

***Table 3**: Composition of main fighting force(s) encountered by farmers in case study area*

Forces	Frequency	Per cent
RUF	36	90
AFRC	1	2.5
Both RUF \ AFRC	2	5
Total	**39**	**100.0**

***Table 4**: Nationality of attackers encountered in case study area*

Nationality	Frequency	Per cent
Sierra Leone	145	77.1
Other (mainly Liberian)	43	22.9
Total	**188**	**100.0**

***Table 5**: Frequency of times farmers were attacked in case study chiefdoms*

Times attacked by fighting forces	freq.	(%)
1	2	5.0
2	8	20.0
3	7	18.0
4	5	13.0
5	8	20.0
6	4	10.0
7	1	3.0
8	1	3.0
10	2	5.0
20	1	3.0
Total	39	100

***Table 6**: First attack and displacement envisioned by farmers in the case study*

	First attack		First displacement		Implications on farming activity			Early returnees	
Year	freq.	(%)	freq.	(%)	freq.	Temporally not farming (%)	Estimated Per cent difference still farming	freq.	(%)
1993	2	5.0	2	5.1	2	5.0	95.0	-	-
1994	3	8.0	-	-	3	8.0	92.0	-	-
1995	10	26.0	6	15.4	10	26.0	74.0	2	5.0
1996	13	33.0	17	43.6	13	33.0	67.0	2	5.0
1997	4	10.0	6	15.4	4	10.0	90.0	8	21.0
1998	6	15.0	6	15.4	6	15.0	85.0	10	26.0
1999	1	3.0	2	5.1	1	3.0	97.0	7	18.0
2000	-	-	-	-	-	-	-	4	10.0
2001	-	-	-	-	-	-	-	4	10.0
2002	-	-	-	-	-	-	-	2	5.0
Total	**39**	**100**	**39**	**100**	**39**	**100**		**39**	**100**

***Table 7**: Abduction envisioned by gender in case-study villages*

Number of abduction	Male farmers				Female farmers			
	Minimum abducted	(%)	Maximum abducted	(%)	Minimum abducted	(%)	Maximum abducted	(%)
None abduction	8	36.4	22	39.0	16	64.0	28	54.0
1	4	18.2	8	14.0	1	4.0	3	6.0
2	1	4.6	2	3.6	2	8.0	6	11.0
3	2	9.0	5	9.0	2	8.0	4	7.0
4	1	4.6	3	5.0	-	-	1	2.0
5	-	-	2	3.6	2	8.0	2	4.0
6	1	4.6	2	3.6	-	-	1	2.0
7	2	9.0	2	3.6	-	-	-	-
8	2	9.0	3	5.0	1	4.0	2	4.0
9	-	-	1	2.0	-	-	-	-
10	-	-	2	3.6	1	4.0	2	4.0
12	-	-	1	2.0	-	-	1	2.0
15	1	4.6	1	2.0	-	-	2	4.0
22	-	-	1	2.0	-	-	-	-
50	-	-	1	2.0	-	-	-	-
Total	22	100.0	56	100.0	25	100.0	52	100.0

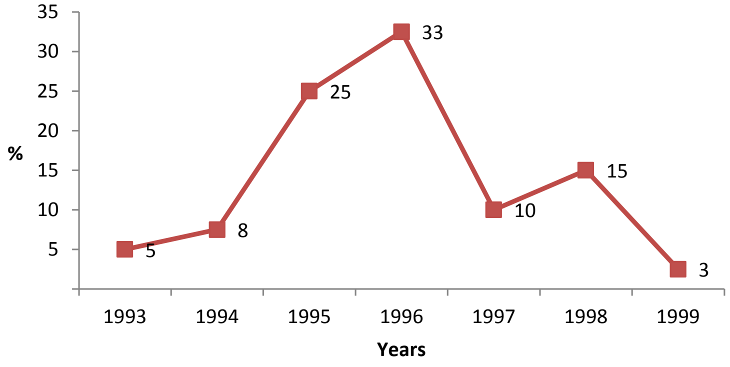
***Table 8**: Traditional 'homelands' of the languages spoken by attackers in regions of Sierra Leone*

Region -	Frequency	(%)
South-East	44	23.4
East	17	9.0
North	105	55.9
South	2	1.1
West	20	10.6
Total	**188**	**100.0**

***Table 9**: Languages spoken by attackers encountered by farmers in case study areas*

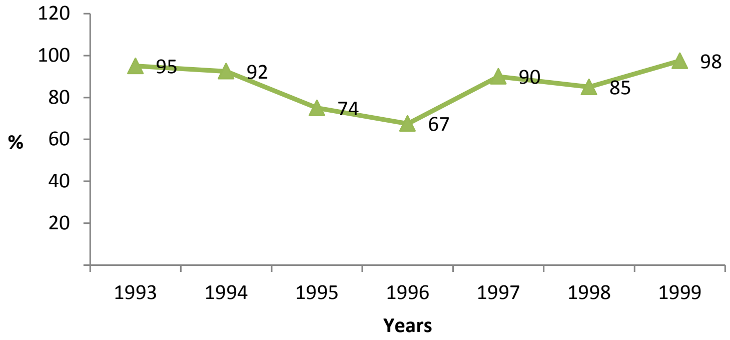
#.	Ethnic dialect	Frequency	(%)	Area\ Region	Homeland
1	Fullah	13	7.0	North	Sa. Leone\Guinea
2	Gbandi and\ or other	9	5.0	South-east	Liberia
3	Kissi	3	1.5	East	Sa. Leone\Guinea\Liberia
4	Kono	14	8.0	East	Sa. Leone
5	Krio	20	11.0	West	Sa. Leone
6	Koranko	2	1.0	North-east	Sa. Leone
7	Limba	30	16.0	North, North-west	Sa. Leone
8	Loko	4	2.0	North, North-west	Sa. Leone
9	Mandingo	1	0.5	North-east	Sa. Leone\Guinea\Liberia
10	Mende	35	18.0	South-east	Sa. Leone\Liberia
11	Sherbro	2	1.0	South-west	Sa. Leone
12	Susu	19	10.0	North-west	Sa. Leone\Guinea
13	Temne	36	19.0	North, North-west	Sa. Leone

Figure 1: *Estimates of farmers displaced resulting from stages of first attack by fighting fighting force(s) encountered on farmers in case study area*



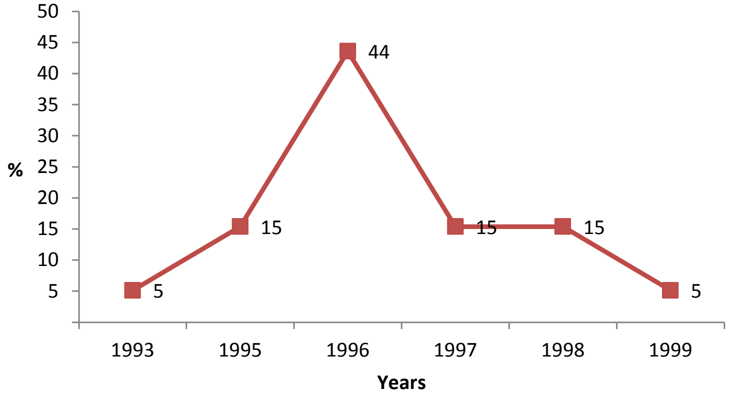
(n=1352)

Figure 2: *Estimates of of those still farming at stages of first attack by fighting fighting force(s) encountered on farmers in case study area*



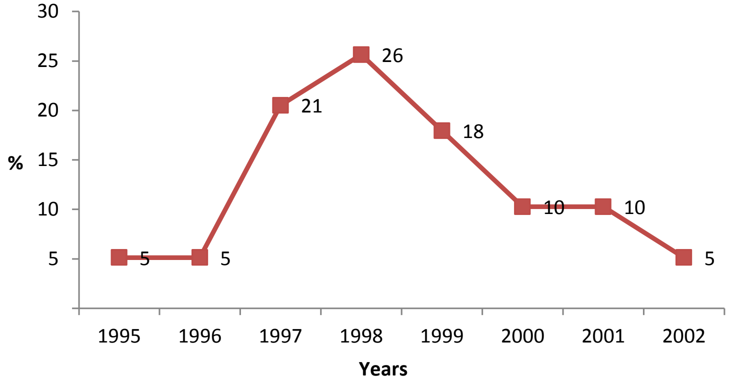
(n=1352)

Figure 3: *Year of first displacement reported by farmers in case study areas (%)*



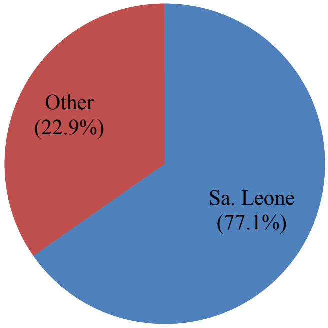
(n=1352)

Figure 4: *Periods of early return in case study areas (%)*



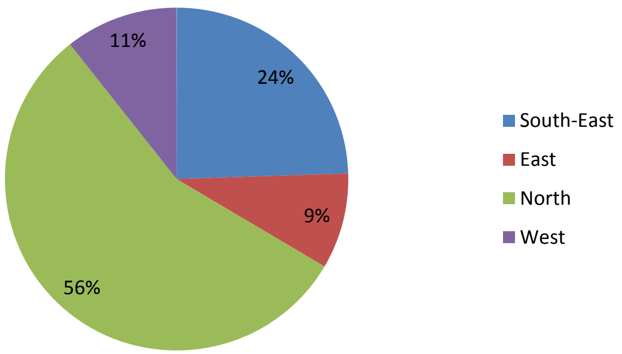
(n=1352)

Figure 5: *Nationality of attackers encountered in case study area*



(n=1352)

Figure 6: *languages spoken by attackers categorised according to home area of Sa. Leone*



(n=1352)

War in case-study chiefdoms

Text Box 1: KAMAJEI CHIEFDOM

In January 1995, RUF forces on their way to **Njama** (Kowa Chiefdom) battled with SLA coming from Mano (Dasse Chiefdom) at **Pelawahun** (Kamajei Chiefdom) six miles north-east of **Mano.** RUF forces overpowered the SLA, forcing them to retreat to Mano. Before this time RUF forces attacked villages in the extreme south of Kori Chiefdom. It appeared RUF forces then separated: one group advanced north into Kamajei Chiefdom, and another going in the direction of Dasse Chiefdom. RUF forces attacked villages in the south of Kamajei Chiefdom, including **Ngiyehun**. Although the RUF did not, at this time, attack the chiefdom HQ, **Senehun**, civilians nevertheless fled. Some (with money) went to **Bo** town, but others went to live in the bush (occupying so-called *sokoihun*, Mende = "corners)". RUF forces had already established a base in **PelewahunKenneh**, where they were to stay for 11 months, and launch attacks on both Kori and Kamajei Chiefdoms. Dressed in army fatigues, but with RUF initials underneath, fighters attacked **Pelewahun** in mid-February 1995. Late in December 1995, the rebels attacked **Senehun**, killing 28 civilians, and burning houses and looting civilian property, mainly money. Remaining civilians left the town and went to camps in **Bo** and **Freetown**. In the far north of the chiefdom RUF forces from Camp **Borkoh** (a camp in the Kangari Hills) attacked **Ketuma** on six occasions in December 1995. They killed 4 civilians, but since this was just after the harvest, there main objective may have been food for the camp. Historically, **Ketuma**, and neighbouring villages, supplied rice to mining camps in the escarpment zone to the north-east. The questionnaires report that attackers included speakers of Mende, Limba, Koranko, Loko, Temne and Liberian dialects (see Tables 9; 8; Figures 5 & 6). The same year **Léibéma** was attacked by same RUF force on two occasions, and 6 people were killed. **Mogbuama** also came under attack on four occasions, resulting in 9 civilian deaths and the abduction of two men into RUF forces. Between 1995 and 1996, **Mobai** was attacked by RUF forces on two occasions, resulting in 5 people killed and 5 women and 4 men abducted. Meanwhile, local recruits had started to join the civil defence fighters. This involved initiation as a *kamajo* (Mende special hunter). In February 1996, the first *kamajoisia* (pl.) started to come back from initiation in (first) Bonthe district and then Moyamba (Bumpeh chiefdom) and numbers soon grew. At about the same time, the north-eastern part of Kamajei Chiefdom came under attack from RUF forces coming from Valunia

Chiefdom (Bo District). In March 1996, an RUF forward base was established in **Yelima** Section. Here, RUF forces abducted young boys and girls to carry loads and to show them passages throughout the Chiefdom. The same month, *Kamajoisia* arrived to protect **Gondama**, a large village in the north of the chiefdom and only a few miles from **Yelima** village. *Kamajoisia* then confronted RUF forces in **Yelima** and rescued many civilians and brought them to **Gondama**. But the *kamajoisia* then left and the RUF attacked **Gondama,** killing 30 people. Most of those killed were civilians recently brought to **Gondama**. They died not because the RUF targeted them specifically, but because they were not from **Gondama**and did not know the secret escape routes. The RUF did not burn any houses, but took mainly livestock. *Kamajoisia* then resumed their attack on Yelima section. In late June 1996, in the cease-fire period for the Abidjan negotiation, the RUF organised a second attack on **Gondama**. No casualties were reported. Most civilians were by then living in the bush. But this time the RUF forces burnt down the town. According to NPWJ this attack was the last RUF incident. Subsequently, the *kamajoisia* started regular patrols around **Gondama**. The farmer interview reports are not quite in agreement. RUF forces from **Camp Borkoh** attacked **Gondama** on three occasions in 1996, killing 111 people, and abducting 12 women and 9 men. Between 1996 and 1997, **Jagbeima** was attacked on five occasions, 8 people were killed, and 10 men and 10 women were abducted. **Kowama** was attacked on ten occasions, with 25 people killed, and 8 women and 7 men abducted. Either during 1996 or 1998 (the source is unclear), RUF forces attacked **Mblama** on five occasions, and 8 people were killed, and 5 women and 4 men abducted. **Tendihun** was attacked on six occasions, and one civilian killed in 1996. **Yéssan** was attacked on two occasions, although no civilian was killed. Later in 1997, at the village of **Gbessebu**, SLA forces killed a *kamajoi* going to **Pelewahun** (both in southern Kamajei Chiefdom). That year RUF forces also attacked **Foya** on ten occasions; although no civilian was killed, one man was abducted. After the junta coup in May 1997 it was announced over the radio that *kamajoisia* should lay down their arms and surrender, but those Moyamba District refused. Moyamba District as a whole subsequently became a target for the junta forces. All men came under suspicion of being dissident *kamajoisia*. To compound the tension, some*kamajoisia*from **Mongere** (Valunia Chiefdom) ambushed vehicles they claimed to belong to junta members. Civilians in the area between **Gondama** and **Mongere**were now caught between two fighting factions. In early June 1997, RUF from Kailahun District raided the town of **Senehun** and took a lot of civilian property as a result of which civilians once more fled the town. *Kamajoisia* then started to behave high-handedly, imposing authority on all and sundry, and establishing their own laws and decrees. Chiefs who did not want to be initiated into the **kamajoi** society were stripped of their powers. The behaviour of the *kamajoisia* in Kamajei Chiefdom began to change after the Abidjan Peace Agreement. They were now described as being the "chiefs", deciding cases and punishing people. Chiefdom authorities were molested by these young civilians. Civilians were maltreated and sometimes in the cages made of sticks and thorns. Some women were harassed and beaten publicly for refusing civil defence fighters in marriage. ECOMOG (Nigerian) forces deployed in Moyamba District after the action against the Junta in February 1998. Operating together with *kamajoisia*, they set up checkpoints at **Senehun** and **Loponga**. The civil defence fighters who assisted ECOMOG forces mistreated civilians and detained vehicles suspected of carrying any RUF/AFRC personnel; goods without documents were also detained. The situation worsened at checkpoints when ECOMOG left them in the hands of volunteer fighters. After RUF/AFRC forces were pushed out of power early 1998 internal fights occurred between different factions of the CDF: *kamajoisia* from the Southern Province accused CDF *gbenti* active in the Northern Province of supporting AFRC. *Gbenti* from neighbouring chiefdoms in Tonkolili District attacked the *kamajoi* base at **Gondama**. Although nobody was killed houses were burnt by the retreating *gbenti*. Days later, the *kamajoisia* launched a counter-attack on at the village of **Pateful** (Gbokolenken Chiefdom, Tonkolili District). Elders eventually helped resolve the tensions between the different factions. Between April and May 1998 a schoolteacher was caught by *kamajoisia* between **Mokonde** (Kori Chiefdom) and **Pelewahun** (Kamajei Chiefdom). The man was dragged in the bush, and his stomach cut opened and entrails removed. The four attackers burnt the body and took the dead man's bicycle and two months' salary because one of them wanted to **revenge** himself on the schoolteacher, who was the new partner of his ex-girlfriend. Following the 7th July peace agreement signed in Lome disarmament was begun on 20th October 1999. On 9th November 2001, at press briefing, disarmament was declared complete in Moyamba District. For the synthesis of events see Tables 10a, 10b.

Text Box 2: KHOLIFA ROWALLA CHIEFDOM

Between the months of June-July in 1993, RUF forces first attacked the village of **Mayemberrie**. The attack resulted in looting, rape and mistreatment of civilians. After burning down one (grass) house, some civilians were forced to head load the looted items. Throughout this period civilians were asked to provide food and palm nut oil to support the

Table 10a: *Synthesis of events (Text Box 1) during insurgency in Kamajei C/dom/Moyamba District**

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered	Town/Village/ Chiefdom under attack	Where Displaced to (if any)	Attrocities/ outcomes / Established base for fighting force reported
In January 1995	At Pelewahun (Kamajei C/dom) RUF from Njama Kowa c/dom vs. SLA from Dasse c/dom			RUF forces had already established a base in PelewahunKenneh and launch attacks on both Kori and Kamajei Chiefdoms
mid-Feb. 1995	RUF	Ngiyehun	1.Civilians nevertheless fled. Some (with money) went to Bo town. 2. Others went to live in the bush (occupying so-called sokoihun, Mende = "corners)"	
	Dressed in army fatigues, but with RUF initials underneath, fighters attacked Pelewahun			
Late in Dec. 1995	Late in December 1995, the rebels attacked Senehun		Civilians left the town and went to camps in Bo and Freetown	RUF forces killed civilians, looting civilian property(money) & burning of houses
In Dec. 1995	In the far north of the chiefdom RUF forces attacked Ketuma on six occasions			RUF forces killed civilian there main objective may have been food for the camp Attackers came from Camp Borkoh (a camp in the Kangari Hills)
1995	RUF	Léibéma		Civilians killed by RUF forces
1995	RUF	Mogbuama		Resulting in civilian deaths and the abduction of few men into RUF force
Between 1995 & 1996	RUF	Mobai		People killed and 5 women and 4 men abducted by RUF forces
Meanwhile, local recruits had started to join the civil defence fighters. This involved initiation as a kamajo (Mende special hunter).				
	In February 1996, the first kamajoisia (pl.) started to come back from initiation in (first) Bonthe district and then Moyamba (Bumpeh chiefdom) and numbers soon grew.			
In March 1996, an RUF forward base was established in Yelima Section				RUF forces abducted young boys and girls to carry loads and to show them passages throughout the Chiefdom.
March, 1996	Kamajoisia arrived to protect Gondama, a large village in the north of the chiefdom and only a few miles from Yelima village			
March,1997	Kamajoisia then confronted RUF forces in Yelima and rescued many civilians and brought them to Gondama. But the kamajoisia then left and the RUF attacked Gondama		RUF forces killed civilians. Most of those killed were civilians recently brought to Gondama and did not know the secret escape routes. RUF did not burn any houses, but took mainly livestock	
In late June 1996		*Kamajoisia* then resumed their attack on Yelima section in the cease-fire period for the Abidjan negotiation		
1996	RUF organised a second attack on Gondama	Gondama	Most civilians were by then living in the bush	No casualties were reported. But this time the RUF forces burnt down the town
	RUF forces from Camp Borkoh attacked Gondama on other occasions in 1996	Gondama		RUF forces killed civilians and abduct women and men Attackers came from Camp Borkoh

(*): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Table 10b: *Synthesis of events (Text Box 1) during insurgency in Kamajei C/dom/Moyamba District**

<table>
<tr><th>Year</th><th>Fighting Force(s) / Town/Village/C/dom fighting were encountered</th><th>Town/Village/ Chiefdom under attack</th><th>Where Displaced to (if any)</th><th colspan="2">Attrocities/ outcomes / Established base for fighting force reported</th></tr>
<tr><td>1996 & 1997</td><td colspan="2">Between 1996 and 1997, Jagbeima was attacked on 5 occassions by RUF forces</td><td rowspan="5"></td><td colspan="2">People were killed, men and women were abducted by RUF forces</td></tr>
<tr><td rowspan="2">1996 or 1998 (unclear)</td><td>Kowama was attacked on 10 occasions by RUF forces</td><td>Kowama</td><td colspan="2">People were killed, men and women were abducted by RUF forces</td></tr>
<tr><td>RUF</td><td>Mblama</td><td colspan="2">People were killed, men and women were abducted by RUF forces</td></tr>
<tr><td>1996</td><td>RUF</td><td>Tendihun</td><td colspan="2">A civilian was killed by RUF forces in 1996</td></tr>
<tr><td>1997</td><td>RUF forces also attacked Foya on 10 occasions</td><td>Foya</td><td colspan="2">No civilian was killed. 1 man was abducted</td></tr>
<tr><td colspan="6">After the junta coup in May 1997 civilians in the area between Gondama and Mongere were now caught between two fighting factions</td></tr>
<tr><td>In early June 1997</td><td>RUF from Kailahun District raided the town of Senehun</td><td>Senehun</td><td>As a result of which civilians once more fled the town</td><td>RUF members took a lot of civilian property</td><td>Attackers came from Kailahun District</td></tr>
<tr><td colspan="4">The behaviour of the kamajoisia in Kamajei Chiefdom began to change after the Abidjan Peace Agreement. Kamajoisia then started to behave high-handedly and establishing their own laws and decrees. Chiefs who did not want to be initiated into the kamajoi society were stripped of their powers.</td><td colspan="2">Civilians were maltreated and sometimes in the cages made of sticks and thorns. Some women were harassed and beaten publicly for refusing civil defence fighters</td></tr>
<tr><td>In Feb. 1998</td><td colspan="2">ECOMOG (Nigerian) forces deployed in Moyamba District after the action against the Junta in February 1998. Operating together with kamajoisia, they set up checkpoints at Senehun and Loponga</td><td colspan="3">The civil defence fighters who assisted ECOMOG forces mistreated civilians and detained vehicles at check points suspected of carrying any RUF/AFRC personnel; goods without documents were also detained, The situation worsened at checkpoints when ECOMOG left them in the hands of volunteer fighters.</td></tr>
<tr><td rowspan="3">Between April and May 1998

In 1998</td><td colspan="5">A schoolteacher was caught by kamajoisia between Mokonde (Kori Chiefdom) and Pelewahun (Kamajei Chiefdom). The man was dragged in the bush, and his stomach cut opened and entrails removed. The four attackers burnt the body and took the dead man's bicycle and two months' salary because one of them wanted to revenge himself on the schoolteacher, who was the new partner of his ex-girlfriend</td></tr>
<tr><td colspan="5">After RUF/AFRC forces were pushed out of power early 1998 internal fights occurred between kamajoisia from the Southern Province accused CDF gbenti active in the Northern Province of supporting AFRC</td></tr>
<tr><td colspan="3">Gbenti from neighbouring chiefdoms in Tonkolili District attacked the kamajoi base at Gondama</td><td colspan="2">Houses were burnt by the retreating gbenti</td></tr>
<tr><td>1999 to 2011</td><td colspan="5">Following the 7th July peace agreement signed in Lome, disarmament was begun on 20th October 1999. On 9th November 2001, at press briefing, disarmament was declared complete in Moyamba District.</td></tr>
</table>

(*): see Tables 9; 8; Figures 5 & 6 for identity of attackers

movement. In 1994, RUF forces from **Ro-mantmebil** "black water" attacked **Rogbesseh** on three occasions. RUF forces killed 4 civilians, and abduct 50 men and 10 women. Same year, RUF forces attacked **Mabomina** on five occasions. They killed 4 civilians, and abducted 3 men and 3 women. Furthermore, RUF forces attacked **Mabai**on five occasions in 1994. They killed 9 people, and abducted 8 men and 4 women. Throughout 1994, the town of **Matotoka** (Tame Chiefdom) close to **Magburaka** became the watershed of RUF attacks between April and May 1994, likely RUF began establishing a foothold in the **Kangari Hills**, from where they assaulted strategic towns. By the end of 1993 to early 1994, tensions between civilians and SLA exacerbated by the formation of Civil Defence Units in the Tonkolili District as stealing of civilian property, the looting of civilian premises and the extortion of money and property at checkpoints by the SLA. The **Tamaboros** were believed to have strong mystical powers. In mid June 1994, a convoy of about 125 trucks left Magburaka, **Makaku** to **Kono**escorted by an SLA armoured vehicle, fell into an ambush with RUF forces firing heavily on the convoy. Trucks crashed into each other and some people jumped out from the trucks. Many people were killed. Ten trucks were destroyed, most simply searched. Luggage and other items were taken. A **one month old baby** was taken from its mother thrown into the bush because an RUF member said the baby was making too much noise. Passengers were told to carry the load to the village of **Rosimbec**, where 170 civilians had been killed a month earlier. **Civilian and SLA mistrust** was due to two beliefs widely held by the public. First, some SLA forces **defected** and joined the RUF. Second, RUF forces in military fatigue often pretended to be SLA. In late June 1994, armed men claiming to be SLA were arrested at KumrabaiMatuku (Kholifa Mabang Chiefdom). Interrogators concluded the armed men were genuine SLA from Bo Town. In 1995, from Ro-mantmebil "black water", RUF forces attacked **Mayemberrie** on 6 occasions although no civilian was killed, they abducted 10 men. The questionnaires report that attackers included speakers of Limba, Mende, Temne and Susu dialects (see Tables 9; 8; Figures 5 & 6). Same RUF forces attacked **Marunka** on 5 occasions. They killed 8 civilians and abducted 5 women and 4 men. Furthermore, same RUF forces from Matotoka (Tane chiefdom) attacked **Makump** on four or five occasions although no civilian was killed, one man was abducted. The questionnaires report that attackers included speakers of Mende, Temne, Limba, Susu and Kono dialects (see Tables 9; 8; Figures 5 & 6). In March 1996, in the cease-fire period for the Abidjan negotiation, remnants of RUF forces inflicted serious physical violence on civilians. They carried out raids in villages, looting for food in an **IDP** camp over **14,000 persons** had found refuge in Matotoka (Tame Chiefdom) and Magburaka. Around Magburaka four women refused to have sexual intercourse with RUF members had their genitals and rectum sewed with fishing line. Four men had their rectum sewed, and two men also had their mouths clamped with padlock. One woman also had her genitals clamped with a padlock. Same year, RUF forces attacked **Mamayllah** on eight occasions. After killing 5 civilians, they further abducted 3 women and one man. RUF forces from Ro-mantmebil "black water" further attacked **Matham on** two occasions in 1996. They killed 5 civilians, and abducted 15 women and 8 men. Following the coup **in 1997, stealing being as its peak**, RUF/AFRC forces in Magburaka launched

"Operation Pay Yourself", free to take property belonging to civilians were a kind of operation, namely, massive stealing widely carried out. Around this period, RUF/AFRC units moved freely from **Mile 91** to Magburaka would bring back stolen items to mile 91 to sell them. They explained to civilians that **they were stealing because they were not paid**. Only the RUF/AFRC member would be allowed to explain their version of a matter arising among a civilian and an RUF/AFRC member; a resulting penalty were to "frog jump" or to "pump" by first holding on the earlobes with two hands crossed holding the right ear lobe and vice versa after which required to jump up and down fast on their haunches - both physically and psychologically painful. RUF/AFRC forces from either **Masanka** or “black water” further attacked **Mapaythor** on four occasions. They killed 16 civilians and abducted 15 men and 15 women. From February to June 1998, the number of civilians wounded or mutilated arriving in Magburaka hospital increased considerably. Some RUF/AFRC members saw a girl and followed her to her house. After fruitless appeals, the father told do what they had to do, for he had no alternative. One of the RUF/AFRC member then shot the father in his left foot, cut off two of his toes. A man in the street was asked about money and replied that the war had brought him to back to "square one" the forces followed him to his house and shot at his house with an RPG, killing the man who was inside the house at the time. The family of the deceased reported the episode to the commander. The member was later identified and shot. Same RUF/AFRC forces from Matotoka (Tane Chiefdom) attacked upper **Mayatha** on five occasions. They killed one civilian. Early in March 1998, ECOMOG Brigade 24 Infantry entered Magburaka. Here Youths were asked to point out any RUF/AFRC member, and collaborators detained. As ECOMOG forces left for **Makeni**, RUF/AFRC members attacked the town the following day. Some civilians were in their houses when set on fire and burnt alive. ECOMOG returned to Magburaka and threatened the civilians, accusing them of allowing RUF/AFRC forces to stay in the chiefdom. Civilian property was taken by ECOMOG forces and those civilians’ wives were also forced to have sexual relations with some ECOMOG members. Equipped with cutlasses, axes, sticks and few AK47s and RPGs, Kamajors attacked RUF positions early in March 1998 at **Magbass** village and **Sugar complex** in the south of Kholifa Rowalla Chiefdom. RUF forces sustained heavy casualties and withdraw towards Magburaka. This defeat was explained by civilians through the mystical power of the Kamajors believed to stop the guns of the enemy. Here Kamajors arrested 50 civilians to carry the stolen property including the zinc roof of the factory. On the same day RUF forces went to Mayatha, some Kamajors captured, killed and returned to

Magburaka after burning down 18. Early in December 1998, Kamajors from **Gbokolenken** Chiefdom went to Kholifa Rowalla Chiefdom, entered **Mabom** south of Magburaka and dislodged the RUF/AFRC forces, resulting in the abduction of young men and women. They took food, furniture, burnt down 15 houses and headed for **Masoria** village and left for Gbokolenken Chiefdom. Sometime in December 1998, after harvesting, RUF forces attacked Matham which resulted in the killing of 4 female and 4 male civilians, rape and torture were encountered. A pregnant woman got drowned resulting from the attack. Late in December 1998, movement of troops were to be seen in Kholifa Rowalla. The troops were actually RUF/AFRC forces and included speakers of Mende and Liberian dialects. Around this time combatants from Liberia allegedly were again taking part in the hostilities in Sierra Leone. Three days following the attack on Koidu Town (Kono District), RUF/AFRC forces entered Magburaka Town around 23 December 1998. RUF Battle Field Commander interviewed on **BBC** declared they would enter Freetown by road which resulted in the abduction of many civilians for use in the fighting. While in Magburaka, a boy working in a garage became more and more distressed threatened with death if he could not repair the Honda motorbike that some RUF/AFRC members had brought him. The boy attempted to run was shot. Another boy was shot in the head when the same members asked him to help them push their Honda motorbike, as he thought the fighters had left the vicinity. That same night in **Bathmorie** near Magburaka, some RUF/AFRC member took a young boy to lead them to where they could find girls. The boy went to a house and told the girls to vacate the premise quietly. When he came back and told the RUF/AFRC members there were no girls to be found, the RUF/AFRC members hit the boy with G3 guns and shot him killing him. Throughout 1999, CDF forces were very active in the chiefdom. People accused of being collaborators or sympathisers of the RUF/AFRC were tortured. By April 2000 tensions between RUF/AFRC and UN-Peacekeepers exacerbated when the RUF forces asked UN-Peacekeepers to dismantle the reception centre meant for combatants. The ground commander for Magburaka and his men launched an attack on the UN peacekeepers. The fighting lasted for three hours and, a gunship came to rescue the peacekeepers and some left their camp in their armoured vehicles using the **Makeni** road to **Bumbuna**. Later in May 2000, a Government gunship flew over Magburaka and open fire on the Central Market. Five civilians were reported killed. The gunship dropped leaflets intended for RUF/AFRC forces. Results of these leaflet caused many civilians to vacate Magburaka area and head for an IDP camp in Mile 91, about 35 miles from Magburaka. Some civilians died from starvation while others were killed by Guinean forces who considered the exodus from Magburaka to be RUF/AFRC members. Results emanated from the sixth meeting of the Joint Committee on **DDR** on 11 October 2001, parties agreed to have disarmament in **Tonkolil**i District simultaneously with **Pujehun** District from November 1 to 14. For the synthesis of events see Tables 11a, 11b.

Text Box 3: BIRIWA CHIEFDOM

Biriwa like other Chiefdoms in **Bombali** District was not directly affected by the conflict until RUF entered Bombali District in February 1994. RUF activity in 1995 concentrated on attacking the **Western Area**. The bases in Bombali District take on a greater significance in 1996 as RUF suffered a series of military defeats. The Parliamentary and presidential elections in 1996 in Bombali district passed without any widespread violence. The ceasefire held until early 1997. Between 26 February and May 1997, it appeared no incidents were recorded in Bombali District, with the exception of Biriwa Chiefdom. On 8 January 1996 either RUF or SLA forces from **Kamabai** (the Chiefdom Headquarter town of Biriwa Chiefdom) attacked the village of Bumban. This attack resulted in 50 civilian deaths (30 women and 20 men) and the abduction of 4 civilians (2 men and 2 women). The abductees were taken to RUF bush camps. The farmer interviews report that attackers included speakers of Kono, Limba, Mende, Temne, Loko and Fullah dialects (see Tables 7 and 8 and Figures 5 & 6). Shortly after the coup in May 1997, RUF forces took positions in Bombali District. Karina and Kamabai were occupied by RUF/AFRC forces, giving them control of a**prosperous agricultural area**. **Karina** situated on top of a hill was favourable for rearing of **animals**. Its high agricultural productivity made it a valuable location for the RUF. Karina was attacked by RUF/AFRC forces in May. They killed 10 civilians celebrating the Muslim feast of "Jonbedeh". RUF/AFRC forces raped women and abducted 30 young men and women. Houses were burned down taking with them the 30 abductees. Some were given military training and forced to join the RUF/AFRC, and some were forced into sexual slavery. The next day residents of Karina returned and buried 10 corpses in a mass grave. The burial was performed quickly given that Karina Town was on a regular patrol route from the RUF/AFRC location at Kamabai. Other settlements in the Chiefdom were also attacked. In Early March 1998, there was an attack from **Lunsa**rwhen ECOMG forces arrived at the village of **Magbema**, 2km west of **Makeni** (both in Bombali Sebora Chiefdom). Following ECOMOG's arrival in Makeni, RUF/AFRC forces dispersed throughout Bombali District

Table 11a: *Synthesis of events (Text Box 2) during insurgency in Kholifa RowallaChiefddom/ Tonkolili District*

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered		Attrocities/ outcomes / Established base for fighting force reported	
Between June to July 1993	RUF	Mayemberrie	Looting, rape & mistreatment of civilians by RUF. A house burnt down, civilians forced to head load looted items. Civilians provide food and palm nut oil for RUF throughout this period.	
End of 1993 to Early 1994	Tensions between civilians and SLA exacerbated by the formation of Civil Defence Unit, inTonkolili District as stealing of civilian property, the looting of civilian premises and the extortion of money and property at checkpoints by the SLA.			
In 1994	RUF forces from Ro-mantmebil	Rogbesseh	RUF forces killed & abducted some civilians	
	RUF	Mabomina	RUF forces killed & abducted some civilians	
	RUF	Mabai	RUF forces killed & abducted some civilians	
Between April and May 1994	RUF	Matotoka (Tame c/dom)	Matotoka became the watershed of RUF attacks	RUF foothold in the Kangari Hills
mid-June 1994	A convoy of about 125 trucks left Magburaka, Makaku to Kono escorted by an SLA armoured vehicle, fell into an ambush with RUF forces	Civilian deaths, trucks destroyed, Luggage and other item carted away, 1 month old baby taken from its mother thrown into the bush bush because an RUF member said the baby was making too much noise.Passengers carry the load to Rosimbec village		
In 1995	RUF	Mayemberrie	Some civilians abducted by RUF	
	RUF	Marunka	RUF forces killed & abduct some civilians	
	RUF from Matotoka (Tane C/dom)	Makump	Some civilians were abducted by RUF	
In March 1996,	RUF inflicted serious physical violence on civilians. They carried out raids in villages, looting for food in an IDP camp over 14,000 persons had found refuge in Matotoka (Tane Chiefdom) and Magburaka		Genitals and rectum sewed with fishing line. Mouths clamped with padlock by RUF members	
In 1996	RUF	Mamayllah	RUF forces killed & abducted some civilians	
In 1997	RUF forces from Ro-mantmebil	Matham	RUF forces killed & abducted some civilians	
	RUF/AFRC forces in Magburaka following the coup in 1997, stealing being as its peak, "Operation Pay Yourself" they explain they were stealing because they were not paid			
In 1998	RUF/AFRC forces from either Masanka or "black water"	Mapaythor	RUF/AFRC forces killed & abducted some civilianss	
	From February to June 1998, the number of civilians wounded or mutilated arriving in Magburaka hospital increased considerably			
	RUF/AFRC forces from Matotoka (Tane c/dom)	upper Mayatha	A civilian kllled by RUF/AFRC force	

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Table 11b: *Synthesis of events (Text Box 2) during insurgency in Kholifa RowallaChiefddom/ Tonkolili District**

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered			Attrocities/ outcomes / Established base for fighting force reported
In 1998	RUF/AFRC	Magburaka	Magburaka	Some civilians were in their houses when set on fire and burnt alive by RUF/AFRC
	ECOMOG returned to Magburaka	Civilian property was taken by ECOMOG forces. Civilians' wives were also forced to have sexual relations with some ECOMOG members.		
Early in March 1998	Kamajors attacked RUF positions		Magbass village and Sugar complex	Kamajors arrested civilians to carry the stolen property of the factory
	RUF vs. CDF kamajor		Mayatha	Some Kamajors captured, killed, houses burnt down
Early in December 1998	Kamajors from Gbokolenken dislodged the RUF/AFRC forces		Mabom	Abduction. Took food, furniture, burnt down houses by RUF/AFRC forces and left for Gbokolenken C/dom
In December 1998	RUF		Matham	Killings, rape & torture by RUF forces & some civilians got drowned
Late in December 1998	Movement of RUF/AFRC troops were to be seen in Kholifa Rowalla			
Around 23rd. December 1998	RUF/AFRC forces entered Magburaka Town on BBC declared they would enter Freetown by road			RUF/AFRC forces abduct many civilians for use in the fighting. A motorbike garage mechanic boy was shot in the head and killed by some RUF/AFRC members
	RUF/AFRC		Bathmorie near Magburaka	An errand boy (to find girls for some RUF/AFRC member) shot and killed afterwards.
Throughout 1999, CDF forces were very active in the chiefdom; sympathisers of the RUF/AFRC were tortured				
By April 2000 tensions between RUF/AFRC and UN-Peacekeepers exacerbated				
Later in May 2000	A Government gunship flew over Magburaka and open fire on the Central Market			Civilian deaths: from starvation; others killed by Guinean forces considered the exodus from Magburaka to be RUF/AFRC members
In October 2001	Parties agreed to have disarmament in Tonkolili District simultaneously with Pujehun District from November 1 to 14, 2001.			

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

staging **hit and-and-run attacks** on settlements including villages and towns in Biriwa Chiefdom. RUF/AFRC forces retreated northward in the direction of Kamabai which had been under RUF control since late May 1997. RUF/AFRC forces **establish** a strong presence, bolstered by forces driven from Makeni in early March 1998 by ECOMOG forces. **RUF/AFRC forces strengthened their positions in Kamabai and commenced frequent "food finding missions" throughout the Chiefdom**. RUF/AFRC established joint civilian military **committee** known as **G5**, followed by promises that commanders would prevent their junior ranks from inflicting violence upon innocent civilians. The G5 administered the collection of contributions (money and food from civilians). ECOMOG's subsequent efforts to secure the highways affected trade routes providing RUF/AFRC basic goods and supplies. The G5 system, however, appeared not to have provided adequate resources to feed or pay

RUF/AFRC members. A few instances of brutal punishment metered out by RUF/AFRC commanding officers did not restrain RUF/AFRC forces from carrying out “food finding missions”, stealing civilian property and food, and selling property in **Guinea trade fairs**. In July 1998, RUF/AFRC forces from the direction of Karina attacked the village of **Masiba** and took captives to **Kortulay** (both GbendembuNdowahun Chiefdom). On the same day, RUF/AFRC members forced captives to take the **rice** from the Section Chief. Captives transported the rice in the direction of Biriwa Chiefdom. On 23 July 1998, RUF/AFRC forces attacked **Matoko** village, north of Biriwa Chiefdom. They captured over 20 civilians, tied in pairs and shot dead by RUF/AFRC forces. The operation ceased on the following day (24 July, 1998). The July 1998 attacks on Masiba and Karina described above are good examples of "food finding missions". Civilians were captured and instructed to lead RUF/AFRC forces to sources of salt, livestock, staple crops and vegetables. The same civilians were then forced to transport the stolen food to an RUF/AFRC base. During the month of December 1998, RUF/AFRC forces commenced a major assault on Makeni Town from three directions. One groiu came from**Gbendembu** and **Kamolo** to the northwest. From the south RUF/AFRC forces entered Bombali district through **Magburaka** Town and continued towards Makeni. A third group came from **Binkolo**, Karina and Kamabai to the northeast. In the beginning of 1999, RUF/AFRC forces controlled Kamabai. There was massive theft of food during the RUF/AFRC encampment, forcing residents to vacate their houses to provide lodging for RUF/AFRC forces. RUF/AFRC forces used the Great Scarcies River to access trade fairs in towns just over the Guinea border where they regularly sold items stolen during attacks to intermediaries who would sell them at the weekly market in the Guinean border towns of **MadinaOula, Sekusoria** and **Lakantha**. In relation, the Guinean authorities tightened border security checks on traders, and RUF/AFRC forces in Kamabai attempted to conscript civilians for a counter offensive mission. For the synthesis of events see Table 12.

Text Box 4: BRAMAIA CHIEFDOM

Sometime in 1993, the village of **Sabouya** was first attacked by RUF forces although none RUF activity was reported, some civilians fled into Guinea and some who stayed went into “dungui” (“Corners”). **Seeds were often protected in trenches** in homes of civilians. Seeds were also acquired from Guinea by through **barter wise** in exchange for Palm oil. In March 1995, RUF forces attacked the village of **Salaamu**. Although no civilian was killed, it was

Table 12: *Synthesis of events (Text Box 3) during insurgency in Biriwa Chiefdom/Bombali District**

Year	**Fighting Force(s) / Town/Village/C/dom fighting were encountered**	**Attrocities/ outcomes / Established base for fighting force(s) reported**
In February 1994	RUF entered Bombali District	
In January 1996	RUF or SLA forces from Kamabai (the Chiefdom Headquarter town of Biriwa c/dom) attacked the village of Bumban.	RUF/AFRC location at Kamabai
In 1996	The bases in Bombali District take on a greater significance in 1996 as RUF suffered a series of military defeats	
Until Early 1997	The ceasefire held until early 1997. Between 26 February and May 1997, it appeared no incidents	
In May 1997	RUF/AFRC forces establish a strong presence in Kamabai which had been under RUF control and bolstered by forces driven from Makeni in early March 1998 by ECOMOG forces	
In May 1997, RUF forces took positions in Bombali District. Karina and Kamabai were occupied by RUF/AFRC forces they forced civilians to transport the stolen food to an RUF/AFRC base		
In May 1998	RUF/AFRC forces strengthened their positions in Kamabai and commenced frequent “food finding missions” throughout the c/dom	
In March 1998	Following ECOMOG's arrival in Makeni, RUF/AFRC forces dispersed throughout Bombali District	
	A joint civilian military committee known as G5 administered the collection of contributions (money and food from civilians)	
In July 1998	RUF/AFRC forces from the direction of Karina attacked the village of Masiba	
	RUF/AFRC forces attacked Matoko village, north of Biriwa c/dom	
In December 1998	RUF/AFRC forces commenced a major assault on Makeni Town, Bombali District from three directions	
Early in 1999	RUF/AFRC forces controlled Kamabai	

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

alleged that the attackers came from **Tonko Limba** Chiefdom. The questionnaires report that attackers included speakers of Limba, Mende, Temne and Fullah dialects (see Tables 7; 8; Figures 5 & 6). In September 1995, the village of **Gbolon** was first attacked by RUF forces which resulted in the killing of one civilian and burning down of 7 houses. They also abducted 6 men and 3 women. After this, **civiliansdeserted the village for 5 months**. Later on civilians left for Guinea, and the RUF forces chased civilians into **Tassein, Guinea** and killed 6 Sierra Leoneans including 3 Guineans. Hardly any agricultural activity was carried out but after this incidence, civilians decided to return. On the last day of January 1996, the **Catholic Mission in Madina** intercepted radio message that RUF forces were planning to attack Madina Town in Tonko Limba Chiefdom. On 1 February 1996, RUF forces attacked

Kukuna, the Chiefdom headquarter town, on the road to Guinea. None RUF activity was accounted during this attack. RUF forces returned to the **Kamakwie Camp** at **Masonkorie** in **SandaLoko** Chiefdom. Later in February 1996, RUF forces attacked Kukuna Town, burnt down between 30 and 50 houses and looted extensively. From Kukuna RUF forces went to **Makindota** in Tonko Limba Chiefdom, moving to base camp at **Ro-Source** in **SandaTandaren** Chiefdom by end February 1996. From May until November 1996, Guinean forces moved into Madina. Together with a locally mobilised civil defence, Guinean forces patrolled all around the Madina-Kukuna route and all the roads around the border with Guinea to prevent RUF infiltration. The signed Abidjan Peace Accord on 30 November 1996 resulting ceasefire held firm in Kambia District until May 1997. In May 1997 while a small RUF force attacked Madina using a red Toyota Hilux stolen previous attack on Madina, they took medicine, clothes, generators and furniture from the Catholic Mission and taken to Ro-Source base, another group attacked Kukuna on the same day. In May 1997, Sabouya was attacked by RUF forces although none RUF activity was reported. Following the ECOMOG intervention in highly built area in the capital of **Freetown**, RUF/AFRC forces attacked and looted civilian property extensively, killing and abducting across September and October 1998. Civilians were killed and mutilated in barbaric ways: victims had one or more limbs amputated by RUF/AFRC members. RUF/AFRC also began imposing a high weekly tax on the houses in RUF/AFRC occupied areas on the Great Scarcies River along the strategic towns and smuggling routes in the within the Chiefdom. The Great Scarcies took on comprehensive logistical importance to the RUF/AFRC forces and revenue by taxing traders. At this time the Guinean forces strengthened their deployment on the border with Sierra Leone. In late September 1998, RUF/AFRC forces staged surprise attack on Kukuna. Guinean ECOMOG forces stationed in Kukuna repelled RUF/AFRC forces. During the attack, RUF/AFRC forces killed 13 civilian: seven of whom died following the amputation of one or more limbs, abducted 10 civilians, 60 houses burnt and much public infrastructure were also destroyed during the battle. After the attack, Guinean ECOMOG hunts for RUF/AFRC collaborators. Same year, from the direction of Mile 14, the village of **Bassia** was attacked on seven occasions by RUF forces. They killed 4 civilian men and raped 3 women. They also abducted 3 men during the attack. Some fled into Guinea in 1998. Those who decided to stay experienced repeated attack, **driving civilians away for 2 or 3 months** and later return after each attack. Farming activity was carried out from **“nukhugie”** so-called “Corners”. It was during the fourth attack when RUF forces started burning down houses in Bassia. Following

RUF/AFRC unsuccessful attempts to capture Freetown in February 1999, RUF/AFRC occupied villages including **Kambia** and **Rukuprr** towns in the Magbema Chiefdom. At this time the wharf town of Kukuna was also occupied. The RUF/AFRC had full control of all the main wharfs on the Great Scarcies River in the Chiefdom. Civilian chairpersons, secretaries administer an extensive system of collecting house taxation and food. The control of Bramaia Chiefdom was part of a general strategy by RUF/AFRC to secure Kambia and encircle Port Loko. Same February, RUF/AFRC forces adopted a mission code-named **"Operation Feed yourself"** which were primarily not designed to include the killing of civilians or destruction of property. Two days later RUF/AFRC returned to Kukuna from the direction of Madina (Tonko Limba Chiefdom) and killed two civilians and raped number young women. RUF/AFRC stole civilian property. Civilians fled from Kukuna into Guinea at some point after 13 February when RUF/AFRC forces between 20 and 50 in number were deployed in Kukuna. On two occasions the village of **Gbolon** came under attack by RUF/AFRC forces during 1999 and one civilian was killed, 9 abducted. In June 2000, RUF/AFRC members harassed civilians in Kukuna, and started beating any civilian who would not hand over their bicycles. Following RUF/AFRC repeated raids on Pamelap in October 2000, Guinean forces reacted by bombarding all the towns and villages along the Great Scarcies River from Pamelap including Kukuna (Bramaia Chiefdom). Throughout October 2000 as did, Guinean forces intensified bombardment resulting in many civilian deaths. During those attacks RUF/AFRC forces killed or abducted civilians. The entire Kambia District remained firm under RUF/AFRC control including Bramaia Chiefdom. Infantry and airborne operations by Guinean contingent against RUF/AFRC positions continued into 2001. After commencement of regular 'contact group' with UNAMSIL, the RUF leader met with UNAMSIL force commander on 3 January and invited UNAMSIL to deploy in Kambia District. RUF opened the road between Mange and Kambia on 12 January 2001, and by February 2001, UNAMSIL-RUF Contact Group meeting was held in Mange. In March same year, the UN High Commissioner for Refugees commenced negotiations with RUF command and to create a demilitarised 'humanitarian corridor' running from Forecariah through Pamelap and Kambia Town to Port Loko to enable the secure passage of (hundreds of thousands) refugees from Guinea to Sierra Leone. In Abuja, Nigeria in early May 2001, the RUF leadership agreed to withdraw from Kambia District by end May 2001. Disarmament plans following this, UNAMSIL access Kukuna in Bramaia Chiefdom. On 18 May 2001, RUF/AFRC forces commenced disarmament at UNAMSIL-run centre in Madina (Bramaia Chiefdom). And on

10 August 2001, disarmament was complete across the Chiefdom. For the synthesis of events see Tables 13a, 13b.

Table 13a: *Synthesis of events (Text Box 4) during insurgency in Bramaia Chiefdom case-study/Kambia District**

Year	Town/Village/Chiefdom under attack	Town/Village/Chiefdom under attack	Where Displaced to (if any)	Attrocities/ outcomes / Established base for fighting force reported
Sometime in 1993	Sometime in 1993, the village of **Sabouya** was first attacked by RUF forces	Sabouya	Some civilians fled into Guinea and some who stayed went into "dungui" ("Corners"). Seeds were often protected in trenches in homes of civilians	None RUF activity was reported
In March 1995	From Tonko Limba Chiefdom RUF forces attacked the village of Salaamu	Salaamu		No civilian was killed
In September 1995	In September 1995, the village of Gbolon was first attacked by RUF forces	Gbolon	Civilians deserted the village for 5 months. Later on civilians left for Guinea	Killing of one civilian and burning down of few houses. RUF forces also abducted some men and women.
	RUF forces chased civilians into Tassein, Guinea and killed 6 Sierra Leoneans including 3 Guineans			
	Hardly any agricultural activity was carried out but after this incidence, civilians decided to return.			
On 1 February 1996	On 1 February 1996, RUF forces attacked Kukuna, the Chiefdom headquarter town, on the road to Guinea		None RUF activity was accounted during this attack. RUF forces returned to the Kamakwie Camp at Kamakwie Camp at Masonkorie in SandaLoko Chiefdom	
	Later in February 1996, RUF forces attacked Kukuna Town		RUF forces burnt down many houses and looted extensively	
By end February 1996	From Kukuna RUF forces went to Makindota in Tonko Limba Chiefdom, Kambia District, moving to base camp at Ro-Source.			Base camp at Ro-Source in SandaTandaren Chiefdom
From May until November 1996	Together with a locally mobilised civil defence, Guinean forces patrolled all around the Madina-Kukuna route and all the roads around the border with Guinea to preven to prevent RUF infiltration			
The signed Abidjan Peace Accord on 30 November 1996 resulting ceasefire held firm in Kambia District until May 1997				
In May 1997	While a small RUF force attacked Madina using a red Toyota Hilux		RUF forces took medicine, clothes, generators and furniture from the Catholic Mission and taken to Ro-Source base, another group attacked Kukuna on the same day	
	In May 1997, Sabouya was attacked by RUF forces although none RUF activity was reported			
Across September and October 1998	RUF/AFRC forces attacked and looted civilian property extensively, killing and abducting across September and October 1998		Civilians were killed and mutilated in barbaric ways. RUF/AFRC also began imposing a high weekly tax on the houses in RUF/AFRC occupied areas on the Great Scarcies River along the strategic towns and smuggling routes within the Chiefdom.	
In late September 1998	RUF/AFRC forces staged surprise attack on Kukuna. Guinean ECOMOG forces stationed in Kukuna repelled RUF/AFRC forces		During the attack, RUF/AFRC forces killed more civilian: seven of whom died following the amputation of one or more limbs, abducted some civilians & houses burnt. Much public infrastructure were also destroyed during the battle	
		Guinean ECOMOG hunts for RUF/AFRC collaborators		
1998	The village of Bassia was attacked on seven occasions by RUF forces	Bassia	Some civilians fled into Guinea in 1998. Those who decided to stay experienced repeated attack, driving civilians away for 2 or 3 months and later return after each attack	RUF forces killed few civilian men and raped some women. They also abducted some men during the attack. Farming activity was carried out from "nukhugie" so-called "Corners".
	RUF	Bassia	It was during the fourth attack when RUF forces started burning down houses in Bassia	
The control of Bramaia Chiefdom was part of a general strategy by RUF/AFRC to secure Kambia and encircle Port Loko District.				

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Table 13b: *Synthesis of events (Text Box 4) during insurgency in Bramaia Chiefdom case-study/Kambia District* /Kambia District**

Year	Town/Village/Chiefdom under attack	Town/Village/Chiefdom under attack	Where Displaced to (if any)	Attrocities/ outcomes / Established base for fighting force reported
February, 1999	Following RUF/AFRC unsuccessful attempts to capture Freetown in February 1999, RUF/AFRC occupied villages including Kambia and Rukuprr towns in the Magbema Chiefdom. At this time the wharf town of Kukuna was also occupied			
February, 1999	RUF/AFRC forces adopted a mission code-named "Operation Feed yourself"			The mission primarily not designed to include the killing of civilians or destruction of property
	Two days later RUF/AFRC returned to Kukuna from the direction of Madina (Tonko Limba Chiefdom)	Kukuna	Civilians fled from Kukuna into Guinea at some point after 13 February when RUF/AFRC forces between 20 and 50 in number were deployed in Kukuna	RUF/AFRC killed few civilians and raped a number of young women & stole civilian propertycivilian deaths. Turture and rape; stole civilian property
	On two occasions the village of **Gbolon** came under attack by RUF/AFRC forces during 1999	Gbolon		Acivilian was killed & some abducted RUF/AFRC forces
In June, 2000		RUF/AFRC members harassed civilians in Kukuna, and started beating any civilian who would not hand over their bicycles		
In October, 2000	Following RUF/AFRC repeated raids on Pamelap in October 2000, Guinean forces reacted by bombarding all the towns and villages along the Great Scarcies River from Pamelap including Kukuna (Bramaia Chiefdom).			Throughout October 2000 as did, Guinean forces intensified bombardment resulting in many civilian deaths. During those attacks RUF/AFRC forces killed or abducted civilians.
In 2001		Infantry and airborne operations by Guinean contingent against RUF/AFRC positions continued into 2001		
0n 12 January 2001	RUF leader met with UNAMSIL force commander on 3 January and invited UNAMSIL to deploy in Kambia District. RUF opened the road between Mange and Kambia on 12 January 2001			
By February 2001	RUF opened the road between Mange and Kambia on 12 January 2001, and by February 2001, UNAMSIL-RUF Contact Group meeting was held in Mange			
In March 2001, the UN High Commissioner for Refugees commenced negotiations with RUF command and to create a demilitarised 'humanitarian corridor' running from Forecariah through Pamelap and Kambia Town to Port Loko to enable the secure passage of (hundreds of thousands) refugees from Guinea to Sierra Leone				
On 2 May 2001, the RUF leadership agreed to withdraw from Kambia District by 30 May 2001				
May, 2001	On 18 May 2001, RUF/AFRC forces commenced disarmament at UNAMSIL-run centre in Madina (Bramaia Chiefdom).			
On 10 August 2001, disarmament was complete across the Chiefdom				

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Text Box 5: TONKO LIMBA CHIEFDOM

During 1995, the village of **Kafanta** was firs attacked on five occasions by RUF forces. The village was first attacked in September same year. Although no civilian was killed, the attack resulted in the abduction of one man and a woman. Shortly before the Parliamentary and Presidential elections on 26 February 1996, RUF forces attacked **Madina**in Tonko Limba Chiefdom. On the last day of January 1996, the **Catholic Mission** in Madina intercepted radio message RUF forces planning to attack Madina. On the first day of February 1996, RUF forces attacked Madina Town at dawn, meeting no resistance. 17 houses were burnt down, and one man was killed. After the event, RUF forces returned to their **Kamakwie camp** at **Masonkorie** in SandaLoko Chiefdom. That same day another group in the main time had attacked **Kukuna** in Bramaia Chiefdom. From May until November 1996, Guinean forces moved into Madina. And together with a locally mobilised civil defence, the two groups patrolled all around the Madina-Kukuna route and all the roads around the border with **Guinea** to prevent RUF infiltration. The signed Abidjan Peace Accord on 30 November 1996 resulting ceasefire, held firm in Kambia District until May 1997. In the month of March 1996, the village of **Kathantinah** was first attacked on two occasions by RUF forces. They killed 4 civilians, and abducted one civilian. The attackers came from **Ro-source**. Some civilians fled into Guinea, **Freetown** and **bush camps**. That same year, the village of **Katherie** was attacked on five occasions by RUF forces. Although no civilian was killed, about 7 men, 2 children and one woman were abducted. Some civilians fled into Guinea, Walla and others into bush camps. The attacker came from **Sanda** (Maforki Chiefdom). The questionnaires report that attackers included speakers of Mende; Temne and Limba dialects (see Tables 9; 8; Figures 5 & 6). Sometime in early February 1996, from **Makindota**, RUF forces attacked the village of **Yibaya** for the first time. Although no killing was reported, 5 civilians were abducted after burning down 2 houses in the village and civilians flee into **bush camp**, and Guinea. Same year, the village of **Mafafilah** was attacked on two occasions which resulted in the killing of 5 men, and abduction of 2 women and one man. Around mid-May 1997, a small RUF force attacked Madina using a red Toyota Hilux stolen earlier attack on Madina. RUF forces took medicine, clothes, generators and furniture from the Catholic Mission and taken to Ro-Source base. Following the SLA successful coup on 25 May 1997 that saw the AFRC leadership joined with the RUF. The RUF/AFRC immediately established a brigade headquarter for Kambia District in the village of Yibaya 10 miles from the international border with Guinea, and became the first seat of the joint RUF/AFRC command in Kambia District. There were few attacks on civilians primarily for fear for provoking Guinean forces. As events went by RUF/AFRC moved into Madina (Tonko Limba Chiefdom). Around 500 RUF/AFRC members were under the command of a senior member of the RUF/AFRC leadership. And before the signing of the Conakry Peace on 23 October 1997, a senior member of the RUF/AFRC leadership carried out "Operation Stay in Madina"(Tonko Limba Chiefdom): a Town Chief was appointed and put in control of **revenue-generating activities** led to a general escalation of ill-treatment of the civilian population in the surrounding villages. On 1 August 1997, the village of **Masunthu** was first attacked by RUF forces. They killed 5 civilians and abducted 6 men (including a-ten year old boy) and 2 women. Attackers came from Sanda (Mgblonthor Chiefdom). The questionnaires report that attackers included speakers of Kono, Mende, Limba and Temne dialects (see Tables 9; 8; Figures 5 & 6). The questionnaires report that on 20 occasions Masunthu was attacked by RUF during the conflict. RUF/AFRC members retaliated by capturing and decapitating 15 residents of Katherie severed heads on poles at the town entrance points. Three civilians had their hands and ears amputated during the attack. A three year old baby was among others wounded when RUF/AFRC members attacked them with bladed weapons. Early October 1998, RUF/AFRC command in Madina focussed attacking the villages of Yibaya, Kathantinah, **Kakula, Kamabala**,**Kasengera**,**Kamasasa**,**Katimbo** and **Kakonteh**. Around 16 civilians were killed by RUF/AFRC members during the attack on Yibaya, Kathantinah and Kakula. The three villages were occupied by Guinean forces on or around September 1998. In **Kamabala** village RUF/AFRC forces infiltrated the town disguised as IDPs, killed eight people, impaled the son of a prominent elder on a sharpened pole, and burnt all the grass houses before heading into the bush to collect money from village residents who had fled the attack. In **Kakonteh** village, RUF/AFRC members cut off a young mother when she stopped them from decapitating her baby. During the attack, a number of civilians were killed and all the houses but one were burnt down. In **Kangawala** village, RUF/AFRC members abducted, raped and then released a number of women. In **Katimbo** village, RUF/AFRC members amputated a hand each from two other civilians. In September 1998, Yibaya was attacked by RUF forces although none RUF activities were reported. In October 1998, a **land dispute** broke out between the villages of Kakula and Yibaya. Yibaya was assisted by RUF/AFRC members stationed in residents to occupy the disputed land. In the resulting battle, 16 people were killed. In (mid) May 1999, RUF/AFRC brigade commander executed six men captured from **Rokamba** (Masungbala Chiefdom), at Madina. Preliminary discussions between RUF/AFRC and Government of Sierra Leone yielded a ceasefire on 24 and 25 May in Togolese Capital. Following the signing of the Lome Peace Agreement, inhabitants of Tonko Limba Chiefdom pay money and feed RUF/AFRC forces. On every

Friday were market day in Madina(Tonko Limba Chiefdom) was levied Le500, three cups of rice or oil from each house. Those who refuted were ill-treated: north of Madina(Tonko Limba Chiefdom) at **Kasuroh**village an old man sustained broken leg for refusing to let RUF/AFRC members take his livestock. In early 2000, RUF/AFRC moved the Kambia Brigade headquarters from Tonko Limba Chiefdom to Rokuprr Town. In April 2000, RUF/AFRC forces interrupted UNAMSIL long patrols in Kambia District and detained around 300 UNAMSIL forces in different locations. Early in May 2000, around 100 Nigerian UNAMSIL contingent near Kambia Town were disarmed by RUF/AFRC forces and released few days later in Madina(Tonko Limba Chiefdom). Around late March and early April 2000, Sierra Government helicopter gunship had dropped leaflets telling RUF to disarm to UNAMSIL, warning that next time it would be bombs. In late May 2000, following Sierra Leone Government helicopter gunship bombarded Rokuprr Town, the helicopter gunship came regularly, and resulted in civilian deaths in Madina(Tonko Limba Chiefdom). This practice continued until June 2000. Early in September 200, following RUF/AFRC attack on Pamelap, two well-known Italian Xavarian missionary priests were also abducted, taken to Madina(Tonko Limba Chiefdom) where they were allowed by RUF/AFRC command to continue their work and later released at **Kamalo**(SandaLoko Chiefdom in Bombali District). The RUF/AFRC Kambia Brigade command who were never informed about this, led to a wave of arrests of RUF/AFRC officers. Arrested culprits were severely beaten: canes with razor blades embedded in them. Infantry and airborne operations by Guinean contingent against RUF/AFRC positions continued into 2001. After commencement of regular 'contact group' with UNAMSIL, the RUF leader met with UNAMSIL force commander in early January and invited UNAMSIL to deploy Kambia District. RUF opened the road between Mange and Kambia on 12 January 2001, and in February 2001 UNAMSIL-RUF Contact Group meeting was held in Mange. In March 2001, the UN High Commissioner for Refugees commenced negotiations with RUF command and to create a **demilitarised 'humanitarian corridor'** running from Forecariah through Pamelap and Kambia Town to Port Loko to enable the secure passage of refugees from Guinea to Sierra Leone. In Abuja, Nigeria on 2 May 2001, the RUF leadership agreed to withdraw from Kambia District by end May 2001. UNAMSIL access Madina in Tonko Limba Chiefdom and by 18 May 2001, RUF/AFRC forces commenced disarmament at UNAMSIL-run centres. And on 10 August 2001, disarmament was complete across the Chiefdom. For the synthesis of events see Tables 14a to 14e.

***Table 14a:** Synthesis of events (Text Box 5)during insurgency in Tonko Limba Chiefdom/Kambia District**

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered	Where Displaced to (if any)	Attrocities/ outcomes / Established base for fighting force reported	
In September 1995	Kafanta was first attacked by RUF forces		Resulted in the abduction of civilains by RUF forces	
In January, 1996	RUF forces attacked Madina Town at dawn. Same day another group in the main time had attacked Kukuna in Bramaia Chiefdom		Houses burnt down, and a civilaian killed	Kamakwie camp at Masonkorie in SandaLoko Chiefdom
Last day of January 1996	On the last day of January 1996, Catholic Mission in Madina intercepted radio message RUF forces planning to attack Madina			
Early in February, 1996	From Makindota, RUF forces attacked the village of Yibaya for the first time	Civilians flee into bush camp, and Guinea	Civilians were abducted after burning down few houses	
End February 1996	RUF forces attacked Madina at dawn		Houses were burnt down, and a civilian was killed by RUF forces	Kamakwie camp at Masonkorie in SandaLoko Chiefdom
In March 1996	Kathantinah was first attacked on two occasions by RUF forces	Some civilians fled into Guinea, Freetown and bush camps	Civilians killed by RUF force & abducted a civilian	Ro-source
From May until November 1996, Guinean forces moved into Madina. And together with a locally mobilised civil defence to prevent RUF infiltration				
The signed Abidjan Peace Accord on 30 November 1996 resulting ceasefire, held firm in Kambia District until May 1997				

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Table 14b:Synthesis of events (Text Box 5)during insurgency in Tonko Limba Chiefdom/Kambia District*

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered	Where Displaced to (if any)	Attrocities/ outcomes / Established base for fighting force reported	
In 1996	Katherie was attacked on five occasions by RUF forces	Some civilians fled into Guinea, Walla and others into bush camps	Cicilians were abducted by RUF forces	Sanda (Maforki Chiefdom).
	That same year, in 1996 Mafafilah was attacked by RUF on two occasions		Resulted in the killings and abduction some civilians by RUF forces	
mid-May 1997	RUF force attacked Madina using a red Toyota Hilux stolen earlier attack on Madina	RUF forces took medicine, clothes, generators and furniture from the Catholic Mission and taken to Ro-Source base		
In May 1997	Following the SLA successful coup on 25 May 1997 that saw the AFRC leadership joined with the RUF	RUF/AFRC immediately established a brigade headquarter for Kambia District in the village of Yibaya		

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Table 14c:*Synthesis of events (Text Box 5) during insurgency in Tonko Limba Chiefdom/Kambia District**

<table>
<tr><th>Year</th><th colspan="2">Fighting Force(s) / Town/Village/C/dom fighting were encountered</th><th>Where Displaced to (if any)</th><th colspan="2">Attrocities/ outcomes / Established base for fighting force reported</th></tr>
<tr><td>In 1997</td><td colspan="2">Before the signing of the Conakry Peace on 23 October 1997 a senior member of the RUF/AFRC leadership carried out "Operation Stay in Madina"</td><td colspan="3">Revenue-generating activities led to a general escalation of ill-treatment of the civilian population in the surrounding villages</td></tr>
<tr><td rowspan="2">In 1997</td><td colspan="2">Masunthu was attacked on 20 occasionsby by RUF forces</td><td></td><td>Civilians were killed and & some abducted by RUF forces</td><td>Attackers came from Sanda (Mgblonthor Chiefdom)</td></tr>
<tr><td></td><td>In Katherie</td><td colspan="3">RUF/AFRC members retaliated by capturing and decapitating 15 residents of Katherie, civilians had their hands and ears amputated during the attack</td></tr>
</table>

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Table 14d:*Synthesis of events (Text Box 5)during insurgency in Tonko Limba Chiefdom/Kambia District**

<table>
<tr><th>Year</th><th colspan="2">Fighting Force(s) / Town/Village/C/dom fighting were encountered</th><th>Where Displaced to (if any)</th><th>Attrocities/ outcomes / Established base for fighting force reported</th></tr>
<tr><td>In September 1998</td><td colspan="2">Yibaya was attacked by RUF forces</td><td></td><td>None RUF activities were reported</td></tr>
<tr><td>Early in October 1998</td><td colspan="3">RUF/AFRC command focussed attacking Yibaya, Kathantinah, Kakula, Kamabala,Kasengera,Kamasasa,Katimbo and Kakonteh.</td><td>Civilians were killed by RUF/AFRC members during the attack on Yibaya, Kathantinah and Kakula</td></tr>
<tr><td></td><td>RUF/AFRC forces infiltrated the town disguised as IDPs</td><td>Kamabala</td><td colspan="2">RUF/AFRC forces impaled the son of a prominent elder on a sharpened pole. Burnt all the (grass) houses</td></tr>
<tr><td></td><td>RUF/AFRC</td><td>Kakonteh</td><td colspan="2">RUF/AFRC members cut off a young mother when she stopped them from decapitating her baby & a number of civilians killed All the houses but one were burnt down</td></tr>
<tr><td></td><td>RUF/AFRC</td><td>Kangawala</td><td colspan="2">In Kangawala village, RUF/AFRC members abducted, raped and then released a number of women</td></tr>
<tr><td></td><td>RUF/AFRC</td><td>Katimbo</td><td></td><td>Katimbo village, RUF/AFRC members amputated a hand each from two other civilians</td></tr>
<tr><td>In October 1998</td><td colspan="3">A land dispute broke out between the villages of Kakula and Yibaya</td><td>In the resulting battle, people were killed</td></tr>
</table>

(*): see Tables 9; 8; Figures 5 & 6 for identity of attackers

***Table 14e:**Synthesis of events (Text Box 5)during insurgency in Tonko Limba Chiefdom/Kambia District**

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered	Where Displaced to (if any)	Attrocities/ outcomes / Established base for fighting force reported
mid May 1999	RUF/AFRC brigade commander executed six men captured from Rokamba(Masungbala Chiefdom), at Madina.		
Following the signing of the Lome Peace Agreement, inhabitants of Tonko Limba Chiefdom pay money and feed RUF/AFRC forces			On every market day in Madina was levied Le500, three cups of rice or oil from each house. Those civilians who refuted were ill-treated
	RUF/AFRC	Kasuroh	RUF/AFRC members raid and/or torture civilians for livestock
In April 2000	RUF/AFRC forces interrupted UNAMSIL long patrols in Kambia District and detained around 300 UNAMSIL forces		
Early in May 2000	100 Nigerian UNAMSIL contingent near Kambia Town were disarmed by RUF/AFRC forces		
In late May until June 2000	Government helicopter gunship bombarded Rokuprr Town. This practice continued until June 2000		Resulted in civilian deaths in Madina
Early in September 200	RUF/AFRC attack on Pamelap		2 well-known Italian Xavarian missionary priests were also abducted, taken to Madina and later released at Kamalo(SandaLoko Chiefdom in Bombali District)
Early in 2001	Infantry and airborne operations by Guinean contingent against RUF/AFRC positions continued into 2001		
On 12th. January 2001	RUF opened the road between Mange and Kambia on 12 January 2001		
In March 2001	A demilitarised 'humanitarian corridor' running from Forecariah through Pamelap and Kambia Town to Port Loko		
On 2st. May 2001	RUF leadership agreed to withdraw from Kambia District by end May 2001		
By 18th. May 2001	RUF/AFRC forces commenced disarmament at UNAMSIL-run centres		
On 10th. August 2001 Disarmament was complete across the Chiefdom			

(*): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Text Box 6: MAGBEMA CHIEFDOM

RUF did not attempt to hold any territory in the Chiefdom in 1995. On 25 January 1995, RUF forces attacked the town of K**ambia**, killing 20 people. The groups were heavily armed with an array of bladed weapons, as well as small arms and grenades. The attack came from the direction of Kolenten Secondary School. The attack lasted for four hours. Around 300 civilians were rounded-up, 70 civilians remaining in RUF custody; three young boys tortured to death. During this attack , RUF abducted a large number of 50 or moreschool **children** and kidnapped seven **Italian Nuns** operating a dispensary. RUF forces paraded the Nuns including 100 other civilians residents around the town for three hours before moving to an unknown destination. Five hours after the attack, two truckloads of SLA arrived. In the wake of the attack, both local youths and the SLA stole civilian property. The attack on Kambia Town was seen as a demonstration of RUF to strike throughout Sierra Leone. Inadequate response and poor discipline of the SLA resulted to a sharp deterioration in civil-military relations in Kambia District. In 1995, RUF forces from **Sanda** (Magblonthor Chiefdom) attacked **Mathoraneh** on two occasions which resulted in the killing of 3 men and one woman. They abducted 4 men and 2 women. The questionnaires report that attackers included speakers of Mende, Temne and Susu dialects (see Tables 9; 8; Figures 5 & 6). In 1996, shortly before the Parliamentary and Presidential elections on 26 February 1996, RUF forces staged a number of attacks on key wharf towns and crossing on the Little Scarcies River enabling seaward river access. **Rokuprr**, a large wharf town and economic centre on the Great Scarcies River was also attacked. On 20 February 1996 RUF forces around 300 targeted Rokuprr. SLA forces were inadequately equipped and numbered too few to resist the RUF offensive. Unknown number of civilians were abducted but released the same day. Members of RUF looted around 250 houses and **stole rice**. The **Research Station** was unconditionally and severely looted and vandalised. The signed Abidjan Peace Accord on 30 November 1996 resulting ceasefire held firm in Kambia District until May 1997. Following the SLA successful coup on 25 May 1997, that saw the AFRC joined with the RUF, the RUF/AFRC immediately established a training camp at **Kamba**(Magbema Chiefdom). There was an escalation in the mistreatment of civilians. Murder, rape and abduction were common place on villages. High profile **brutal killings** spread, **prompting many civilians to cooperate with the RUF/AFRC** taking on roles such as load carriers, porters, administrators or PROs. Civilians were killed and mutilated in barbaric ways: victims had one or more limbs amputated by RUF/AFRC members. RUF/AFRC also began imposing a high weekly tax on the houses in RUF/AFRC occupied areas on the Great Scarcies. River in the Chiefdom. Following ECOMOG intervention in the capital of Freetown between 6 and 12 February; on 14 February 1998, RUF/AFRC forces attacked Kambia Town. They killed 8 men, and stole civilian property and burnt down houses. On 19 February 1998, they assaulted Rokuprr town. During the attacks, they looted extensively, killing and abducting civilians across September and October 1998. Civilians were killed and mutilated: others had one or more limbs amputated by RUF/AFRC members. They began imposing a high weekly tax on the houses in RUF/AFRC occupied areas in the Chiefdom. Guinean ECOMOG deployed from **Guinea** to Kambia Town at some point in early March 1998. In late February 1998, youths in Kambia Town burnt alive 2 RUF members in retaliation for attack on **Bamoi**where RUF/AFRC forces disrupted the town market. Late in October 1998, Guinean ECOMOG deployed 3,000 troops along the border with Sierra Leone. A further 1,000 were deployed into Kambia District including Kambia Town. Same 1998, RUF forces from camp Ro-source first attacked **Kayorkneh** although no civilian was killed, they abducted 8 men. In April 1998, **Senthai** was first attacked by RUF forces. They killed 2 women and one man and abducted 2 women and one man. The questionnaires report that attackers included speakers of Kono, Mende, Temne, Fullah, Susu and Limba dialects (see Tables 9; 8; Figure 5& 6). Further speculated questionnaires report that the village of **Magbema** was attacked on two occasions by RUF forces which resulted in the killing of 3 men and 2 women and abduction of 22 men by RUF forces. The attackers came from Senthai and included notorious speakers of Mende, Temne and Limba dialects (see Tables 9; 8; Figure 5& 6). Following the attack, some civilians fled to LokoMassama and bush camps. After RUF/AFRC unsuccessful attempts to capture Freetown in February 1999, RUF/AFRC occupied Kambia and Rukuprr towns and villages in the Chiefdom. In February 1999, RUF/AFRC forces attacked Kambia, engaging Guinean ECOMOG forces. RUF/AFRC forces established a base in Kambia Town where they remained until late May 2001. At this time the Guinean forces in Kambia Town retreated to positions, engaged RUF/AFRC forces throughout March for full control of the town. RUF/AFRC forces soon started harassing civilians asking them constantly for food. People had to buy "passports". Civilians were killed if refuse to comply or unable to give food or money: a fisherman who came back from the sea without fish was killed. Late in February 1999, RUF/AFRC forces entered Rokuprr without firing a shot, wearing white strips of cloth claimed seeking peace. Civilians welcomed their arrival. The peace did not last long. By early March, however, RUF/AFRC forces began taxing civilian and abducting young men, taking them to a training camp established at nearby village of Kamba. Villages nearby Kamba present at least Le 200,000, a large amount of food to the RUF/AFRC command. At this time the RUF/AFRC had full control over all the main wharfs on the Great Scarcies River, civilian chairpersons, secretaries administer an extensive system of collecting house taxation and food, imposed monthly tax of Le 1,000 per house in all villages in Magbema Chiefdom. The farmer interview reports are not quite in agreement. On two occasions RUF forces first attacked the village of Kamba which resulted in the killing of 2 men. They abducted 12 men and 3 women. Attackers came either from Kamakwei or camp Ro-source. March 3 1999, Consolidation of control of Kambia District was general strategy to encircle Port Loko. Around mid-March 1999 Guinean ECOMOG counter attacked Kambia Town seizing parts of the town from RUF/AFRC forces. In 1999, RUF forces from Camp Ro-source. Attackers included speakers of Mende, Limba, Temne, Susu, Fullah and Liberian dialects (see Tables 9; 8; Figure 5& 6). In early 2000, RUF/AFRC moved the Kambia Brigade headquarters from Tonko Limba Chiefdom to Rokuprr Town at some point. Around late March and early April 2000, Sierra Government helicopter gunship had dropped leaflets telling RUF to disarm to UNAMSIL, warning that next time it would be bombs. RUF/AFRC forces shoot civilians attempting to take one of the leaflets. Later in May 2000, Sierra Government helicopter gunship bombarded Rokuprr Town, killing three civilians. After 26 May 2000, helicopter gunship came regularly, and resulted in civilian deaths in Rokuprr and Kambia Town. This practice continued until June 2000 when Guinean forces bombarded Rokuprr killing up to 17 civilians. UNAMSIL commenced long-range patrols into Kambia district. Following RUF/AFRC repeated raids on Pamelap in 2000, on October 10, Guinean forces reacted by bombarding all the towns and villages along the Great Scarcies River from Pamelap and locations including Rokuprr and Kambia. Throughout October 2000 as did, Guinean forces intensified bombardment resulting in many civilian deaths. During those attacks RUF/AFRC forces killed or abducted civilians. The entire Kambia District remained firm under RUF/AFRC control including Magbema. In November 2000, many civilians being unable to continue paying money to RUF/AFRC forces fled Rokuprr to nearby villages and there were progressively fewer civilians to provide RUF/AFRC members with food. RUF/AFRC members who became concerned sent a chairperson to order civilians to return, otherwise RUF/AFRC forces start amputating limbs of civilians in the vicinity. Result of which many people travelled to **Freetown** by boat. Infantry and airborne operations by Guinean contingent against RUF/AFRC positions continued into 2001. After commencement of regular 'contact group' with UNAMSIL, the RUF leader met with UNAMSIL force commander on 3 January and invited UNAMSIL to deploy KambiaDistrict . RUF opened the road between Mange and Kambia in January 2001, and in February 2001 UNAMSIL-RUF Contact Group meeting was held in Mange. In March 2001, the UN High Commissioner for Refugees commenced negotiations with RUF command and to create a demilitarised **'humanitarian corridor'** running from **Forecariah** through Pamelap and Kambia Town to Port Loko to enable the secure passage of hundreds of thousands of refugees from Guinea to Sierra Leone. UNAMSIL commander visited Rokuprr and Kambia Town following the reopening of the bridge at Mange. In **Abuja**, Nigeria on 2 May 2001, the RUF leadership agreed to withdraw from Kambia District by 30 May 2001. Disarmament plans following this,

Table 15a: *Synthesis of events (Text Box 6) during insurgency in Magbema Chiefdom/Kambia District**

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered	Town/Village/Chiefdom under attack	Displacement	Attrocities/ outcomes / Established base for fighting force reported
On 25 January 1995	1. From the direction of Kolenten Secondary SchoolRUF forces attacked the town of Kambia1.	Kambia		Killing some people; civilians remaining in RUF custody; few young boys tortured to death. RUF abducted a large number of more school children and kidnapped 7 Italian Nuns operating a dispensary.
	2. Five hours after the attack, two truckloads of SLA arrived			Youths and the SLA stole civilian property
	Inadequate response and poor discipline of the SLA resulted to a sharp deterioration in civil-military relations in Kambia District			
In 1995	RUF forces from Sanda (Magblonthor C/dom) attacked Mathoraneh	Mathoraneh		Resulted in the killing of few men and a woman & abducted men and women
In 1996	On 26 February 1996, RUF forces staged a number of attacks on key wharf towns and crossing on the Little Scarcies River enabling seaward river access			
On 20 February 1996	RUF forces around 300 targeted Rokuprr. SLA forces were inadequately equipped and numbered too few to resist the RUF offensive		Members of RUF looted around 250 houses and stole rice. The Research Station was unconditionally and severely looted and vandalised	
Following the SLA successful coup on 25 May 1997, that saw the AFRC joined with the RUF, the RUF/AFRC immediately established a training camp at Kamba			Resulting in the escalation in the mistreatment of civilians. Murder, rape and abduction were common place on villages. High profile brutal killings spread, prompting many civilians to cooperate with the RUF/AFRC taking on roles such as load carriers, porters, administrators or PROs. Civilians were killed and mutilated in barbaric ways: victims had one or more limbs amputated by RUF/AFRC members. RUF/AFRC also began imposing a high weekly tax on the houses in RUF/AFRC occupied areas on the Great Scarcies. River in the Chiefdom	
On 14th. February 1998	RUF/AFRC forces attacked Kambia Town following ECOMOG intervention in the capital of Freetown between 6 and 12 February			RUF/AFRC forces killed some male civilians, and stole civilian property and burnt down houses
On 19 February 1998	RUF/AFRC assaulted Rokuprr town	Rokuprr town		RUF/AFRC force looted extensively, killing and abducting civilians
In late February 1998 youths in Kambia Town burnt alive 2 RUF members in retaliation for attack on **Bamoi**				
In early March 1998	Guinean ECOMOG deployed from **Guinea** to Kambia Town			
Across September and October 1998	During the attacks, they looted extensively, killing and abducting civilians across September and October 1998. Civilians were killed and mutilated			RUF/AFRC members imposing a high weekly tax on the houses in RUF/AFRC occupied areas in the Chiefdom
Late in October 1998, Guinean ECOMOG deployed 3,000 troops along the border with Sierra Leone. A further 1,000 were deployed into Kambia District				
1998	RUF forces from camp Ro-source first attacked Kayorkneh	Kayorkneh		Although no civilian was killed, RUF forces abducted some men / Attackers came from camp Ro-source
In April 1998	Senthai was first attacked by RUF	Senthai		RUF forces killed few women and one man and abducted women and one man
	Magbema was attacked on two occasions by RUF forces	Magbema	Some civilians fled to LokoMassama and bush camps	Resulted in the killing of some men and abduction of men

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

Table 15b: *Synthesis of main events (Text Box 6) during insurgency in Magbema Chiefdom case-study/Kambia District**

Year	Fighting Force(s) / Town/Village/C/dom fighting were encountered	Town/Village/Chiefdom under attack	Displacement	Attrocities/ outcomes / Established base for fighting force reported
In February 1999	After RUF/AFRC unsuccessful attempts to capture Freetown in February 1999, RUF/AFRC occupied Kambia and Rukuprr towns and villages in the Chiefdom			
In February 1999	RUF/AFRC forces attacked Kambia, engaging Guinean ECOMOG forces. RUF/AFRC forces established a base in Kambia Town where they remained until late May 2001			RUF/AFRC started harassing civilians asking them constantly for food and passport. Civilians killed if refuse to comply
Late in February 1999	RUF/AFRC forces entered Rokuprr without firing a shot, claimed seeking peace. The peace did not last long			Abducting young men, taking them to a training camp. RUF/AFRC had full control over all the main wharfs on the Great Scarcies River, imposed monthly tax in all villages in Magbema Chiefdom
Early March 1999	RUF/AFRC forces began taxing civilian and abducting young men, taking them to a training camp established at nearby village of Kamba			Villages nearby Kamba present at least Le 200,000, a large amount of food to the RUF/AFRC command
	RUF forces first attacked the village of Kamba			Resultin in the killing of few people & abducted men and women Attackers came either from Kamakwei or camp Ro-source
mid-March 1999	Guinean ECOMOG counter attacked Kambia Town seizing parts of the town from RUF/AFRC forces.			
March and early April 2000	Sierra Government helicopter gunship had dropped leaflets telling RUF to disarm to UNAMSIL			RUF/AFRC forces shoot civilians attempting to take one of the leaflets
Later in May until June 2000	Sierra Government helicopter gunship bombarded Rokuprr Town			Killing civilians
	Guinean forces bombarded Rokuprr killing more civilians. UNAMSIL commenced long-range patrols into Kambia district			
UNAMSIL commenced long-range patrols into Kambia district. Following RUF/AFRC repeated raids on Pamelap in 2000				
Throughout October 2000 as did, Guinean forces intensified bombardment	In November 2000, many civilians being unable to continue paying money to RUF/AFRC forces fled Rokuprr to nearby villages, Result of which many people travelled to Freetown by boat			Resulting in many civilian deaths. During those attacks RUF/AFRC forces killed or abducted civilians
In 2001	Infantry and airborne operations by Guinean contingent against RUF/AFRC positions continued			
In March 2001 The UN High Commissioner for Refugees commenced negotiations with RUF command and to create a demilitarised 'humanitarian corridor' running from Forecariah through Pamelap and Kambia Town to Port Loko				
In Abuja, Nigeria on 2 May 2001, the RUF leadership agreed to withdraw from Kambia District by 30 May 2001				
On 18 May 2001 RUF/AFRC forces commenced disarmament at UNAMSIL-run centre in Rukuprr				
The 11th. Battalion SLA and 30 SSD members deployed to Kambia Town				
On 10 August 2001, disarmament was complete across the Chiefdom				

(*****): see Tables 9; 8; Figures 5 & 6 for identity of attackers

UNAMSIL access other areas in Magbema Chiefdom. On 18 May 2001, RUF/AFRC forces commenced disarmament at UNAMSIL-run centre in Rukuprr. On 29 and 30 May, the 11th. Battalion SLA and 30 SSD members deployed to Kambia Town. And on 10 August 2001, disarmament was complete across the Chiefdom. For the synthesis of events see Tables 15a, 15b.

CHAPTER THREE

Rice seed system dynamics: farmer seed choices under adversity

Alfred Mokuwa

Abstract

This chapter seeks to analyze whether and how rice seed distribution modalities were at risk during the invasion of Sierra Leone by the Revolutionary United Front (1991-2002). The focus in this chapter narrows to a picture based on 287 upland rice farms surveyed in the 2007-2008 season in four chiefdoms in Sierra Leone. Some reports of war-shaped seed dynamics are ground-truthed from collection records maintained for one village since 1983. Molecular and morphological analysis provided a basis for recognizing four main rice groups, *glaberrima*, *sativa-indica*, *sativa-japonica* and farmer-hybrid, reported to be grown at three periods: *pre-war, during-war and post-war.* Reported values are compared with field measurements in 2007. Trends, based on farmer reports, are identified. Anthropological tools were employed to assess farmer seed system dynamics in relation to land use changes. There is little evidence to support a conclusion that long-term damage to rice genetic diversity resulted from the impact of war. The limited varietal changes attributable to the war are partly due to the pattern of the war itself and partly due humanitarian aid interventions. One main factor, in terms of safeguarding seed diversity, lies in the characteristics of local seed channel structures. The war had little more than a passing impact on the functioning of the local seed system. Effective informal seed distribution channels sprang back to life as soon as farmers resettled their villages. However, some organizational changes have occurred. Restocking via seed loans was important before the war but has declined to insignificance in the post-war period.

Key words: Adversity; insurgency; seed systems; farmer rice varieties, humanitarian assistance, post-war recovery

Features of informal seed channels under "normal" conditions

This chapter examines how informal seed channels in four different chiefdoms in Sierra Leone were affected by low-level insurgency and displacement. To understand these dynamics it is relevant to note how different crops are managed in different ways under "normal" conditions. Rice (in our case study a subsistence crop) displays considerably more varietal diversity than cash crops. Seed management for rice is accordingly more complex than for other crops. It involves seed selection, local crop development and variety exchange among many individual farmers and between many farming communities. Grasping this complexity of this "normal" seed dynamics forms the basis for understanding the results on seed system performance in wartime, as presented in this chapter. It is important to note that a high turn-over rate of varieties by individual farmers and farming communities is typical in "normal" times. In the case study villages, a farmer might typically cultivate two, three, four varieties in dryland farming areas and there are many reasons for variety turnover. Varieties are abandoned or replaced, according to personal preference, specificity of ecological niches to specific plot locations in the farm shifting cultivation cycle, or in response to factors such as labour availability or timing constraints relating to farm operations, both on rice and on other crops. A reduction in the labour force within the farm family or a change in the usual crops sown thus can inspire a change in the varieties planted. Much of this depends on seed swaps between farmers, and between neighbouring villages. The particular portfolio of varieties maintained by a specific farmer, or farming community, is thus only a sample and snapshot of a broader range of varieties kept in play over a wider area and over time. Specific varieties can be conserved over generations *in situ* through this local process of circulation (including abandonment and re-adoption at farmer or village level), even if the variety in question is only ever grown in small amounts, provided it is hardy. Some varieties even endure as weedy relatives, even when they drop out of cultivation, and then from time to time are re-domesticated as need arises.

For farmers in the case study, introduction of a new variety reflects the opportunity to travel to visit a relative, trader, or even a researcher, or to work for a period in other areas, and then return home again. A factor favouring the farmer-to-farmer circulation of local rice types is the effective functioning of a strong traditional culture based on gift-giving, borrowing and seed exchanges, and trust within and among farm families, plus stranger-and-host relations of hospitality. Death ceremonies and wedding celebrations are important in stimulating inter-village visits to one's extended family and friends, and these visits can serve to facilitate seed exchanges, not least because feasting requires preparation of large amounts of rice. An abundant or tasty variety will excite conversation about its merits as seed. Seed acquisitions also accompany inter-village trade and marketing of goods and services, sometimes over long distances. Seed exchange networks are dense, complex and not necessarily confined to local connections alone.

Rates of seed-saving vary for different crops and for different individual farmers and farmer groups. A 1994 survey by Longley (1998) reported that saved seed as proportion of the total seed planted in north-western Sierra Leone was higher for rice than for cash crops. Rice seed planted by farmers is saved from the previous harvest. A re-study for Mogbuama (one of the case study villages covered in this thesis) shows that self-saved seed still accounts for about 53.0% of all rice seed planted in this community in 2013 (Mokuwa and Richards, in progress). But not all rice seed reported saved for the succeeding year is eventually planted because some is used to feed the workforce at land preparation, "ploughing" (hoeing in of the rice), and seedbed preparation. Where the variety is saved in over-abundance some of this surplus may then be swapped for other varieties with other farmers. In Mogbuama in 2013 seed swaps were the third most important seed source (12.0% of all seed planted).

Whether resulting from lack of key inputs (such as labour) or erratic rainfall and/or pest infestation, a poor harvest is an impediment to saving seed for the succeeding year. Age, experience and gender may partly determine success in seed acquisition, due to different household responsibilities and livelihood strategies of different farmers in the various case study locations. Seed shortfalls on the previous harvest can be made good through a variety of means. According to the recent Mogbuama re-study (Mokuwa and Richards, in preparation) these include purchase (18.0% of all farms in 2013), gifts (10.0%) and loan (4.0%). This last figure (loans) was much higher in Mogbuama in 1983 (33.0% of all farms in 1983).

In the case study villages, as in all rural Sierra Leone, rice is regarded as the principal food crop. A cash crop is incorporated into the market economy in a way that rice seed is not. Cash crops can be readily purchased in the open market, whereas seed rice can only be bought if arrangements have been made in advance. Such arrangements may be made particularly at harvest time to ensure the proper dry-moisture content for post-harvest seed management. Any rice sold on the open market tends to be cleaned grain for consumption (predominantly types with white pericarp), and not seed. If it is husked rice, traders often intentionally mix different varieties together and this makes it impossible for farmers to sow it successfully, due to likely variations in growing period. In some cases it seems that war conditions sometimes lead to intensification of varietal mixing creating “unusually dynamic varietal profiles” (Sperling, 1997). Even so, faced with no alternatives, farmers will take mixed seed and pick and choose, eventually making order and beauty out of a big mess.

Chapter 2, focusing on the impact of the war on agriculture in the case study villages, also elaborated further on how a low-intensity insurgency affected farmer rice seed selection dynamics. It was shown that the war, while it may have depressed productivity, for instance through varietal mixing, did not have any major or permanent negative effects on farmer seed selection dynamics. There was little or no war-induced loss of varieties and no major break in selection dynamics during the war. The current chapter further examines the functioning of informal rice seed channels, and will show that farmer selection for robustness in a challenging environment was already the norm before the war. This norm was maintained across all the three main periods into which the analysis is divided. These divisions will be referred to as *pre-war*, *during-war* and *post-war* periods (or "pre", "during" and "post" for short). Seemingly, selection for robustness, and strategies of adaptation drawing on a large set of farmer varieties, as will be further elaborated in the later chapters, protected Sierra Leonean rice farmers against some of the worst effects of wartime dislocation.

It is argued that while war had many destructive side-effects, and disrupted farming, thus temporarily disrupting local management of rice genetic resources and seed systems. A loss of locally adapted planting materials was considered to be caused by faming populations sometimes being repeatedly uprooted by attacks, and their seed stocks pilfered and burnt by armed factions (Richards 1998). This study, based on data collected a decade later, makes clear that there is little evidence to support a conclusion that long-term damage to rice genetic diversity resulted. Displacement was only for short periods and over short distances, and that recovery was rapid. However, much depended on the pattern of attacks, and as seen already in chapter 2 these varied a good deal depending on the actual cases examined. This is largely because farmers did not necessarily move far. Many either hid locally and then coexisted with the armed bands, or they came back to their land almost immediately the danger receded, even if they left many dependents in camps for the displaced. This reduced food demands in villages in the immediate post-war recovery phase and allowed farmers to sift and save seed, and build up supplies of some of the most robust varieties.

Thus what is needed is a precise and context specific analysis of the impact of low-level insurgency on local seed management and rice genetic resources in war-time and post-war rural Sierra Leone. Local seed management is defined here as farmers' conscious or unconscious efforts to acquire, test and maintain, develop and disseminate seed resources, from one season to the next, and over the long-term. It is necessary to unravel the details in order to arrive at a picture of the possible range of ways in which rice genetic diversity was most at risk prior to and during the invasion of Sierra Leone by the Revolutionary United Front (RUF). This is the aim of the present chapter.

The picture for Sierra Leone emerging in this chapter is consistent with work by FAO in Rwanda that suggested informal seed channels are more resilient than previously thought, given that a war does not necessarily affect the organization of all seed channels in the same ways (FAO, 1998). It is therefore relevant to focus comparable attention on the seed system in rural Sierra Leone, and on those structures, organizations and processes through which seeds are disseminated. This will give an understanding of local seed management strategies under normal conditions, and particularly how the seed system is shaped by livelihood strategies and social organization, as major determinants of seed adoption and adaptation, in times of crisis.

Micro-social dynamics of farmers' seed systems

The four core chiefdom-level case studies described in this chapter exemplify some of the typical consequences of low-level insurgency for farmer-based seed systems. When conflict was prolonged over several cropping seasons, as in Liberia, options for recovery through local action were often limited. Where conflict accelerated social change, as Richards et al. (1997) argued was the case for Guinea-Bissau, it may substantially disrupt established control of the productive labour force, with implications for rice production, thus under post-war farming conditions restoration of the seeds system requires more than agro-technical options. But the guerrilla war in Guinea Bissau was a Marxist-inspired war of independence. In Sierra Leone the war was not of this sort. If anything, it entrenched the control over land and labour of a local class of small-scale farmers, supported by the "hunter" civil defence. This, in turn, re-validated a range of local tried and tested aspects of the micro-social dynamics of farmer seed systems, drawing on a resilient egalitarian culture of trust and gifting among farmers that appears to have long been the basis of the local agrarian economy. It was sometimes feared that combatants were deploying techniques intended to destroy trust, thus freeing lightly armed guerrilla bandits to roam the countryside unchallenged. In the worst-case scenario the informal seed system would cease to function (Richards 1998). As will be shown, the four core chiefdom-level case studies considered in this chapter show now evidence of such breakdown.

Two basic situations existed for rural communities during the war. Some received NGO interventions. These were mainly in the southern half of the country. Others did not. These were mainly in the northern half of the country – where it is reported that *Oryza glaberrima* and farmer hybrids rices dominated the landscape (Richards 2006). These became the main rice species in areas controlled by the RUF. The data compiled by Paul Richards *et al.,* for a baseline survey for the agency CARE, portray a regional picture of differences between enclaved and accessible communities in the research area. The baseline established the existence of significant differences in variety portfolios, including strategies for seed rehabilitation.

It might be supposed that when farmers are affected by war and displacement, the farming system will change, affecting processes of local crop development. Reasonably, the cultivation of some crops may become intensified, while other crops may be grown in smaller quantities. Consequently, varieties of particular crops planted may be altered to favour varieties which require lower labour inputs. The agrarian change brought about by the war may have a more dramatic effect on local crop development in the longer term of agricultural production. There is evidence that this happened. Rice, being the most important subsistence crop in the case study villages, shows the greatest variability, and is the major focus of the discussion. But this activated local adaptive responses. Farmers coped within local norms, using local genetic resources. Hence disruption and collapse was avoided. Perhaps, even, there was modest improvement, in terms of strengthening the local low input system against future shocks, such as those that may eventuate from climate change. How local seed management is affected by low-level insurgency and displacement in the case study villages is presented in detail below.

Analytical approach

Rice farmers in Sierra Leone grow many varieties. It is important to note that out of the six chiefdom-level ethnographic accounts of war impacts between 2007 and 2010 (reflecting data gathered from 117 focus groups and 1352 individual farmers in Biriwa, Bramaia, Kholifa Rowalla, Magbema and Tonko Limba chiefdoms in the north and Kamajei chiefdom in the south) discussed in chapter 2, the focus of the analysis now narrows down in this chapter to a picture based on 287 upland rice farms surveyed in the 2007-2008 season in six settlements selected from just four chiefdoms (Biriwa, Magbema, Kholifa Rowalla in the north, and Kamajei in the south) of Sierra Leone. It should be further noted that the 287 farms studied are not a sample, but constitute the total number of upland rice farms found in those six villages during the fieldwork period (2007-2008). A reason for this time-demanding inclusive approach was to try and capture intra-village and more specifically inter-farm dynamic aspects of variety choice, seed exchange and genetic erosion influenced by local natural and/or social factors. Seeds do travel over large distances over time, but most of the daily seed exchange activity comprises very short movements among neighbours, friends and kin. The seed system is as face-to-face as the daily lives of the rural people. This chapter will allow some probing into the impact of different seed distribution modalities to test the conclusions derived from chapter 2.

This section is a presentation and discussion of a set of tables and figures showing varieties per village before, during and after the war, though in most cases as reported from a single point in time (farmer interviews in 2007-2008). Some of the farmer reports could verified with collection records maintained for one village in Kamajei chiefdom since 1983 by Richards (see Richards 1986, 1995, and Mokuwa & Richards, in progress). The data for these three periods are rice variety names recalled and reported by farmers in the four case-study chiefdoms. The post-war reports are compared with a comprehensive collection of farmer varieties planted in six case-study villages in the year 2007. Named types are often true varieties (rice is an in-breeder and mainly produces true-to-type material if seed is rogued at harvest). But names can also on occasion be misleading. Some names are generic; they describe the functionality of a group of rices - e.g. *yaka*, possibly = "charity" (zakat), i.e. rices that can be grown in wetlands in 'spare time' of household workers. In other cases a single variety can develop multiple names (e.g. *saidou gbéli* also known as *pa kiamp*). Also, every community has a number of rices grown by only one or two farmers (these are varieties that have newly arrived, or old varieties kept alive by some (often old and eccentric) individuals. Analysis can become very bogged down in details at this point.

So a summary approach based on some organizing principle is needed. Here analysis proceeds on the basis of recognition of four main groups. These are the two species of rice (*sativa* and *glaberrima*), with the *sativa* species sub-divided into *indica* and *japonica*, and farmer selected *indica* × *glaberrima* hybrids (as identified through molecular and morphological analyses to be discussed in chapters 4, 5 and 6). Farmer-named varieties are assigned to these four groups according to morphological and molecular criteria. Some of the farmer-named varieties (72) were collected and included in the molecular analysis. The other varieties were collected and grown in morphological characterization trials.

In summary, then, analysis in this chapter is based on varieties farmers recall grown at three periods (*pre-war, during-war and post-war*) assigned into the four groups (*glaberrima*, *sativa-indica*, *sativa-japonica* and farmer-hybrid) across settlements in four case-study chiefdoms, comparing post-war reported values with reference values (field measurements in 2007), and assessing reported (i.e. farmer-perceived) trends.

Annexes 1 – 3 provide details on the prevailing agro-ecological conditions, farming systems and common growing seasons.

Analysis

Our framework in this chapter is to look at patterns or trends across these three periods, backed by analysis that embodies simple anthropological tools of direct observation, supported by qualitative accounts from case studies, and in-depth individual and focus group interviews. The analysis incorporates ethno-history of agro-ecological and land use changes and data relating to socio-economic and cultural environments and micro-ecological niches.

The relevant data are presented in Tables 1 and 2 and Figures 1 to 35, and will be further described below. Also relevant to the subsequent discussion are Tables 3 (showing data profiles on varietal performance) and Tables 4, 5, 6, 7 and 8 (on rice seed acquisition dynamics by farmers from the pre-war period to 2007).

Farmers were asked (in 2007) to provide accounts of varieties grown at three periods - prewar, during the war and post war. Actual varieties grown by all farmers in six villages were collected and identified in 2007. Many were included in the molecular and morphological analyses to be described in chapters 4-6. Farmers' reported post-war rice plantings were compared with the actual plantings, as an end-line check on the farmer reports of changes. For one village it was also possible to compare farmer reported pre-war plantings with data gathered in 1983 and 1987 by Paul Richards (Richards 1986, 1995, and Mokuwa and Richards, in progress). These data are presented in Table 9.

Trends as based on farmer reports are visualized through sets of histograms showing the distribution of the three main rice groupings for which we have data (farmer hybrids, *glaberrima* and *sativa-indica* (the histograms for the villages in the centre of the country, where a lot of *sativa-japonicas* are grown have a fourth column as well). It is worth stressing here not to assume that the histograms show farmers to be exaggerating the numbers of varieties they have managed. Current reported varieties are well matched to varieties collected (Table 9). But count variables are not comparable across the five columns (broadly speaking farmers grow fewer varieties the further north they are located), so the figures have been turned to percentages. Trends are "eye-balled". It would be inappropriate to apply time-series statistical analysis, since strictly the data are not time series, but farmer recollections at a single point in time. The data can thus be summarized as farmer post-war perceptions of rice variety planting trends, with some ground-truthing based on baseline and endline data.

To repeat, the columns for 2007 are based on data from all farmers per village, and verified against an "endline" collection of all rices grown in 2007. This provides us with a secure picture of the actual pattern in 2007. Again, as noted above, these reports were cross-checked for one village in the centre of the country with reference to actual collections made in 1983 and 1987, as a measure of reliability of the recall data. Table 3 shows these data, and the farmer recalls are mainly consistent with actual base-line entries. It may be added that rice farming is of great importance to all villagers, and knowledge of varieties is high (Richards 1998). It is no surprise, therefore, to find that recalls (where we could check them) were largely accurate.

Variation over time in farmer seed selection in six case studied villages in four chiefdoms

Tables 1 to 9 and Figures 1 to 35 show estimates of rice varieties belonging to different botanical groups cultivated at different periods, according to farmers' memories on varietal losses across six villages in four selected chiefdoms in North and Southern Sierra Leone.

Based on per cent averages for Bumban, Kamba and Mayemberrie in the north, *glaberrima* remained quite significant but not dominant (pre-war 27.8 %, during war 26.0%, 2007 25.0%) apparently compensated by a steep rise in hybrids from 25.8% pre-war to 42.0% in 2007, with an initial rise to 30.7% during the war. *Indica* fell during the war from 46.4% to 33.0%, *indica* recovered slightly in the immediate post-war period to 46.9% perhaps due to arrival of seed aid from humanitarian organizations, then fell back to (a measured) 33.0% in 2007 (Table 1 and Figures 1 to 4). Estimated per cent averages for farmer hybrid losses (Table 2 and

Table 1: *Rice varieties belonging to different botanical groups cultivated pre to post-war in six villages from four chiefdom (Biriwa, Magbema, and Kamajei) KholifaRowalla*

		Region															
		1. North (n=121)								**2. South (n=166)**							
		Chiefdom						Per cent average for varieties belonging to the different rice types within period for northern region	Total count within rice type across villages within period	**Chiefdom**						Per cent average for varieties belonging to the different rice types within period for southern region	Total count within rice type across villages within period
		Biriwa		**Magbema**		**Kholifa Rowalla**				**Kamajei**							
		Bumban (n=48)		**Kamba** (n=35)		**Mayemberrie** (n=38)				**Mobai** (n=41)		**Mogbuama** (n=68)		**Jagbeima** (n=57)			
Period	Rice category	count	%	count	%	count	%			count	%	count	%	count	%		
Pre-war (1984-1988)-Reported	Hybrids	94	39.5	26	13.0	49	24.8	**25.8**	169	1	0.5	3	1.3	3	1.0	**1.0**	7
	Glab.	64	26.9	62	31.2	50	25.4	**27.8**	176	0	0.0	1	0.4	6	2.0	**0.8**	7
	Ind.	80	33.6	111	55.8	98	49.8	**46.4**	289	103	53.4	105	46.1	203	67.7	**55.7**	411
	Jap.	0	0.0	0	0.0	0	0.0	**0.0**	0	89	46.1	119	52.2	88	29.3	**42.5**	296
	Total	**238**		**199**		**197**			**634**	**193**		**228**		**300**			**721**
During war (1989-2000)-Reported	Hybrids	115	51.1	22	12.0	50	28.3	**30.7**	187	1	0.6	3	1.5	0	0.0	**0.7**	4
	Glab.	53	23.6	31	18.0	65	36.7	**26.0**	149	2	1.2	1	0.5	1	0.3	**0.7**	4
	Ind.	57	25.3	121	70.0	62	35.0	**43.3**	240	79	48.2	77	37.5	164	54.7	**46.8**	320
	Jap.	0	0.0	0	0.0	0	0.0	**0.0**	0	82	50.0	124	60.5	135	45.0	**51.8**	341
	Total	**225**		**174**		**177**			**576**	**164**		**205**		**300**			**669**
Post-war (2001-2)-Reported	Hybrids	115	50.4	31	14.4	50	23.2	**29.3**	196	2	1.0	12	4.9	2	0.5	**2.1**	16
	Glab.	54	23.7	34	15.8	69	31.9	**23.8**	157	3	1.5	1	0.4	1	0.2	**0.7**	5
	Ind.	59	25.9	150	69.8	97	44.9	**46.9**	306	87	44.4	97	39.4	237	56.0	**46.6**	421
	Jap.	0	0.0	0	0.0	0	0.0	**0.0**	0	104	53.1	136	55.3	183	43.3	**50.5**	423
	Total	**228**	**100.0**	**215**		**216**			**659**	**196**		**246**		**423**			**865**
Reference (2007)-Measured	Hybrids	48	60.8	31	39.7	24	25.0	**42.0**	103	1	0.8	10	5.2	2	1.0	**2.3**	13
	Glab.	22	27.8	6	7.7	38	39.6	**25.0**	66	0	0.0	5	2.6	0	0.0	**0.9**	5
	Ind.	9	11.4	41	52.6	34	35.4	**33.0**	84	53	41.7	60	31.1	111	54.1	**42.3**	224
	Jap.	0	0.0	0	0.0	0	0.0	**0.0**	0	73	57.5	118	61.1	92	44.9	**54.5**	283
	Total	**79**		**78**		**96**			**253**	**127**		**193**		**205**			**525**

Table 2: *Rice varieties belonging to the different botanical groups claimed missing in six villages in four chiefdoms (Biriwa, Magbema, Kholifa Rowalla and Kamajei)*

Region															
1. North (n=121)								2. South (n=166)							
Chiefdom						Per cent averages for varieties belonging to the different rice categories claimed missing within northern region	Total count within rice type across villages	Chiefdom						Per cent averages for varieties belonging to the different rice categories claimed missing within southern region	Total count within rice type across villages
Biriwa		Magbema		Kholifa Rowalla				Kamajei							
Bumban (n=48)		Kamba (n=35)		Mayemberrie (n=38)				Mobai (n=41)		Mogbuama (n=68)		Jagbeima (n=57)			
count	%	count	%	count	%			count	%	count	%	count	%		
6	7.6	8	7.0	8	6.1	**7.0**	22	0	0.0	1	0.6	5	2.4	**1.0**	6
34	43.0	50	45.0	18	13.9	**34.0**	102	3	2.2	0	0.0	4	2.0	**1.4**	7
39	49.4	54	48.0	104	80.0	**59.0**	197	103	74.1	111	67.3	139	67.1	**69.5**	353
-	-	-	-	-	-	-	-	33	23.7	53	32.1	59	28.5	**28.1**	145
79		**112**		**130**			**321**	**139**		**165**		**207**			**511**

Figure 5) were lower (7.0%) than reported average *glaberrima* losses (34.0%) and reported average *indica* losses (59.0%), implying that for Biriwa, Magbema and Kholifa Rowalla Chiefdoms in the Northern region, farmer hybrids increased in significance while *glaberrimas* remained significant but not dominant.

For Mobai, Mogbuama and Jagbeima in the South (Table 1 and Figures 1 to 5), per cent averages for *indicas* appeared to be in decline, and *japonicas* became increasingly dominant. *Indicas* (55.7%, pre-war) accounted for only 42.3% of post-war farmer rice plantings. Hybrids seemed to be on the rise but are not (yet?) sown in significant amounts across all three villages taken together. Hybrids (1.0% pre-war) accounted for 2.3% of farmer rice plantings post-war. *Glaberrimas* remained very low but constant across the period (around 1.0%), and per cent losses for *japonica* (Table 2 and Figure 5) were lower (28.1%) than reported *indica* losses (69.5%), further suggesting that *japonicas* increased in significance and that the fall in the planting of *indica* types during the war was quite marked.

Accuracy of farmer recall evidence assessed by comparing recall data with survey collection data for all upland rice farms 2007

Accuracy of farmer recall evidence is estimated by comparing post-war recall data with survey collection data for all upland rice farms in the six case study villages in 2007-2008. The aggregate figure shown is the rate of turn-over for that particular village.

(i). In Bumban (Figures 6 to 9), indicas appeared to be in decline, and farmer hybrids became increasingly dominant. Hybrids (40.0% pre-war) now accounted for 61.0% of farmer rice plantings. Indica (34.0% pre-war) now accounted for only 11.0% of farmer rice plantings in 2007. Glaberrima remains significant but is not dominant (pre-war 27.0%, 2007 28.0%), and reported hybrid losses (Figure 10) were lower (8.0%) than reported glaberrima losses (43.0%) and reported indica losses (49.0%), all implying that farmer hybrids seemed to have been strongly established in Bumban before the war, and became of markedly rising significance (and dominant in fact). Glaberrimas remained significant but not dominant. Fall in indicas during the war was also quite marked in Bumban. The proximity and existence of the weekly market outlets “loomah” in the chiefdom suggests that farmers are producing some of these hybrids for marketing.

Figure 1: *Hybrids cultivated at different periods in six village case studies from 4 Chiefdoms in Sierra Leone*

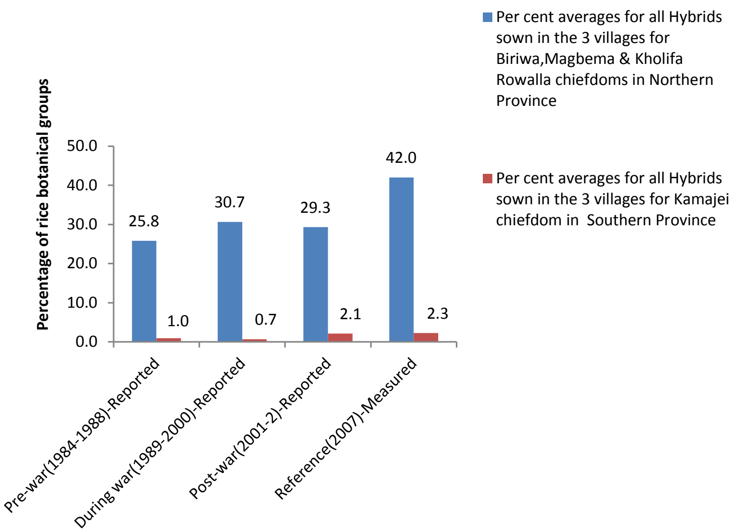


Figure 2: *Per cent averages for the Glaberrimas cultivated at different periods in six village case studies from 4 Chiefdoms in Sierra Leone*

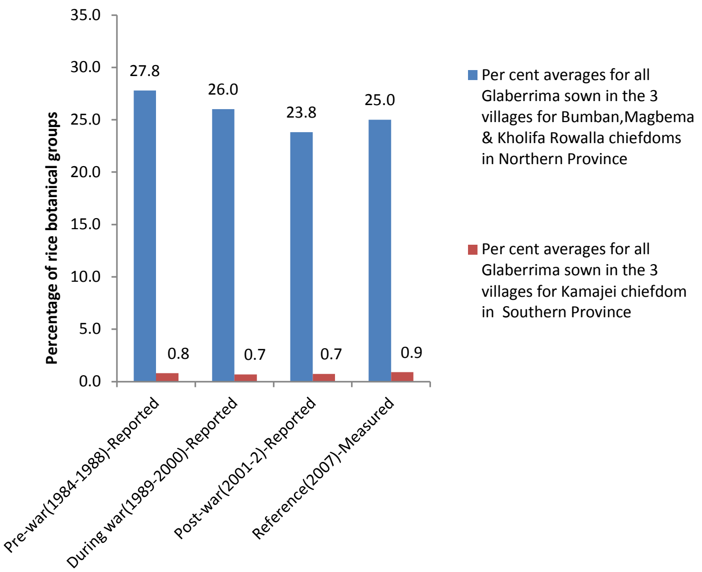


Figure 3: *Per cent averages for the Indicas cultivated at different periods in six village case studies from 4 Chiefdoms in Sierra Leone*

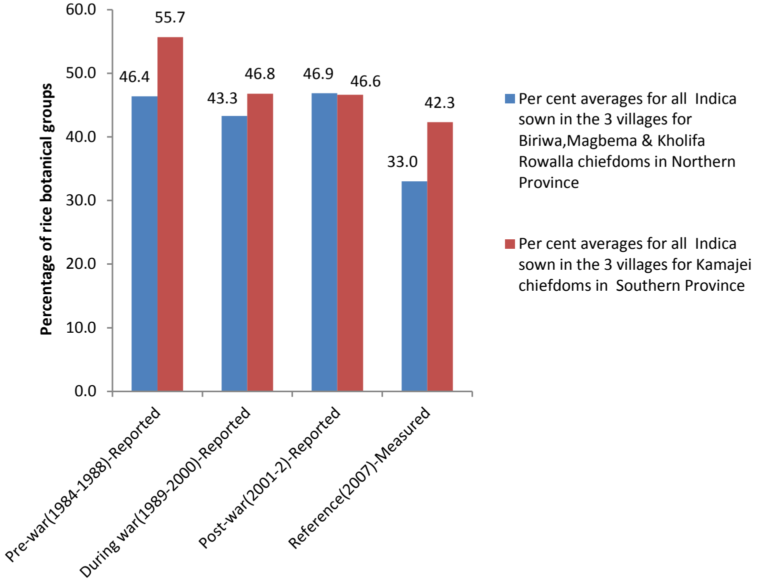


Figure 4: *Per cent averages for the Japonicas cultivated at different periods in six village case studies from 4 Chiefdoms in Sierra Leone*

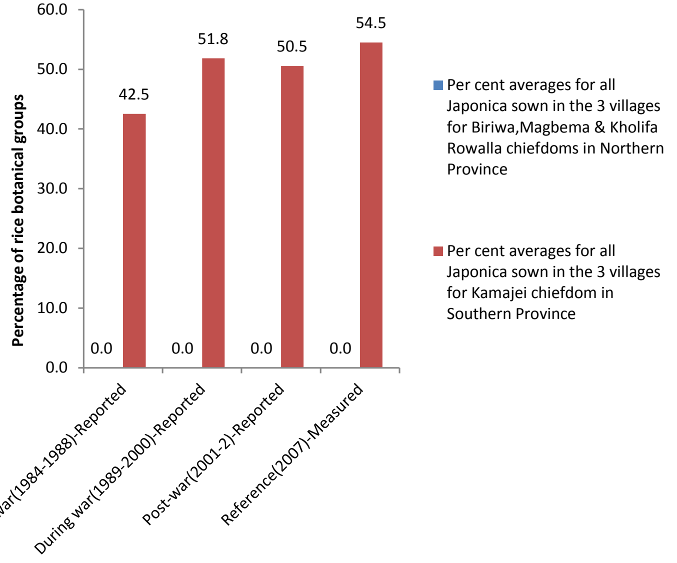


Figure 5: *Per cent average losses for rice varieties belonging to the different rice botanical groups in 6 villagse in four core chiefdom-level case study*

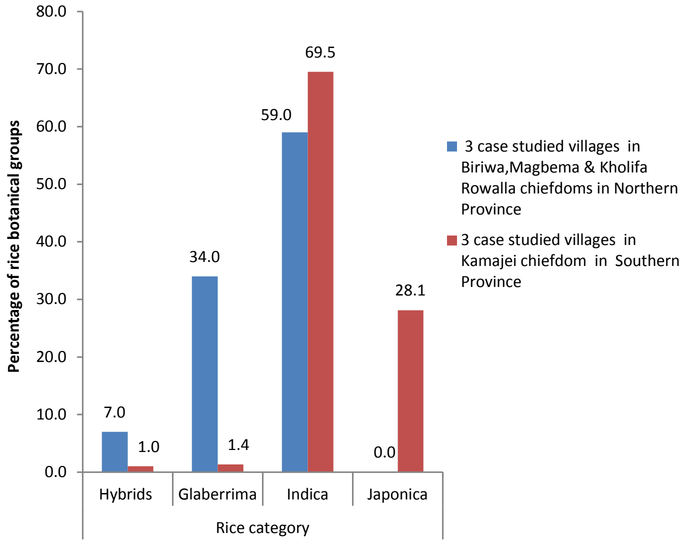


Figure 6: *Rice varieties belonging to different botanical groups cultivated at pre to post-war by farmers in Bumban*

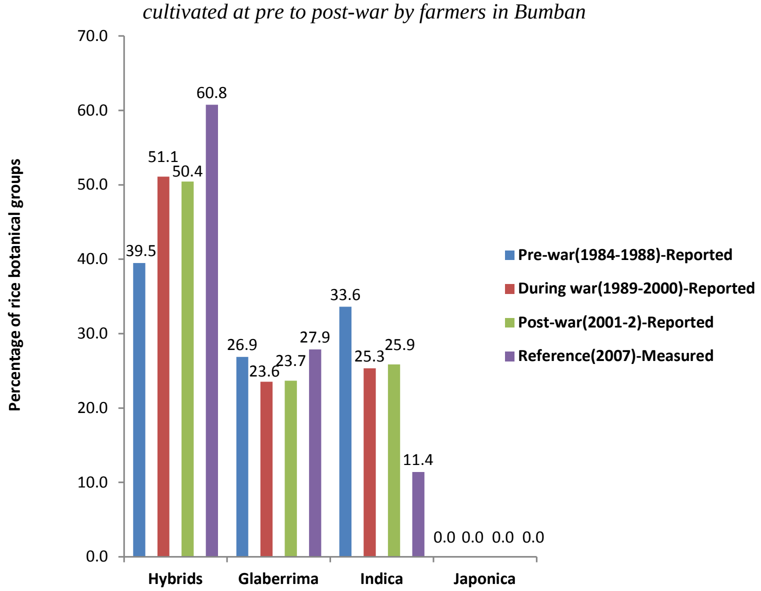


Figure 7: *Rice varieties belonging to Hybrids group cultivated at pre to post-war by farmers in Bumban*

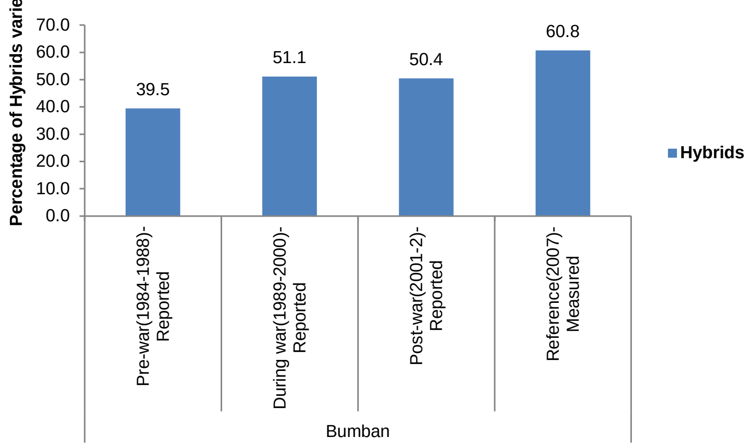


Figure 8: *Rice varieties belonging to the Glaberrima group cultivated at pre to post-war by farmers in Bumban*

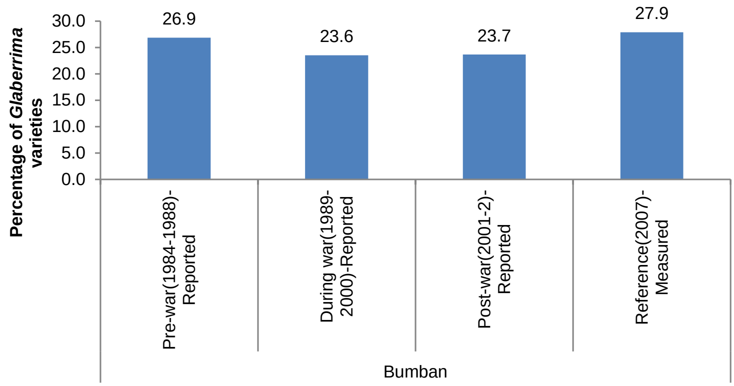


Figure 9: *Rice varieties belonging to the Indica group cultivated at pre to post-war by farmers in Bumban*

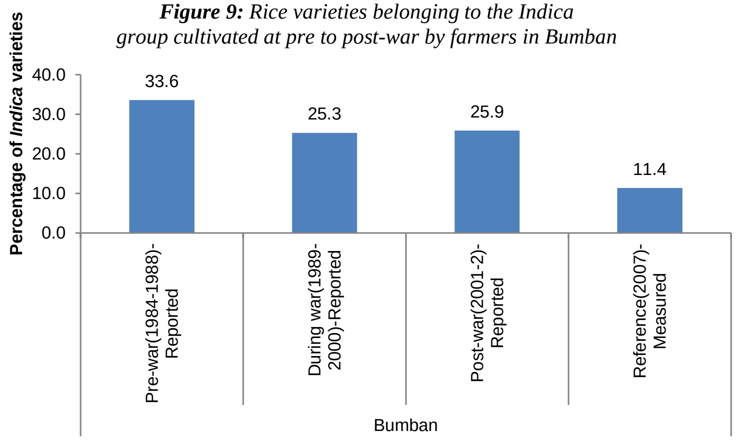
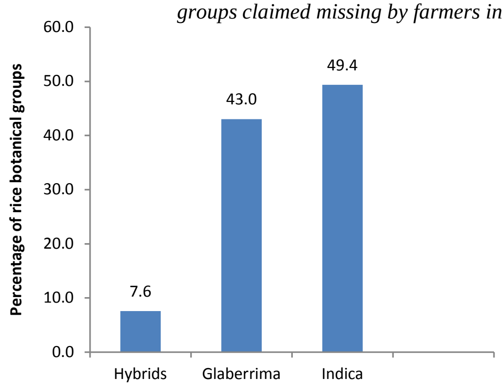


Figure 10: *Per cent rice varieties belonging to the different botanical groups claimed missing by farmers in Bumban*



(ii). In **Kamba** (Figures 11 to 14), indica was still important (2007 53.0%, pre-war 56.0%). But glaberrima was in steep decline (from 31.0% to 8.0%) apparently compensated by a steep rise in farmer hybrids (from 13.1% to 40.0%). Reported hybrid losses (Figure 15) were lower (7.1%) than reported glaberrima losses (45.0%) and reported indica losses (48.2%), implying that the farmer hybrids were markedly rising in Kamba. The peaking of farmer hybrids in the immediate post-war period is also worth noting. Notwithstanding the strong influence of the Rice Research Station in pre-war recovery of indicas in this region the continued decline in indica is also worth noting. As in Bumban, farmers in Kamba also sell some of their upland rice in local markets. In the past the main varieties offered for sale will have been indica types. The decline of indica and rise of farmer hybrids strongly suggests that farmers in Kamba (close to an imporant regional market at Barmoi) are producing (some) farmer hybrids formarket sales.

Figure 11: *Rice varieties belonging to different botanical groups cultivated at pre to post-war by farmers in Kamba*

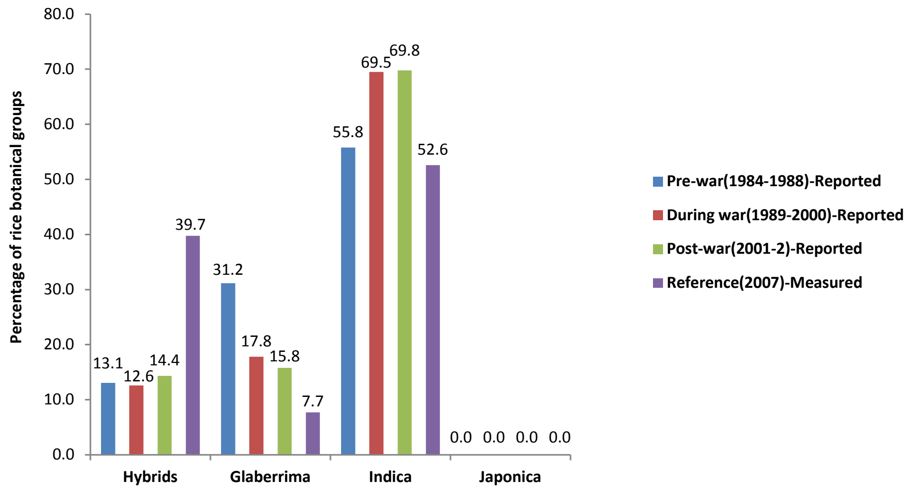


Figure 12: *Rice varieties belonging to the Hybrids group cultivated at pre to post-war by farmers in Kamba*

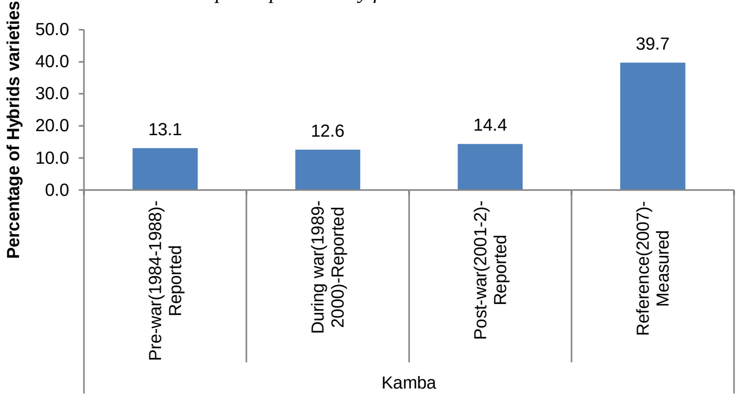


Figure 13: *Rice varieties belonging to the Glaberrima group cultivated at pre to post-war by farmers in Kamba*

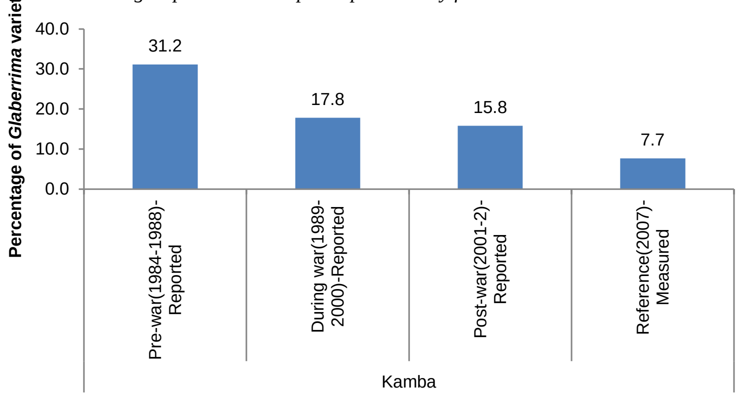


Figure 14: *Rice varieties belonging to the Indica group cultivated at pre to post-war by farmers in Kamba*

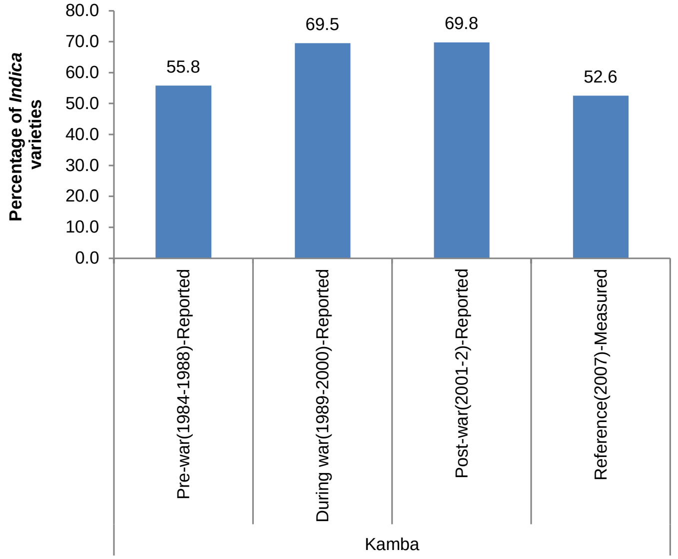
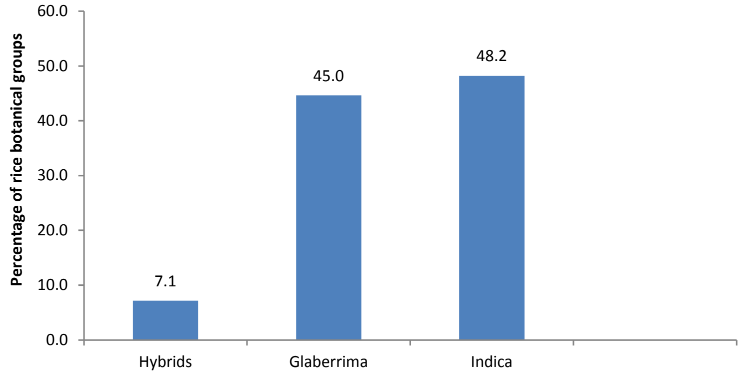


Figure 15: *Rice varieties belonging to the different botanical groups claimed missing by farmers in Kamba*



(iii). **Mayemberrie** (Figures 16 to 18) was perhaps most heavily impacted by the war, since it was under RUF occupation for several years from 1998. Glaberrima appeared to have increased from 25.4% pre-war to 40.0% in 2007, with an initial rise to 37.0% during the war. Indica fell during the war from 50.0% to 35.4%, recovered slightly in the immediate post-war period to 45.0% (perhaps) due to arrival of seed aid from humanitarian organizations, and then fell back to a measured 35.4% in 2007. Hybrids remained more or less constant across the period at about 25.0%, and reported hybrids losses (Figure 19) were lower (6.2%) than reported glaberrima losses (14.0%), and reported indica losses (80.0%), all indicating that in Mayemberrie glaberrimas increased in significance, and that the peaking of glaberrimas during the war in Mayemberrie is worth noting. People reported that they had to stay close to the village for security and farmed old and exhausted plots, on which only glaberrima would grow. The hybrids were markedly of an intermediate but stable significance. The fall in indicas during the war was also quite marked. Apart from some post-war recovery of indicas in Mayemberrie the trend is probably related to the security situation in an occupied zone.

Figure 16: *Rice varieties belonging to different botanical groups cultivated at pre to post-war by farmers in Mayemberrie*

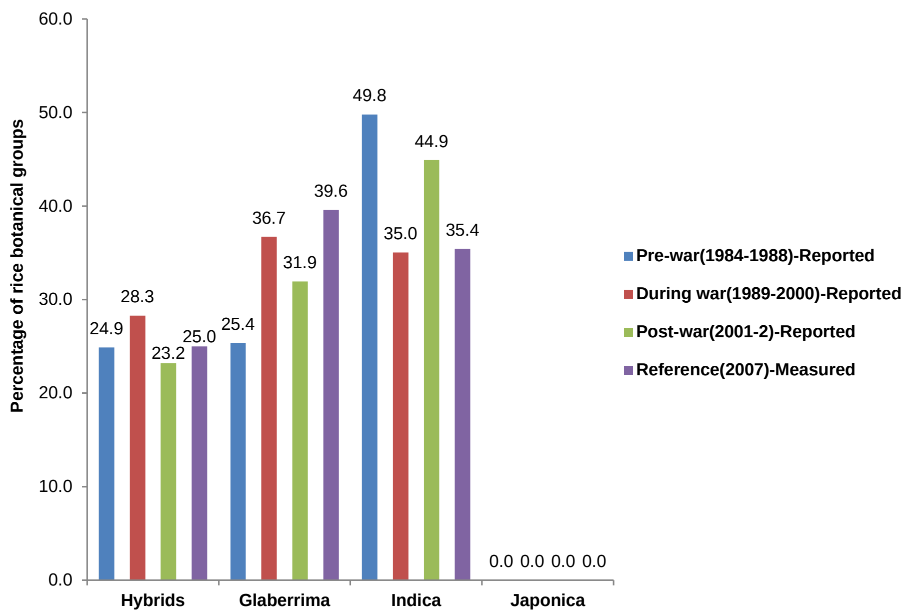


Figure 17: *Rice varieties belonging to the Hybrids group cultivated at pre to post-war by farmers in Mayemberrie*

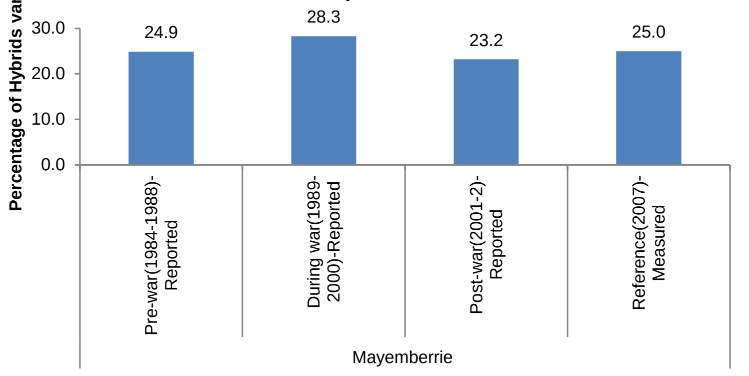


Figure 18: *Rice varieties belonging to the Indica group cultivated at pre to post-war by farmers in Mayemberrie*

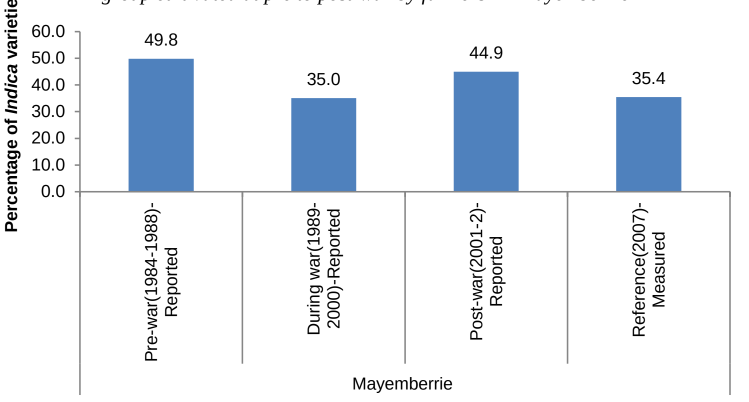
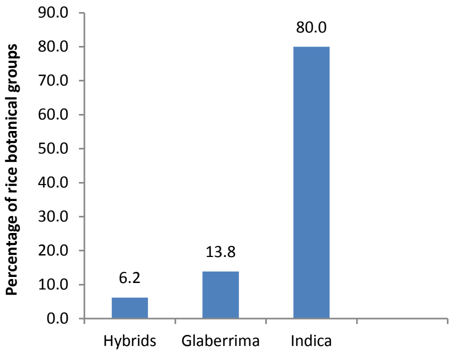


Figure 19: *Per cent rice varieties belonging to the different botanical groups claimed missing by farmers in Mayemberrie*



(iv). In **Mobai** (Figures 20 to 23) japonicas appeared to have increased from 46.1% pre-war to 57.5% in 2007, with an initial rise from 50.0% during the war but peaking slightly in the immediate post-war period to 53.1%. Indica (53.4% pre-war) accounted for only 42.0% of farmer rice plantings in 2007. Like the hybrids, glaberrima remained of low significance (1.2%) during the war, and this continued (2.0%) in the immediate post-war period. Farmer hybrids also remained low across the period at around 1.0%. Reported glaberrima losses (Figure 24) were lower (2.2%) than reported japonica (24.0%) and indica (74.1%) losses, implying that japonicas increased in significance and indicas were significant but not dominant.

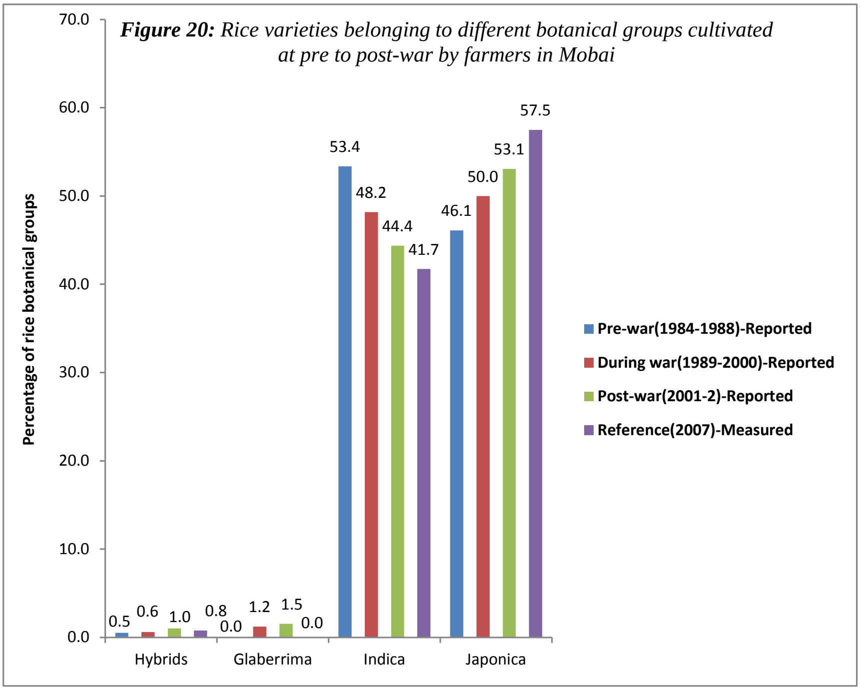


Figure 20: *Rice varieties belonging to different botanical groups cultivated at pre to post-war by farmers in Mobai*

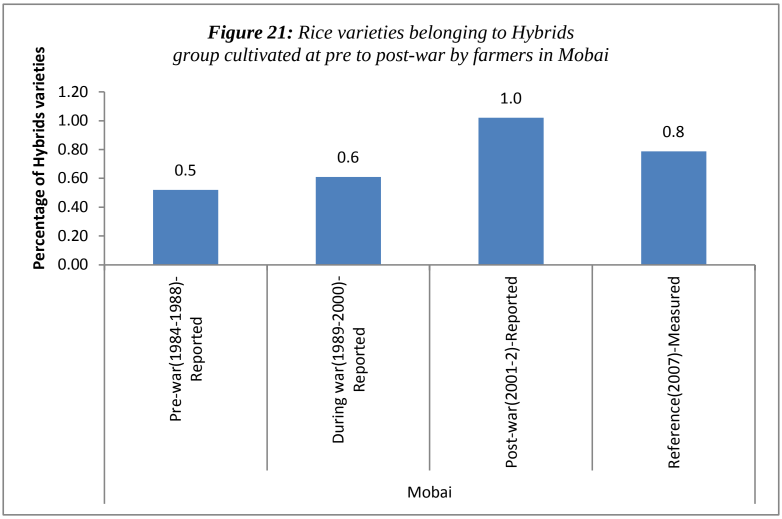


Figure 21: *Rice varieties belonging to Hybrids group cultivated at pre to post-war by farmers in Mobai*

Figure 22: *Rice varieties belonging to Glaberrima group cultivated at pre to post-war by farmers in Mobai*

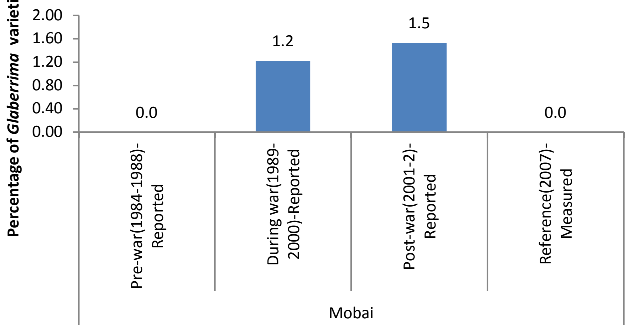


Figure 23: *Rice varieties belonging to Indica group cultivated at pre to post-war by farmers in Mobai*

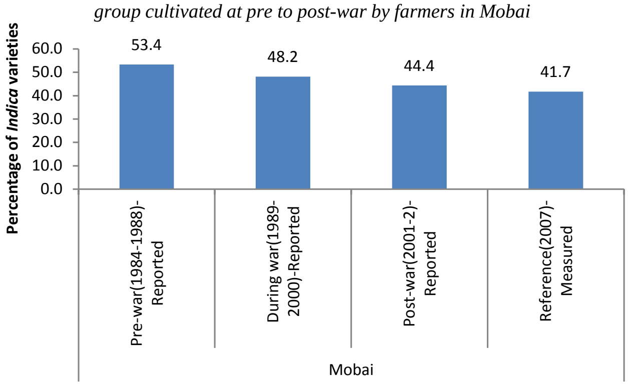
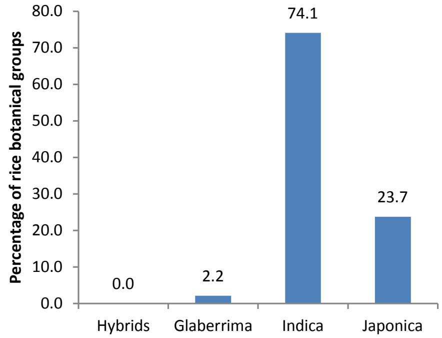


Figure 24: *Rice varieties belonging to the different botanical groups claimed missing by farmers in Mobai*



(v). In **Mogbuama** (Figures 25 to 29), *japonica* was still important (2007 61.1%, pre-war 52.2%). *Indica* remained significant but not dominant (46.1% pre-war, post-war accounting for only 31.1% of farmer rice holdings). *Glaberrima* was in steep decline and remained less significant (from 0.4% pre-war to 3.0% 2007), hybrids remained more or less constant across the periods (2007 5.2%, pre-war 1.3%), and reported hybrids losses (Figure 30) were lower (1.0%) than reported *japonica* (32.1%) and *indica* (67.3%) losses, further implying that *japonicas* seemed to have been strongly established in Mogbuama before the war, of markedly rising significance, meaning that in Mogbuama *indicas* remained markedly significant but not dominant, that the fall in *indicas* during the war is worth noting.

Figure 25: *Rice varieties belonging to different botanical groups cultivated at pre to post-war by farmers in Mogbuama*

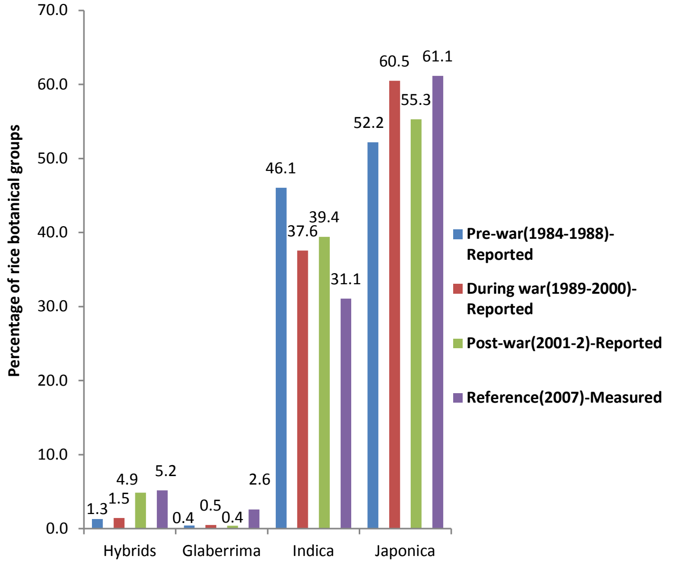


Figure 26: *Rice varieties belonging to Hybrids group cultivated at pre to post-war by farmers in Mogbuama*

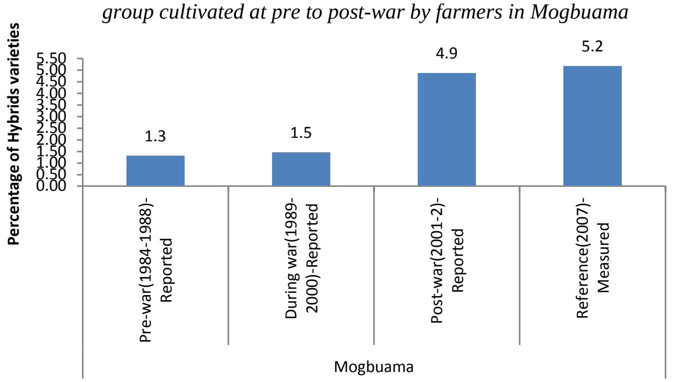
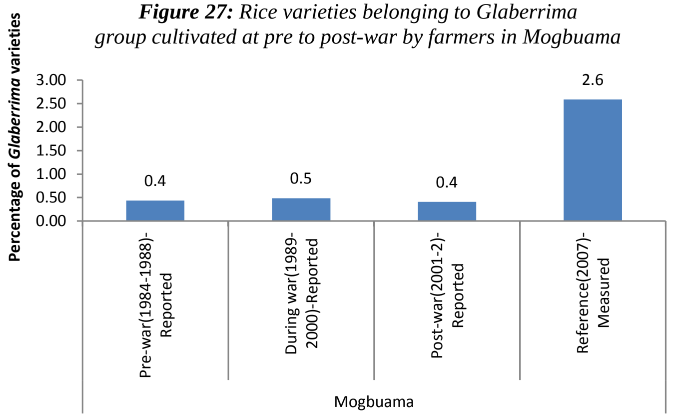


Figure 27: *Rice varieties belonging to Glaberrima group cultivated at pre to post-war by farmers in Mogbuama*



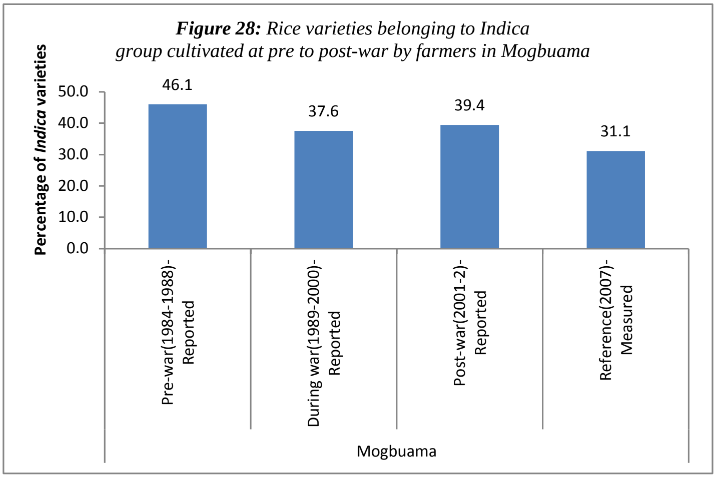


Figure 28: Rice varieties belonging to Indica group cultivated at pre to post-war by farmers in Mogbuama
Percentage of Indica varieties
50.0
40.0
30.0
20.0
10.0
0.0
46.1
37.6
39.4
31.1
Pre-war(1984-1988)-Reported
During war(1989-2000)-Reported
Post-war(2001-2)-Reported
Reference(2007)-Measured
Mogbuama

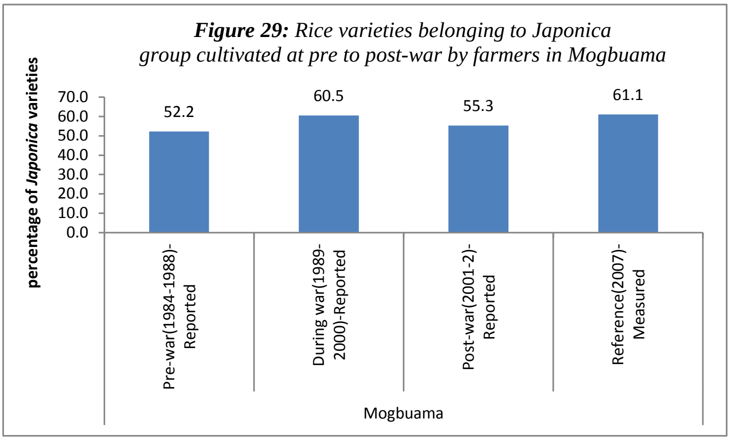
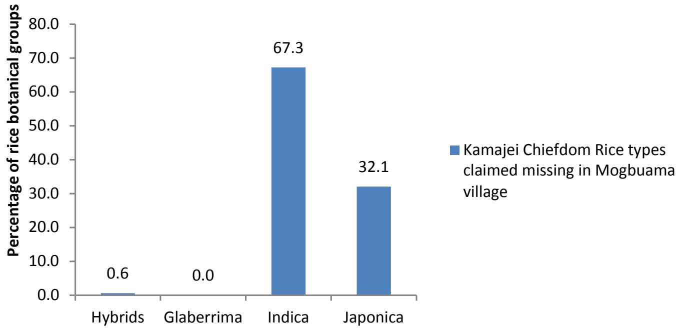


Figure 29: Rice varieties belonging to Japonica group cultivated at pre to post-war by farmers in Mogbuama
percentage of Japonica varieties
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
52.2
60.5
55.3
61.1
Pre-war(1984-1988)-Reported
During war(1989-2000)-Reported
Post-war(2001-2)-Reported
Reference(2007)-Measured
Mogbuama

Figure 30: *Rice varieties belonging to the different botanical groups claimed missing by farmers in Mogbuama*



(vi). In **Jagbeima** (Figures 31 to 34), japonica appeared to have increased from 29.3% pre-war to 45.0% in 2007, with an initial rise to 45.0% during the war. Indica fell during the war from 68.0% to 54.7%, but recovered slightly in the immediate post-war period to 56.0%, perhaps due to arrival of seed aid from humanitarian organizations, then falling back to a measured 54.2% in 2007. Hybrids and glaberrimas remained more or less constant across the period at around 1.0%, and remained insignificant; reported hybrid and glaberrima losses (Figure 35) were also lower (2.0%) than reported japonica (29.0%) and indica (67.1%) losses, indicating that japonicas increased in significance and indicas were somewhat significant but not dominant. The fall in indicas reported during the war was also quite evident.

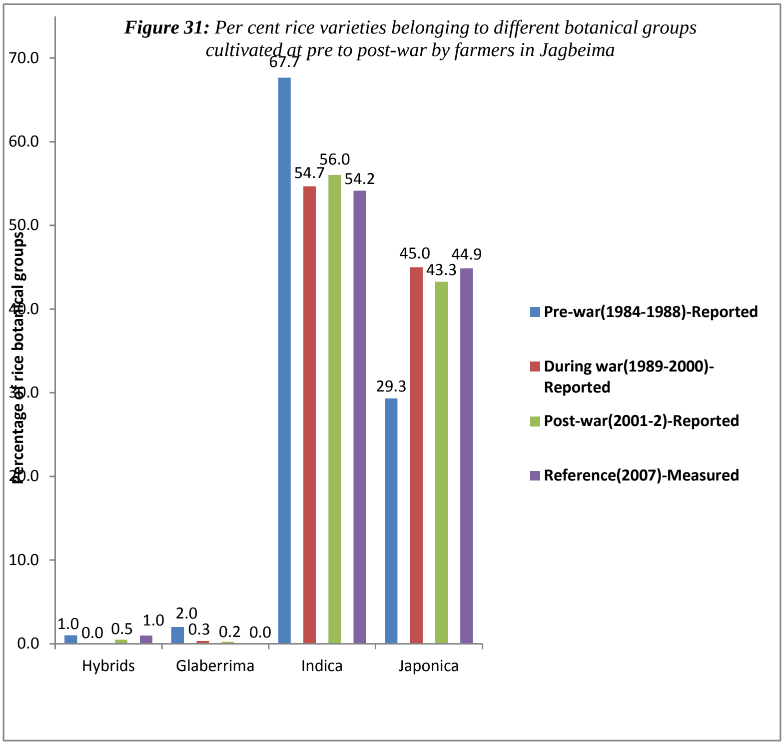


Figure 31: *Per cent rice varieties belonging to different botanical groups cultivated at pre to post-war by farmers in Jagbeima*

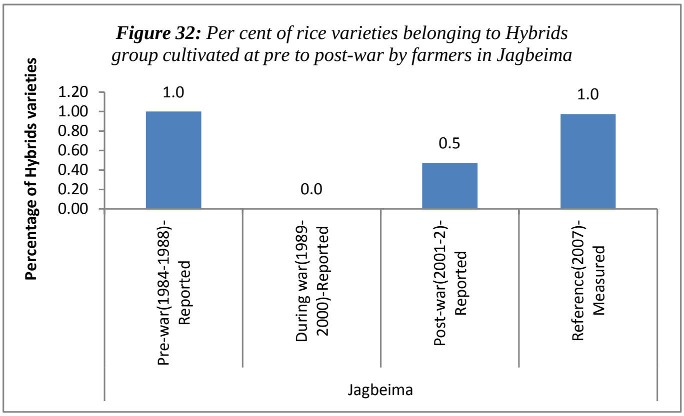


Figure 32: *Per cent of rice varieties belonging to Hybrids group cultivated at pre to post-war by farmers in Jagbeima*

Figure 33: *Per cent of rice varieties belonging to Glaberrima group cultivated at pre to post-war by farmers in Jagbeima*

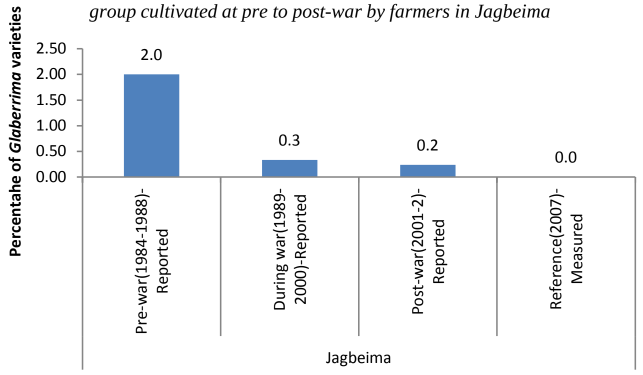


Figure 34: *Per cent of rice varieties belonging to Indica group cultivated at pre to post-war by farmers in Jagbeima*

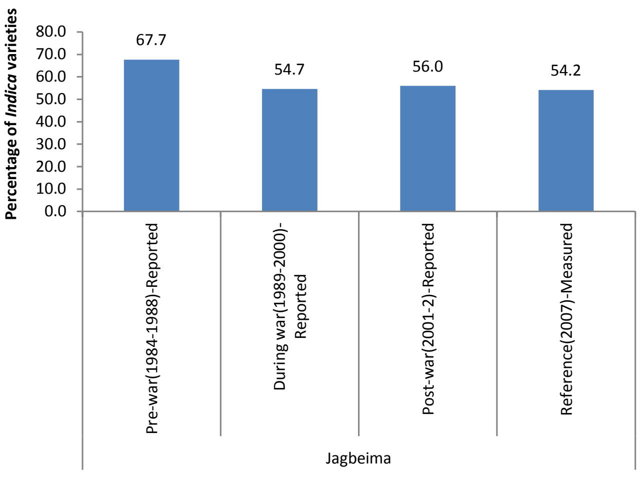


Figure 35: *Per cent rice varieties belonging to the different botanical groups claimed missing by farmers in Jagbeima*

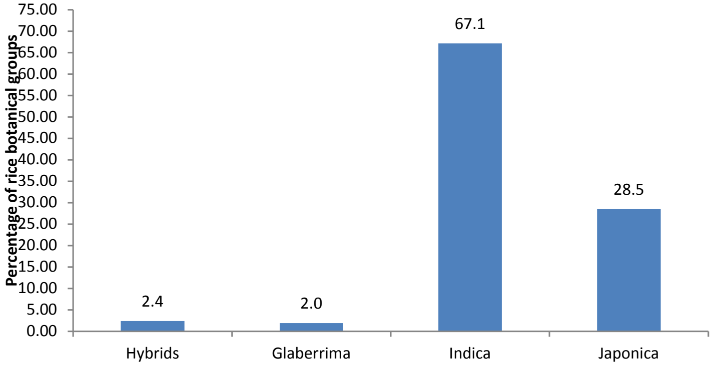


Table 3: *Rice varieties sown: regional variations at different periods*

Species	Region	Pre-war	During war	(%)Pre-war profile represented among key components used during war (n=137)	Immediate post-war	(%)Pre-war profile represented among key components used during immediate post-war (n=158)	2007_2008 cropping season	(%)Pre-war profile represented among key components sown in 2007-2008 season (n=104)
Hybrids	North	3	3	2.1	3	1.9	3	2.9
	South	3	1	0.7	2	1.3	2	1.9
	Total	6	4	2.8	5	3.2	5	4.8
Oryza glaberrima	North	17	14	10.2	13	8.2	6	5.8
	South	3	1	0.7	1	0.6	1	0.9
	Total	20	15	10.9	14	8.8	7	6.7
Oryza sativa indica	North	64	31	22.6	35	22.1	14	13.5
	South	43	32	23.4	19	12.0	23	22.1
	Total	107	63	46.0	54	34.2	37	35.6
Oryza sativa japonica	North	0	0	0.0	0	0.0	0	0.0
	South	22	21	15.3	21	13.3	21	20.2
	Total	22	21	15.3	21	13.3	21	20.2
TOTAL		155	103	75.0	94	59.5	70	67.3

Table 4: *Process of seed distribution, average of all reported periods, Northern Province*

Process	Village			Total	%Total
	Bumban	Kamba	Mayemberrie		
Barter wise	22	30	25	77	30.5
Purchase	18	30	26	74	29.4
Gifting	7	7	2	16	6.3
(Seed)Rehabilitation	1	0	0	1	0.4
Seed loan	9	3	22	34	13.5
Reward	4	0	2	6	2.4
Non-specific	18	9	17	44	17.5
Total	79	79	94	252	100.0

Table 4.1: *Chi-Square Tests*

SPECIES		Value	df	Asymp. Sig. (2-sided)
Hybrid	Pearson Chi-Square	46.545	25	0.006
	Likelihood Ratio	38.712	25	0.039
	N of Valid Cases	116		
Indica	Pearson Chi-Square	130.075	35	0.000
	Likelihood Ratio	121.242	35	0.000
	N of Valid Cases	302		
Japonica	Pearson Chi-Square	59.309	12	0.000
	Likelihood Ratio	64.784	12	0.000
	N of Valid Cases	284		
Glaberrima	Pearson Chi-Square	23.226	18	0.182
	Likelihood Ratio	26.166	18	0.096
	N of Valid Cases	68		
Total	Pearson Chi-Square	236.511	35	0.000
	Likelihood Ratio	229.981	35	0.000

Table 5: *Process of seed distribution , average of all reported periods, Southern Province*

Process	Village			Total	%Total
	Mobai	Mogbuama	Jagbeima		
Barter wise	24	27	27	78	15.1
Purchase	54	50	25	129	24.9
Gifting	20	32	33	85	16.4
(seed)Rehabilitation	1	12	4	17	3.3
Seed loan	0	15	2	17	3.3
Reward	2	6	2	10	1.9
Non-specific	24	46	112	182	35.1
Total	125	188	205	518	100

Table 5.1: *Chi-Square Tests*

SPECIES		Value	df	Asymp. Sig. (2-sided)
Hybrid	Pearson Chi-Square	46.545	25	0.006
	Likelihood Ratio	38.712	25	0.039
	N of Valid Cases	116		
Indica	Pearson Chi-Square	130.075	35	0.000
	Likelihood Ratio	121.242	35	0.000
	N of Valid Cases	302		
Japonica	Pearson Chi-Square	59.309	12	0.000
	Likelihood Ratio	64.784	12	0.000
	N of Valid Cases	284		
Glaberrima	Pearson Chi-Square	23.226	18	0.182
	Likelihood Ratio	26.166	18	0.096
	N of Valid Cases	68		
Total	Pearson Chi-Square	236.511	35	0.000
	Likelihood Ratio	229.981	35	0.000
	N of Valid Cases	770		

Table 6: *Process of seed distribution, measured, for 2007*

	Village							
Process	Bumban	Jagbeima	Kamba	Mayemberrie	Mobai	Mogbuama	Total	%Total
Barter wise	21	54	10	18	20	30	153	19.9
Perchase	20	31	19	23	57	46	196	25.5
Gifting	32	110	50	31	45	83	351	45.6
(Seed)Rehabilitation	0	8	0	2	0	6	16	2.0
Seed loan	5	2	0	20	3	19	49	6.4
Other means	1	0	0	0	0	4	5	0.6
Total	79	205	79	94	125	188	770	

Table 6.1: *Chi-Square Tests*

SPECIES		Value	df	Asymp. Sig. (2-sided)
Hybrid	Pearson Chi-Square	33.975	15	0.003
	Likelihood Ratio	33.626	15	0.004
	N of Valid Cases	116		
Indica	Pearson Chi-Square	87.248	25	0.000
	Likelihood Ratio	79.133	25	0.000
	N of Valid Cases	302		
Japonica	Pearson Chi-Square	32.632	10	0.000
	Likelihood Ratio	37.893	10	0.000
	N of Valid Cases	284		
Glaberrima	Pearson Chi-Square	15.947	12	0.194
	Likelihood Ratio	12.158	12	0.433
	N of Valid Cases	68		
Total	Pearson Chi-Square	128.784	25	0.000
	Likelihood Ratio	129.968	25	0.000
	N of Valid Cases	770		

Table 7: *Farmers' seed source for 2007 in three villages in Northern Province (measured)*

Source	Village Bumban	Kamba	Mayemberrie	Total	%Total
Institution	0	0	1	1	0.4
Farmer to-Farmer	8	26	17	51	20.2
Kinship	71	52	66	189	75.0
Trader&\ or Seed Vendor	0	1	10	11	4.4
Total	79	79	94	252	

Table 7.1: *Chi-Square Tests*

SPECIES		Value	df	Asymp. Sig. (2-sided)
Hybrid	Pearson Chi-Square	36.691	10	0.000
	Likelihood Ratio	25.392	10	0.005
	N of Valid Cases	116		
Indica	Pearson Chi-Square	43.496	15	0.000
	Likelihood Ratio	45.712	15	0.000
	N of Valid Cases	302		
Japonica	Pearson Chi-Square	32.098	6	0.000
	Likelihood Ratio	36.991	6	0.000
	N of Valid Cases	284		
Glaberrima	Pearson Chi-Square	25.134	9	0.003
	Likelihood Ratio	18.594	9	0.029
	N of Valid Cases	68		
Total	Pearson Chi-Square	103.092	15	0.000
	Likelihood Ratio	122.492	15	0.000
	N of Valid Cases	770		

Table 8: *Farmers' seeds source for 2007 Agricultural Year in three villages in Southern Province (measured)*

Source	Village: Mobai	Mogbuama	Jagbeima	Total	%Total
Institution/Relief supply	0	12	11	23	4.0
Farmer to-Farmer	33	40	14	87	17.0
Kinship	62	110	157	329	64.0
Trader&\ or Seed Vendor	30	26	23	79	15.0
Total	125	188	205	518	

Table 8.1: *Chi-Square Tests*

SPECIES		Value	df	Asymp. Sig. (2-sided)
Hybrid	Pearson Chi-Square	36.691	10	0.000
	Likelihood Ratio	25.392	10	0.005
	N of Valid Cases	116		
Indica	Pearson Chi-Square	43.496	15	0.000
	Likelihood Ratio	45.712	15	0.000
	N of Valid Cases	302		
Japonica	Pearson Chi-Square	32.098	6	0.000
	Likelihood Ratio	36.991	6	0.000
	N of Valid Cases	284		
Glaberrima	Pearson Chi-Square	25.134	9	0.003
	Likelihood Ratio	18.594	9	0.029
	N of Valid Cases	68		
Total	Pearson Chi-Square	103.092	15	0.000
	Likelihood Ratio	122.492	15	0.000
	N of Valid Cases	770		

Accuracy of farmer recall for "pre-war" assessed by comparing with survey data, for Mogbuama, 1983 and 1987

Data were classed as "incompatible" where a variety was surveyed in 1983 or 1987 and was not recalled for the pre-war period by farmers in 2007, or where a variety was recalled by farmers in 2007 but was not found in the 1983 and 1987 survey data sets for rices in Mogbuama. It follows that data were classed as ”compatible” when the same variety was found in both data sets.

Column A in Table 9 provides the variety count. There were 61 varieties in all. As much as 61 per cent of varieties were judged "incompatible" when reports are compared with the actual baseline. However, many of the varieties classed "incompatible" were singleton varieties, or varieties grown by very few farmers. It is understandable that a large number of singleton varieties will have been misreported.

Columns B and C in Table 9 show the "compatible" and "incompatible" data when weighted by the numbers of farmers growing the variety in question. Here, incompatibility drops sharply to 27.0% and 22.0%, depending on whether the anomaly (non-occurrence) is found in the survey data (actual) or in the farmer reported data sets.

Table 9: *Rice varieties in Mogbuama, based on survey data 1983 (Richards 1986) and 1987 (Richards 1995), and farmer estimates in 2007 of planting choices before the civil war*

	(A) variety count	(B) farmer actual	(C) farmer report	A + B
incompatible actual/reports	37 (61.0%)	45 (27.0%)	42 (22.0%)	82 (23.0%)
compatible actual/reports	24 (39.0%)	120 (73.0%)	150 (78.0%)	270 (77.0%)
TOTAL	61 (100.0%)	165 (100.0%)	192 (100.0%)	352 (100.0%)

In fact only one large anomaly was found. Sixteen Mogbuama farmers claimed to have grown a variety known as giligoti before the war, but no records were found for this variety in the two survey data sets. If this variety was earlier known by a different name we would expect a matching anomaly, i.e. a variety in the surveyed data set but not recalled in 2007. Another possibility is that the variety was, indeed grown "pre-war" but not in the two base-line survey years (1983 and 1987). The war only began in 1991.

In all, about three-quarters of all farmer 2007 reports were compatible with data in the 1983 and 1987 survey data sets. This shows an impressive accuracy of recall over 20-25 years. It shows how well farmers know and remember their local rice varieties, and also gives us some confidence that those parts of the 2007 recall data set without pre-war "ground-truthing" can be regarded as giving a plausibly accurate picture of actual trends in farmer rice variety use in war-affected Sierra Leone. (NB: this section is drawn from a paper in preparation by Mokuwa and Richards).

Discussion

No evidences in farmer perceptions of a sharp drop in available varieties during the war

Taken in aggregate the four chiefdoms did not show evidence of a sharp drop in available varieties during the war. Caution should be exercised in extending this generalization to all 149 chiefdoms of the country since war effects vary. Care was taken in the choice of research sites to ensure a reasonable range of war impacts in terms of length of period of insecurity. Villages in the southern Province had only short periods of insecurity. One of the villages (Mayembere) in Northern Province was under rebel occupation for several years. Results are only applicable to the farming systems, communities and environments as defined and described in this study for the four chiefdoms.

When data for the period 1983 to 2013 based on measured changes are taken into account some extinction, and adoption of novelties resulting from long term processes of adaptation and selection and interaction with formal research, becomes apparent, but few if any of these changes can be directly and unambiguously linked to the war.

The conflict mapping report in the six chiefdom (chapter 2) added to the picture just painted for the total of 287 farms in the six sampled villages farmers in this chapter suggests that recovery after dislocation was quite quick. In the southern rural districts mass mobilization of able-bodied men into the CDF in 1995-1996 drove out the rebels in these districts, and villagers were able quickly to resume and focus on subsistence farming. In parts of the north, however, the period of dislocation was much longer, and this seems to have been accompanied by some adaptation in terms of greater use of hardy hybrid and glaberrima rice types.

Recovery relates to local seed production and supply

Where farmers had lost varieties, e.g. when pre-war plantings are compared with varieties collected in 2007 (Table 3) focus group consultations help trace the variety. A variety can be 'lost' in a given village, but can also routinely be re-accessed by a farmer through informal seed channels linking surrounding villages. However, agro-biodiversity of seeds is maintained (or lost) under a range of operational conditions in communities just emerging from war, implying that varieties may shift among villages in response to changing local circumstances. A variety may be abandoned in places where they are becoming less well suited to local conditions, only to be adopted where they are becoming better suited. Clearly, there was turn-over of varieties from village to village across the three periods assessed, but again, there is little evidence that these turn-over processes were harmed or interrupted by war.

Degrading soils fertility, erratic rainfall patterns and high labour demands remain major reasons for varying cropping patterns in the case study villages (see Kandeh and Richards, 1996).

The "hit and run" pattern of the war did not destroy farmer knowledge of micro-ecological seed management strategies

The nature of the "hit and run" short duration direct effect of the war makes the Sierra Leone conflict different from other rural wars in sub-Saharan Africa. Perhaps the most striking result seeming to reflect the war situation is the reported peak of glaberrima production in Mayemberrie during the height of RUF occupation. This supports the conclusion from the conflict mapping report (chapter 2) that incidents of atrocity were not very frequent for the agricultural populations as a whole (atrocities occurred in less than a quarter of all chiefdoms). This reflects the fact that the fighting forces beyond the reach of regular supply chains relied heavily on farmers for their food security. The data clearly show evidence of a robust egalitarian culture based on gifting, seed exchange and distribution in the rural economy. Farmers continued to do what they had always done, and where there were more stable, settled rebel groups, the fighters also had access to food. The pattern is probably different where rebel forces were suddenly scattered by peace enforcement troops or international private security operatives. Life clearly became very difficult for villagers caught on the line of rapid retreat of RUF forces from Freetown in January-Feburary 1999, for example. None of the case study villages appears to have been caught in this way. Micro-ecology is central to the functionality of the local seed system. Farmers remain a range of seed types adapted to a variety of local conditions, and these adapted varieties then became available to re-settling farmers, or tow farmers who found that post-war farming conditions had changed. Tables 3 to 8 provide some of the evidence for the continued functionality of enclave rice farming communities centred of informal seed system exchanges in a diverse if fragile micro-ecological world.

Come war or peace, farmers continue to make adaptive changes resulting in a lot of local seed differentiation

Respondents reported that they limited their farming operations to areas close to their settlements. Among farmers interviewed in 2007, over 80.0% had previously farmed in their communities and knew the micro-ecology well, including suitable seeds to sow. The other data are consistent with the picture we paint (in later chapters) for the sub region more widely – that farmers continue to select among their rices, and make adaptive changes come rain or shine, war or peace, and that as a result there is a lot of local differentiation. But there are some macro-changes under way. In particular, farmer hybrids seem to be taking over the role of Oryza glaberrima in the drier, drought-prone north of Sierra Leone, while Oryza sativa japonica makes a steady advance in the better-watered boliland zone.

In-situ and ex-situ crop genetic resources are maintained

Seed planted each year by the farmer is seed harvested by the farmer the previous season, stored until sowing time. In the process farmers select certain types of seed to be kept for subsequent planting. It is a common practice for farmers to pick out off-types in situ and ex situ. This suggests that the farmers experiment by rogueing out off-types to obtain pure and more healthy seed kept as for planting. This way they even select out products of unintentional cross-fertilization, and thus bring along new rice types. But a key issue in this respect is the stability of the farm population. Over 80.0% of the case-study populations reported that they resumed farming after a peak of displacement in 1996. Seeds may have been mislaid, but there was no major and sudden loss of farmer knowledge.

Why the issue of "seed losses" is not evidence of "genetic erosion"

On the issue of "losses" it should be emphasised that these are not instances of "genetic erosion" but reports of individual losses of a particular variety by a specific farmer. This study had no means to track these losses. Reports of losses are based on farmer recall. However, the accuracy of farmer recall evidence was checked by comparing the post-war recall data set with the survey collection data set for all upland rice farms in the case study villages in 2007. A warning is necessary. All the aggregate data show is the rate of turn-over for that particular village. High rates of turn-over could also be an index of the enthusiasm of farmers to experiment with new varieties, so any temptation to simply aggregate these figures to arrive at a measure of genetic erosion should be resisted.

In light of the above, it is evident that not many, if any, varieties were lost. Varieties favoured by aid agencies for resettling war-displaced farmers show up in the survey data but have served to recycle and diversify existing stocks rather than displace local choices. This practical concern relates to seed development and supply considerations in humanitarian crises. It is apparent that data require to be further analysed to bring out more plausible arguments about whether abandonment rates and inter-village effects match adoption rates for a given geographical zone, but this will not prove erosion. Whether we want to mention NERICA is a moot point. The promotion efforts (by World Bank and MAFFS) began in 2004 and have continued ever since. Perhaps year 2007 is too early to say much. If (as some informal reports and personal communications suggest) NERICA has now taken off in some areas of Sierra Leone older varieties may now being lost. But this is a post-war development. There is evidence for both change and recovery at village level. Taken as whole the data seem to show that farmer local seed systems were resistant to war-induced effects.

Wider comparisons

It is finally relevant to compare the Sierra Leone case study with empirical research findings from seed systems affected by war in other places. Sperling (1997) has collected case studies from Nicaragua, Cambodia and Rwanda, and Richards et al. (1997) include case studies from Guinea Bissau, Liberia and southern Sierra Leone. Longley (1998) describes a case study from northern Sierra Leone. These case studies are concerned with crop biodiversity rather than seed sourcing and cropping pattern, although the latter two aspects are both closely related to biodiversity. In Rwanda the Seeds of Hope initiative collected cropping data during the first three post-conflict seasons in order to assess and plan how best to meet the needs of farmers. Sperling (1997), Pottier (1996) and Longley (1997) advocate that more attention should have been given to the seed channels of farmers affected by war. Surveys undertaken by Sperling and Pottier were built on the considerable amount of pre-war research conducted in Rwanda in the early 1980s. Three points tend to show up very clearly and these are resonant with findings in the Sierra Leone case studies. First is the stability of varietal trends in pre- and post-war periods; second, varietal changes cannot be explicitly linked to war, but rather to local processes and conditions, some of which may be enhanced (though rarely created) by low-level insurgency and third, the impact of war varies by particular crop varieties and seed systems.

About stability of varietal trends, it should be emphasised that regular change in varieties grown by subsistence farmers in Sierra Leone is the usual practice. Nuijten (2005) emphasised that (for farmers in The Gambia) certain crops like late millet populations slowly adapt to changing climatic conditions, while for rice it is more of a “stop-and-go process” that tends in the direction of replacement when older varieties do not fit the local conditions anymore. At the community level, the management of crop genetic resources by small scale farmers is dependent upon farmers’ expertise on locally adapted crop genetic resources within the micro-ecology (Nuijten, 2005; Longley 1998). A farmer losing a particular seed must be able to replace it with either the same variety or one that is appropriate to his/her requirement and, in the process, such unintended changes may prompt the farmer to drop certain varieties in favour of new types better suited to the micro-ecology. In indigenous agricultural systems, variety turn-over rates may rise in times of crisis. Farmers had been growing beans in mixtures long before the events of 1994 in Rwanda. Due to conflict, the intensification of varietal mixing resulted in “unusually dynamic varietal profiles” (Sperling, 1997) and the data for Sierra Leone look somewhat similar.

Sperling’s comparison of two crops, beans and potatoes, in the Rwandan conflict illustrates very clearly the variable way in which different seed systems react under stress condition. Farmers in Rwanda rely largely on the formal system to acquire seed potato, and the formal seed system was severely devastated by war, resulting in an absolute lack of seed. The bean seed system, which is highly dependent on local channels, continued to function, partly due to the rapid re-establishment of informal markets following the war. Farmers did not experience an absolute lack of bean seed but they suffered from relative lack of seed because they were often unable to purchase the seed they required due to inordinate prices for seed, and increased war-induced poverty. Thus it is important to distinguish an absolute lack of seed from a relative lack of seed (due to lack of entitlement, such as purchasing power). Here the robustness of the Sierra Leone rice system, largely still dependent on non-market channels, becomes readily apparent. There was no absolute lack of seed in each of the case study villages, and informal not-monetized channels of seed acquisition remained open to all.

Guhuray & Ruiz (1997) highlight the difficulty in separating out the effects of war from the effects of post-war agricultural policies. This implies that variation of other related factors must also be included when examining the impact of war on farmer seed system. The Sierra Leone case shows that war-time seed portfolio changes require to be understood in relation to processes of seed development and distribution continuous between peace and war. This includes the policy environment, in which the design and implementation of humanitarian seeds-and-tools interventions played an important part.

The low intensity conflicts in Rwanda and Sierra Leon show war effects are variable. In Sierra Leone only a few areas experienced long-term mass exodus of populations directly affected by war and these areas sometimes suffered a drastic collapse of agricultural system. More typical were other areas in which war effects were limited and agricultural production remained largely intact.

Studies focused on means of seed acquisition and stocks frequently show that the formal seed system was much harder hit by the war than the informal seed system. Local sources of seed supply proved robust. Results for the analysis of one crop species, therefore, cannot be transferred to another. Furthermore, areas where the informal seed source of supply has not been badly hit may offer potential source(s) of locally adapted planting material for distribution elsewhere (Longley, 1997). For this reason it is important to ask questions about the robustness of local seeds when moved to other areas. This question is addressed in Chapter 5.

Conclusion

This chapter has presented evidence that war was not a major factor in disrupting or changing local seed development and dissemination practices in six varied villages examined in southern and central Sierra Leone. Circumstances change, and farmers adopt an experimental approach to coping with such changes. Thus new seeds are adopted and old seeds are (at least) temporarily let go. But this pattern of coping is long established, and has not been disturbed by war, any more than it has (yet) been disrupted by commercialization of the seed supply chain - a source of vulnerability for some other crops and some countries experiencing war. Rice seed in rural Sierra Leone is still mainly disseminated by local practices, including keeping, swapping, loaning and gifting of seed. These practices were not disrupted by the war. In fact, they belong to the social and cultural practices of everyday rural life, and kicked back into action as soon as farmers resettled their areas after short periods of displacement, and began to resume their normal pattern of social relations. Unsurprisingly, therefore, little evidence of serious losses of planting material was uncovered. There are important differences in rice types planted before and after the war, but these have been interpreted as mainly resulting from the continued operation of already established practices of farmer variety development. Local seed systems, seemingly, are robust. This chapter has not proved this point, only that village rice seed systems have continued to develop along regular lines through the war and afterwards. Subsequent chapters will now turn to this topic of robustness, and where it comes from. How and why do farmer seed systems for rice in Sierra Leone exhibit durability and internal capacity for innovation? For this question we now need to devote attention to the genetic make-up and morphological character of farmer rice seeds, and ask what can be inferred from information of this sort about farmer seed management and selection practices.

Annexes

Annex 1 Prevailing agro-climatic variables over agro-ecological conditions and average fallow across region and farming systems of the villages under study

Region within country	Village	Topography & Ecology	Farming Conditions	Average bush fallow (yrs.)	Effective Rainfall duration (months)	Effective Rainfall (mm.)	Mean Annual Rainfall (mm)	*Eto (mm.)	*R/Eto	Climatic Water Surplus (mm.)	Growing period duration (dys.)
North [Relief:100-500metres]	Bumban	Transition-Undulating-Upland-Pure Uphill & *IVS	Rain-fed+less-Hydromorphic environs	8.26	7	1,005	2,216	1,403	1.44	1,211	259
North-west [Relief: <100metres]	Kamba	Transition-Undulating-Flat-Upland & IVS	Rain-fed+less-Hydromorphic environs	8.26	7	1,070	2,662	1,442	1.7	1,592	259
central-North [Relief: <100metres]	Mayemberrie	Transition-Undulating-Flat-Upland & IVS	Rain-fed+less-Hydromorphic environs	8.26	7	1,070	2,662	1,442	1.7	1,592	259
central-South [Relief: <100metres]	Jagbeima Mobai Mogbuama	Transition-Undulating-Flat-Upland & IVS	Rain-fed+ Hydromorphic environs	11	8	1,100	2,451	1,440	1.56	1,351	275

(*): IVS = inland valley swamp; Eto = mean annual evapotranspiration; R/Eto = moisture availability index.

Annex 2 *The physical regions and farming systems of the villages under study*

Region within country	Chiefdom	Village	Physical region	Farming system
North	Biriwa	Bumban	Interior Plateau (over 300m asl)	1. *****RBS: upland & IVS rice without tree crops. 2. *PFS
North-west	Magbema	Kamba	Interior Lowlands (less than 150m asl)	1. RBS: upland & IVS rice with and without tree crops. 2. *FFS. Rice on boli-lands and on tidal swamps
central-North	Kholifa Rowalla	Mayemberrie	Interior Lowlands (less than 150m asl)	1. RBS: upland & IVS rice with and without tree crops. Rice on boli-lands
central-South	Kamajei	Jagbeima Mobai Mogbuama	Interior Lowlands (less than 150m asl)	1. RBS: upland & IVS rice with and without tree crops. 2. FFS. Rice on boli-lands & on riverain grasslands

(*****): **RBS** = rotational bushfallow system. **PFS** = pastoral farming system. **FFS** = floodland farming system.

Annex 3 *Synthesis of the six usual seasons in Sierra Leone each with its own special characteristics across region and (rice) cropping season* of the villages under study*

Region	**Chiefdom**	**Village**	***Early dry season.*** (late November to mid-December).	***Cool dry season.*** (mid-December to mid-February).	***Hot dry*** **season.** (mid-February to April or May).	***Early squalls season.*** (April to July).	***Persistent or deep rains season.*** (July to September).	***Late squalls season.*** (mid-September to mid-November).
North	Biriwa Magbema Kholifa Rowalla	Bumban Kamba Mayemberrie	RH=90% to 60%. High temperatures with 32° C maximum & 21° C minimum. This season is short and early in the extreme north.	RH as low as 10%. Hot days 32° C atleast; cold nights below 16° C. This season lasts longest in the extreme north. In the south it is less continuous.	Upland rice farmers regard this period as the most unpleasant - busy with farmlands preparations and water may have to be taken to the villages from streams, pools, or swamps.	High winds at speed of 130 kph (80 mph). Often long and extended from north to south. Many local thunderstorms also occur. A drop in the temperature takes place as line-squall passes over a place. The rice farmers are busy on their burnt farms, ready for sowing.	Often with bright sunny periods. A time of cloudy, wet, and relatively cool weather, and frequent rain but little or no thunder. The wet and still warm conditions favour rapid growth of rice crop.	Squalls becomes progressively fewer, and ends earliest in the west and north, and latest in the south-east. This period is known for upland rice harvesting.
South	Kamajei	Jagbeima Mobai Mogbuama						

(*****): The cropping season was found variable because it was highly affected by the monsoon winds.

CHAPTER FOUR

Evidence for the emergenc of new rice types of interspecific hybrid origin in West African farmers' fields

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Abstract

In West Africa two rice species (*Oryza glaberrima* Steud. and *Oryza sativa* L.) co-exist. Although originally it was thought that interspecific hybridisation is impossible without biotechnological methods, progenies of hybridisation appear to occur in farmer fields. AFLP analysis was used to assess genetic diversity in West Africa (including the countries The Gambia, Senegal, Guinea Bissau, Guinea Conakry, Sierra Leone, Ghana and Togo) using 315 rice samples morphologically classified prior to analysis. We show evidence for farmer interspecific hybrids of African and Asian rice, resulting in a group of novel genotypes, and identify possible mechanisms for in-field hybridisation. Spontaneous back-crossing events play a crucial role, resulting in different groups of genetic diversity in different regions developed by natural and cultural selection, often under adverse conditions. These new groups of genotypes may have potential relevance for exploitation by plant breeders. Future advances in crop development could be achieved through co-operation between scientists and marginalised farmer groups in order to address challenges of rapid adaptation in a world of increasing socio-political and climatic uncertainty.

Keywords: Interspecific hybridisation, *Oryza sativa*, *Oryza glaberrima*, West Africa, farmer varieties

Introduction

Rice (*Oryza* spp.) is one of the two most important grain crops worldwide. Its genetic diversity is a factor in securing local and global food security. West Africa is important for genetic diversity of rice, because, uniquely, two species – African rice (*Oryza glaberrima Steud*.) and Asian rice (*Oryza sativa L.*) – co-exist within the region. African rice was presumably first cultivated in Mali, Senegal and Guinea Conakry, ± 3500 years ago [1,2]. The history of Asian rice in West Africa is still uncertain, with introduction possible via Arab and/or Portuguese trading networks, ± 500–800 years ag*O.* Asian rice has more recently tended to replace African rice, but African rice has persisted or made a modest come-back in some areas, including parts of coastal West Africa.

Several reports claimed that *O. sativa* is completely isolated from *O. glaberrima* by an F1 sterility barrier [3,4]. Hence, the development of the Nericas (New Rice for Africa) based on the hybridisation of *O. sativa* and *O. glaberrima* was considered a technological breakthrough [5,6]. However, some scientists suggested that introgression between the two rice species occurs in the field [7,8]. Based on experiments, Sano [9] argued that pollen flow occurs mainly from *O. sativa* to *O. glaberrima*. Other experimental studies showed that introgression from *O. glaberrima* to *O. sativa* is possible, although at a low frequency [10-13]. Artificial backcrosses produced fertile progenies which resembled the parental phenotypes, indicating that under natural conditions it will be difficult to detect hybrid derivatives [9,14]. This means that, for example, plants belonging to *O. glaberrima* can incorporate *O. sativa* genetic material but remain typically *O. glaberrima* to the eye.

Recent evidence suggests that interspecific hybridisation does occur in farmers' fields resulting in new varieties [15-18]. Our paper shows that West African farmers have generated their own rices of interspecific background - genetically different from and independent of the scientific initiative leading to Nerica - and suggests possible mechanisms for in-field hybridisation behind this major local genetic development, with spontaneous backcrossing playing a crucial role. Our results strongly suggest that interspecific hybridisation in West Africa farmers' fields is a recurrent and continuing process, resulting in different groups of genetic diversity in different rice growing areas stimulated by (cultural) differences in selection. Our findings support the hypothesis by Sano *et al*. [14] that hybridisation followed by backcrossing between *O. sativa* and *O. glaberrima* might lead to the development 'of new variants not belonging to either of the two species'. These findings might have important implications for understanding crop development and human adaptation. For some time, it has been argued that small-scale farmers in the poorest countries should be consulted about crop improvement, to ensure a better fit between scientific innovation and local food security needs [19]. Now, molecular information is available on the importance of farmer agency during the domestication of rice [20]. We suggest that the current relationship between science and African farmers needs change. Our evidence shows that African farmers are active agents in plant improvement and we suggest that their agency may be taken as a starting point for scientific technology development. New lateral forms of cooperation are required to exploit fully the available genetic diversity of rice.

***Figure 1**: Geographic overview of the West African study area. Pushpins indicate study areas.*

Materials and Methods

We sampled the coastal West African rice belt, including Senegal, The Gambia, Guinea Bissau, Guinea Conakry and Sierra Leone, and the Togo hills rice cultivation outlier in Ghana and Togo (Figure 1). For demarcation of the upland rice ecology we followed local farmers' definitions. Per country, three or four villages/village clusters were selected, based on ecological and/or cultural contrasts. Per village, as full a set as possible of locally available dryland rice varieties was assembled. Per rice sample, 100–200 panicles were taken at random from the harvest as representative of a variety. Based on farmers' descriptions of the morphological identity of varieties, each rice sample was cleaned carefully. Thus farmer variety samples were morphologically as uniform as formal (released) varieties in the study.

Molecular analysis with AFLP markers, using the EcoRI primer E13 in combination with each of the MseI primers M49 or M51, basically followed the procedures described in Nuijten and Van Treuren[16]. AFLP data from 231 collected samples were combined with those of 84 rice samples analysed previously by Nuijten and Van Treuren [16]. A total number of 176 bands was scored, of which 161 were found to be polymorphic. The programme 'SplitsTree' was used to visualise phylogenetic relationships between the samples [21] and version 2.2 of the software package 'Structure' was used to analyse genetic population structure and to assign samples to populations [22, 23]. To quantify gene variation within groups of samples, Nei's gene diversity (H_e) was calculated [24].

Information about trait and variety preferences, and the origin and spread of varieties, was obtained through quantitative and qualitative interviews with farmers from whom the rice samples were collected (in countries listed above).

Information on morphological features was collected in a field trial carried out in Sierra Leone to characterise morphologically the majority of the materials. The trial design and measurement of the traits followed the procedures described in Nuijten and Van Treuren [16].

Definitions

Interspecific hybrids: varieties that result from hybridisation between *O. sativa* and *O. glaberrima*.

Nerica: improved varieties released by the African Rice Center (formerly WARDA) that result from artificial hybridisation between *O. sativa* and *O. glaberrima* followed by two backcrosses to the *O. sativa* parent.

Farmer hybrid: variety that results from spontaneous hybridisation between *O. sativa* and *O. glaberrima* followed by backcrossing in farmers' fields and subsequent self-pollination.

Off-type: rice plant with a phenotype distinctive from the sown variety and unknown as a variety (including non-cultivated and 'lost' varieties). Off-types can result from mixture, genetic mutation or spontaneous hybridisation.

Mixture: a rice stand consisting of various genetically different varieties caused by intentional or unintentional mixing.

Results

An unrooted phylogenetic network of the 315 rice samples is presented in Figure 2. As could be expected, *Oryza sativa* ssp. *indica*, *O. sativa* ssp. *japonica* and *O. glaberrima* form three distinct clusters. Nerica varieties of interspecific origin align along the *japonica* axis, with Nerica 1 and 2 facing the *O. glaberrima* branch. In addition to these three clusters, a fourth distinct cluster, consisting of two sub-clusters, was observed, at the junction of the *O. glaberrima-indica-japonica* axes.

Analyses with the software 'Structure' showed that the major structure in the data was captured when four populations were assumed. Three of these populations corresponded with *Oryza sativa* ssp. *indica, O. sativa* ssp. *japonica* and *O. glaberrima*, respectively, while the fourth population corresponded with cluster 4 in Figure 2. Of the 315 materials 285 samples were assigned to a cluster with more than 91% probability. All materials in cluster 4 in Figure 2 were assigned to cluster 4 with more than 81% probability in Structure, except two varieties from Senegal that were assigned to cluster 4 with 59% and 46% probability.

Prior to the molecular analysis, all varieties collected from farmers were classified as *O. sativa*, *O. glaberrima*, hybrid or unclear. None of the materials assigned to the two *O. sativa* clusters with more than 81% probability were classified as *O. glaberrima* and vice versa (Table 1). The single sample classified as *O. sativa* that was assigned to *O. glaberrima*, and the single sample classified as *O. glaberrima* that was assigned to *O. sativa*, were most likely caused by interchanging of materials during the experiment.

Cluster 4 comprised two subclusters (Figure 2). All varieties in sub-cluster 4-2 had been taxonomically determined as *O. sativa* prior to the molecular study, while cluster 4-1 consisted of samples that had been determined either as *O. sativa*, *O. glaberrima*, hybrid or unclear (Table 2). The main distinctive features between these two sub-clusters were panicle stature at maturity and pericarp (or seed) colour. Sub-cluster 4-1 consisted of varieties with an erect panicle, typical for *O. glaberrima* (Figure 3), or a semi-erect or slightly drooping panicle, and a red pericarp, except for a single variety from Senegal which had a brown pericarp. Farmers classify particularly the varieties with an erect panicle as *O. glaberrima*,

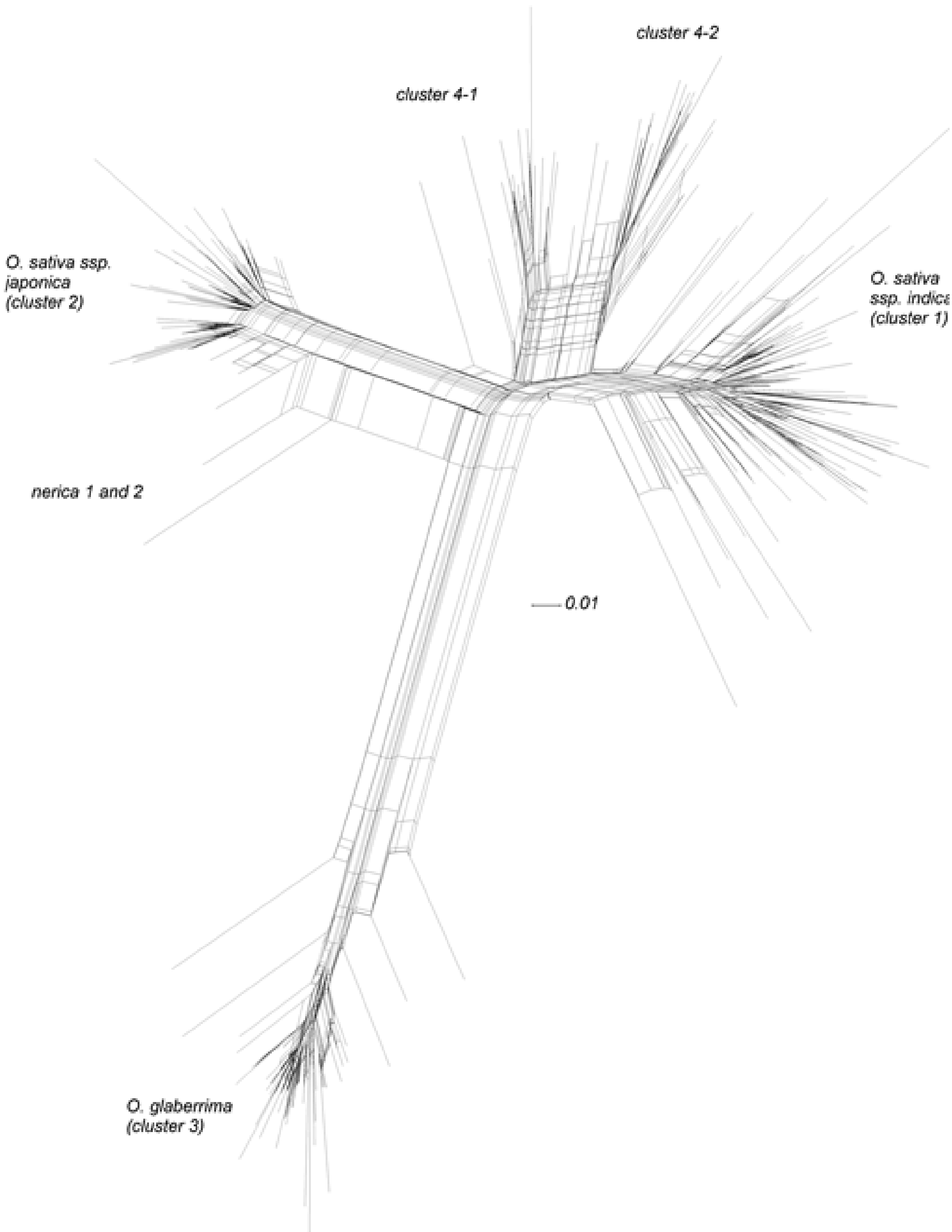

***Figure 2**: Phylogenetic relationships among the 315 samples studied.*

***Table 1**: Presumed taxonomic origin of the 289 farmer varieties in relation to the assignment probabilities to the four observed clusters.*

		O. glaberrima	Hybrid	Unclear	*O. sativa*
P (Gla)*	0.91 - 1.00	56		6	1
	0.81 - 0.90	2			
	0.71 - 0.80				
	0.61 - 0.70				
	0.51 - 0.60				
	0.41 - 0.50				
	0.31 - 0.40				
	0.21 - 0.30				
	0.11 - 0.20		3		
	0.00 - 0.10	8	16	18	179
P (Ind)	0.91 - 1.00	1	2	6	71
	0.81 - 0.90			1	3
	0.71 - 0.80		1		1
	0.61 - 0.70	1	1		2
	0.51 - 0.60			1	2
	0.41 - 0.50				2
	0.31 - 0.40				
	0.21 - 0.30				
	0.11 - 0.20	1	1		
	0.00 - 0.10	63	14	16	99
P (Jap)	0.91 - 1.00		5	5	70
	0.81 - 0.90		2		3
	0.71 - 0.80		1		
	0.61 - 0.70				
	0.51 - 0.60				
	0.41 - 0.50				1
	0.31 - 0.40				
	0.21 - 0.30				
	0.11 - 0.20	1	1		1
	0.00 - 0.10	65	10	19	105
P (Cl4)	0.91 - 1.00	6	6	5	23
	0.81 - 0.90		1		2
	0.71 - 0.80				
	0.61 - 0.70				
	0.51 - 0.60				1
	0.41 - 0.50				2
	0.31 - 0.40			1	2
	0.21 - 0.30	1	1		1
	0.11 - 0.20			1	2
	0.00 - 0.10	59	11	17	147

** Probabilities of the materials assigned to O. glaberrima (Gla), O. sativa ssp. indica (Ind), O. sativa ssp. japonica (Jap) and the fourth cluster (Cl4).*

because of the similarity in panicle stature. Farmers do not recognise the varieties of cluster 4 as a separate group. They divide all varieties into two types: those that resemble *O. sativa* and those that resemble *O. glaberrima*. Farmers are not specifically interested in varieties of interspecific origin, but in varieties that perform best under their conditions.

The three varieties in sub-cluster 4-1 that were classified as *O. sativa* had semi-droopy panicles which made them less distinctive from *O. sativa*. Sub-cluster 4-2 consisted of varieties in which panicles were predominantly strongly drooping, similar to *O. sativa*, and in which the pericarp colour varied from white to brown (90% of the varieties had a brown pericarp colour). Except for pericarp colour, the varieties in sub-cluster 4-2 did not have any clearly distinctive morphological features from *O. sativa* varieties (Table 3). Detailed morphological analysis of some varieties belonging to sub-cluster 4-2 in 2002 showed that when characteristics were aggregated in a Principal Component Analysis these farmer varieties were different from *O. sativa* ssp. *indica* and *O. sativa* ssp. *japonica* [16].

***Table 2**: Presumed taxonomic origin of the farmer hybrid varieties observed in sub-clusters 4-1 and 4-2 in figure 2.*

Presumed taxonomic origin	Sub-cluster 4-1	Sub-cluster 4-2
O. sativa	3	24
O. glaberrima	6	0
Hybrid	7	0
Unclear	5	0
Total	21	24

Genetic diversity within groups (H_e) was calculated for each of the four clusters. For this purpose an assignment probability of 91% was used as cut-off point to define the four clusters. The H_e value for cluster 4 was highest (0.098; n = 40) followed closely by the H_e value for the *O. sativa* ssp. *indica* group (0.089; n = 92). Relatively low values were observed for the *O. sativa* ssp. *japonica* group (0.045; n = 87) and the *O. glaberrima* group (0.034, n= 66).

Varieties in sub-cluster 4-1 not only displayed characteristics typical of *O. glaberrima*, such as the easily observable erect panicle stature (Figure 3), but also characteristics of *O. sativa*, such as the long, pointed ligule typical of *O. sativa* (Figure 4), a less conspicuous feature. The only explanation for this new morphotype is interspecific hybridisation between *O. sativa* and *O. glaberrima*. This was supported by the molecular data, separating cluster 4 from *O. sativa* ssp. and *O. glaberrima,* and showing large within-group diversity.

Cluster 4 consisted of a considerable number of different farmer interspecific hybrids originating from the Upper West African coastal rice belt (Table 4). None of the modern varieties and none of the samples collected in Ghana and Togo were found in cluster 4 in

Table 3*: Main distinctive morphological features of 12 varieties from cluster 4**

Variety name	Country	Sub-cluster	Panicle attitude	Ligule shape	Pericarp colour	Days to 80% flowering
Tebeleh	Sierra Leone	4-1	erect	pointed, long	red	105.8
Pa DC	Sierra Leone	4-1	erect	pointed, long	red	103.8
Pa Trimont	Sierra Leone	4-1	semi-droopy	pointed, long	red	92.5
Wonyonwonyon yi	Guinea Conakry	4-1	semi-droopy	pointed, long	red	96.3
Untufa	Guinea Bissau	4-1	erect	pointed, long	red	98.0
Dissi	Guinea Bissau	4-1	erect	pointed, long	red	104.0
Mani Konsunkuto	Guinea Bissau	4-2	strongly droopy	pointed, long	brown	87.5
Kolosar, Mani Wulendingo	Guinea Bissau	4-2	strongly droopy	pointed, long	white	91.8
Mani Wulengo	Gambia	4-2	strongly droopy	pointed, long	brown	88.0
Binta Sambou**	Gambia	4-2	strongly droopy	pointed, long	light brown	103.3
Ablie Mano	Senegal	4-2	droopy	pointed, long	brown	89.5
Madina Wulengo	Senegal	4-2	strongly droopy	pointed, long	brown	90.8

** Varieties of O. glaberrima included in this study had erect panicle, round short ligule and red pericarp colour. Varieties of O. sativa ssp. included in this study had strongly droopy panicle, pointed medium to long ligule, and white or red pericarp colour.*
*** In The Gambia Binta Sambou flowers only a few days later than Ablie Mano.*

Figure 2, nor were any of these samples assigned to cluster 4 in Table 4 with more than 40% probability. Thirty samples - originating from almost all countries, and including two modern varieties - were assigned with less than 91% probability to one cluster. No samples from Togo were assigned with less than 91% probability to one cluster. Although no samples from Ghana were assigned to cluster 4, five samples were assigned with high probabilities to two clusters. These samples may require further study to know whether they have an interspecific background. But we cannot assume that all such materials have an interspecific nature since one variety from IRRI was assigned to the *O. sativa* ssp. *indica* group with 76% probability (Table S1). Likewise, existence of samples with a very high assignment percentage probability does not rule out an interspecific origin. For example, WAB 450-I-B-P-105-HB, a Nerica that was never officially released was assigned with 100% probability to the *O. sativa* ssp. *japonica* group.

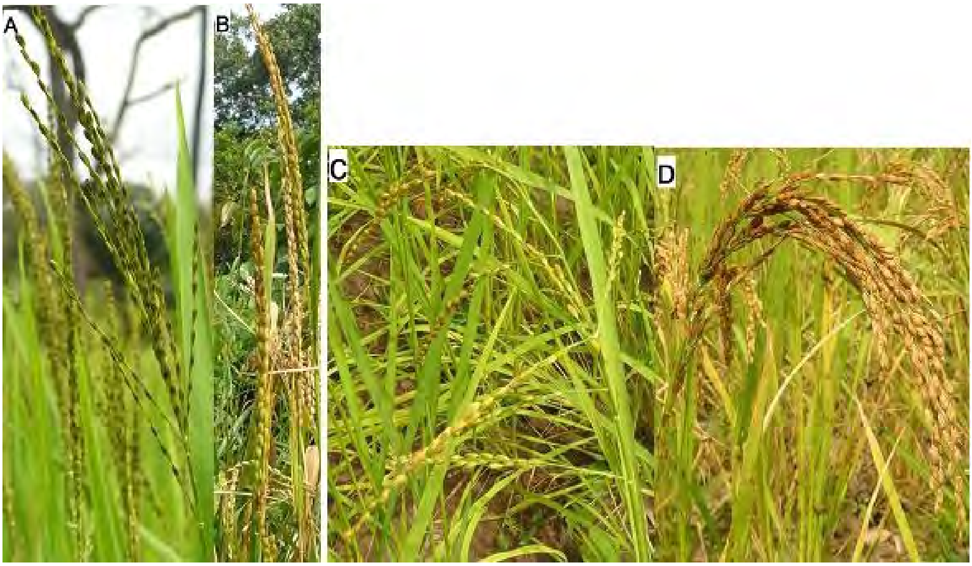

Figure 3*: Main panicle types found in this study. Panicle stature of O. glaberrima (A), interspecific hybrids from sub-cluster 4-1 with erect (B) and intermediate (C) panicles respectively, and O. sativa and interspecific hybrids from sub-cluster 4-2 (D).*

To a certain extent, the sub-clusters relate to the countries of collection and local seed colour preferences. The varieties in sub-cluster 4-1 originate from Guinea Bissau (4), Guinea Conakry (2), Senegal (1) and Sierra Leone (14), while the varieties in sub-cluster 4-2 are from The Gambia (9), Guinea Bissau (6) and Senegal (9). Whereas in Guinea Conakry and Sierra Leone farmers commonly cultivate red rice (both African and Asian rice), farmers in The Gambia, Senegal and northern Guinea Bissau predominantly cultivate white rice. Southern

Guinea Bissau occupies an intermediate position, as red rice is still cultivated but farmers strongly prefer white rice.

Discussion

Development of interspecific hybrid varieties

The molecular data showed that cluster 4 is more closely related to *O. sativa* than to *O. glaberrima.* This can be explained by the following scenario for the development of interspecific hybrids in farmer fields. The progeny of an F1-hybrid between *O. sativa* and *O. glaberrima* can maintain itself in the gene pool only through backcrossing to either species (*O. sativa* or *O. glaberrima*), because of a high level of sterility of the F1-hybrid. Farmers do not harvest the panicles of an F1-hybrid because (almost) all grains are empty. Hybrids as such are not maintained in a plant population. The event of a flower being pollinated by pollen of the other rice species is not observable. A panicle that carries one seed which is the result of pollination by the other species (and 200 by self-pollination) looks normal. If that panicle is selected for sowing seed, the seed that is produced by the flower pollinated by the other species is sown in the rice field, germinates and produces a hybrid plant. Only after grain filling (usually at harvesting time) can a farmer recognise this plant as an interspecific hybrid because it does not carry any seed and therefore he/she will not harvest it. Backcrossing is the only way for the genes of a hybrid to be incorporated into a new genotype. From this point two sub-scenarios are possible. The first sub-scenario is that a hybrid plant is pollinated by surrounding normal plants and the few seeds produced by the hybrid remain in the field, germinating next season, then to be pollinated by surrounding normal plants, after which fertility is restored and the offspring may be harvested by farmers. This scenario was also suggested by Sano *et al*. [14]. For this scenario to be possible a farmer needs to crop the same field to rice for at least three consecutive growing seasons, as sometimes happens where land is initially fertile and where abandoned plots are then cleared for re-use by members of a household with low labour capacity, such as widows. Work on Nerica [5] and speciation in rice [14] suggests that two backcrosses are sufficient to obtain ‘offspring’ with good fertility. The second sub-scenario is that during flowering the F1-hybrid may pollinate the surrounding normal plants. A panicle of a normal plant in which one flower is pollinated by the hybrid looks normal and may be included in the seed for next season. Two such backcrossing events to *O. sativa* or *O. glaberrima*, and subsequent replanting of the progeny by farmers should also lead to fertile offspring, given enough time and opportunities.

Subsequently, off-types of interspecific origin showing potential may be selected by farmers to be tested, multiplied and grown as new varieties. If other farmers show an interest in such a new variety, it may spread over a wider region. The whole process of the development of interspecific hybrid varieties is a combination of a random process of cross-pollination and backcrossing, followed by a selection process of those off-types that show most potential as new varieties by farmers.

***Figure 4**: Main ligule shapes found in this study. Ligule shape of O. glaberrima (A: small, rounded) and O. sativa and interspecific hybrids from cluster 4 (B: long, pointed)*

Field studies suggested that introgression can occur in both directions (from *O. glaberrima* to *O. sativa* and vice versa) [7,8], although some experimental studies have indicated that introgression from *O. sativa* to *O. glaberrima* occurs more often than introgression in the opposite direction [11,12], as confirmed by field observations in 2002 by Nuijten [25]. Artificial backcrosses produced fertile progenies which resembled the parental phenotypes, indicating that under natural conditions it is difficult to detect hybrid derivatives [9,14]. Given that the hybrid group (cluster 4) is closer to *O. sativa* than to *O. glaberrima*, successful backcrossing events in the field to *O. sativa* might be more likely than to *O. glaberrima*. According to Sano [9] the combination of nuclear DNA of *O. glaberrima* with cytoplasmic DNA of *O. sativa* always results in cytoplasmic male sterility. This suggests that the farmer hybrids may be the result of backcrossing to *O. sativa* and carry a combination of cytoplasmic DNA of *O. glaberrima* with nuclear DNA mainly from *O. sativa.* Chloroplast DNA analysis may give more conclusive information on whether the farmer hybrids result from *O. glaberrima* × *O. sativa* hybrids or *O. sativa* × *O. glaberrima* hybrids [26,27]. These results may also clarify which scenario of backcrossing in farmer fields led to the development of the farmer hybrids. But it should also be noted that in both species varieties may exist that are able to overcome the sterility system - so-called Wide Compatibility Varieties [11].

Rice hybridisation in farmer's fields may occur when *O. glaberrima* and *O. sativa* flower side by side. There are various scenarios to explain this co-occurrence at field level. The first possibility is the deliberate sowing of mixtures, which has been reported for several localities in the upper West African coastal zone [15,21,28]. The second, perhaps more common, possibility is the non-deliberate mixing of *O. glaberrima* within *O. sativa* seed stocks.

Roguing off-types requires skill and effort, and is sometimes neglected due to pressure to harvest the crop quickly, resulting in contamination of *O. sativa* seed batches with *O. glaberrima* seeds. Seed contamination can also reflect indebtedness, since farmers harvesting seed intended for loaning to poorer farmers rarely bother to rogue the material [29]. Because the separation of seed types after threshing is a much harder task than panicle roguing at harvest, contamination of *O. sativa* seed batches with *O. glaberrima* may be as high as 30%. These figures boost chances of spontaneous interspecific hybridisation on the farms where seed has been loaned.

Another non-intentional factor is the presence of weedy rice types intermediate between wild African rice (*O. barthii*) and *O. glaberrima* in farmers' fields. Gene flow between weedy types and cultivated Asian rice may also result in some in-field interspecific hybridisation. Weedy rice types like "*ngewobei*" and "*ngafabei*" (as named by Mende-speaking farmers in central Sierra Leone) may be the result of interspecific hybridisation between *O. barthii* and *O. sativa* (Table S1). Such weedy types may provide a bridge between wild and cultivated species for breeders to transfer useful characteristics from wild to cultivated rice.

Time depth of farmer hybrid-derived rices – historical evidence

Given the release of hybrid-derived interspecific rice varieties in the Nerica series from WARDA (Africa Rice Center) in the late 1990s it is appropriate to provide evidence that the farmer intermediate types analysed in this paper pre-date the Nerica releases. Rice varieties with the name elements 'three month' and '*disi*' (also written as 'DC') and the same morphological features as the collected varieties with the same name elements belonging to cluster 4-1 were collected by Richards and Jusu in Sierra Leone in 1987–88 and 1995–96, respectively.

***Table 4**: Number of farmer varieties, modern varieties and (semi-) wild relatives assigned by the software 'Structure' to the four observed clusters. Data for the farmer varieties are presented separately per country of origin.*

		The Gambia	Senegal	Guinea Bissau	Guinea Conakry	Sierra Leone	Ghana	Togo	Modern	(Semi) wild
P (Gla)*	0.91 - 1.00	4	3	4	25	8	10	9		3
	0.81 - 0.90		1	1						1
	0.71 - 0.80									1
	0.61 - 0.70									
	0.51 - 0.60									
	0.41 - 0.50									
	0.31 - 0.40									
	0.21 - 0.30									
	0.11 - 0.20	2					1			
	0.00 - 0.10	53	18	36	21	52	35	6	21	
P (Ind)	0.91 - 1.00	23	7	5	14	8	20	3	12	
	0.81 - 0.90	1			1	1	1			
	0.71 - 0.80		1				1		1	
	0.61 - 0.70	2			1		1			
	0.51 - 0.60		1	1			1			
	0.41 - 0.50		1				1			
	0.31 - 0.40									
	0.21 - 0.30									
	0.11 - 0.20		1		1					1
	0.00 - 0.10	33	11	35	29	51	21	12	8	4
P (Jap)	0.91 - 1.00	18		18	2	29	10	3	7	
	0.81 - 0.90	1		2	1		1			
	0.71 - 0.80	1							1	
	0.61 - 0.70									
	0.51 - 0.60									
	0.41 - 0.50						1			
	0.31 - 0.40									
	0.21 - 0.30									
	0.11 - 0.20	1	1	1						
	0.00 - 0.10	38	21	20	43	31	34	12	13	5
P (Cl4)	0.91 - 1.00	8	7	10	2	13				
	0.81 - 0.90	1	1			1				
	0.71 - 0.80									
	0.61 - 0.70									
	0.51 - 0.60		1							
	0.41 - 0.50		1	1						
	0.31 - 0.40	1					2			
	0.21 - 0.30		1		1		1		1	
	0.11 - 0.20	1				1	1		1	
	0.00 - 0.10	48	11	30	43	45	42	15	19	5

** Probabilities of the materials assigned to O. glaberrima (Gla), O. sativa ssp. indica (Ind), O. sativa ssp. japonica (Jap) and the fourth cluster (Cl4).*

Farmers from Guinea Bissau provided the following information in the present study. The interspecific farmer hybrids belonging to cluster 4-1 collected in northern Guinea Bissau were reportedly cultivated before 1940. How much earlier they were cultivated is not clear, since precise data from before 1940 are largely absent. Some farmers considered them to have always been there. This gains some support from some of the names. In northern Guinea Bissau farmers referred to these varieties by names also used for *O. glaberrima*, such as '*jangjango*', '*untufa*', and '*wansarang*'. '*Jangjango*' specifically refers to the upright panicle typical of *O. glaberrima*. The meaning of the variety name '*untufa*' is 'rice from here' because it is considered ancient, implying farmers think it is *O. glaberrima*, the rice originally domesticated in West Africa.

The origin of many varieties from cluster 4-2, such as '*mani wulengo*', '*mani wulendingo*', '*mani konsonkuto*', '*ablie mano*', collected in The Gambia, Senegal and Guinea Bissau can be traced back to northern Guinea Bissau. One variety in The Gambia,'*binta sambou*', was developed from an off-type found in a field of '*ablie mano*' around 1990. Except for the variety '*binta sambou*' farmers could not pinpoint place or time of origin. In one village, Pantufa, in northern Guinea Bissau farmers indicated that varieties such as '*mani wulengo*', '*mani konsonkuto*', '*mani wulendingo*' and '*ablie mano*' were cultivated before 1940.

The information available so far suggests the countries where the interspecific farmer varieties were first cultivated were Sierra Leone and Guinea Bissau. No precise dates of origin can be specified, but the aforementioned data suggest that some existed for more than half a century, and thus long before the first release of Nerica varieties.

Spread of interspecific farmer hybrids

Adversity such as war and drought appear to have favoured the selection and spread of spontaneous interspecific rice hybrids among West African farmers. War has forced some farmers into intensively farmed pockets of land without access to fertilisers. Farmer hybrids appear to share the adaptation to poor soils of the *O. glaberrima* parent. Parts of the war zone in Sierra Leone, cut off from aid assistance over several years, appeared to be mainly growing interspecific hybrid varieties (or pure glaberrimas) in the period immediately after fighting ceased [31]. Farmers noted that war reduced the amount of time available for clearing of forest, weeding and careful harvesting new fields, since civilians were reluctant to linger for fear of encountering fighters. In other cases (e.g. as a result of war in Guinea-Bissau and southern Senegal) they fled across borders, taking their hardy varieties with them. Farmer hybrids are particularly frequent in our samples from southern Senegal, Guinea-Bissau and Sierra Leone (Table 4) − all regions affected by recent episodes of armed conflict.

In Senegal and The Gambia the farmer hybrids have probably helped farmers to cope with climatic fluctuation. The farmer hybrids (belonging to sub-cluster 4-2) collected in these two countries tend to flower about one week earlier than the farmer hybrids (belonging to sub-cluster 4-1) collected in Sierra Leone (Table 3). Senegal and The Gambia have been badly affected by drought in recent times. In addition, both countries have faced increased demographic pressure, exacerbated by armed conflict in southern Senegal and Guinea Bissau. Farmer hybrids may embody considerable adaptive plasticity to suboptimal farming conditions associated with such difficulties.

An important reason why in Senegal and The Gambia farmers mainly grow farmer hybrids belonging to sub-cluster 4-2 is that in these two countries farmers do not like a red pericarp colour (the variety belonging to sub-cluster 4-1 and cultivated in Senegal does not have a red pericarp). In addition, some farmers mentioned they do not like an erect panicle when mature. In Sierra Leone and Guinea Conakry the farmer hybrids found belonged to sub-cluster 4-1. In these two countries farmers prefer a red pericarp colour because they claim it is related to slow digestion. Also they do not consider an erect panicle a negative trait. These two traits are the main traits that differentiate sub-clusters 4-1 and 4-2. Both can be considered polygenic traits which may explain why farmer selection practices have resulted in large genetic differences between the two sub-clusters, as is shown by the molecular data. Given the different ecological and climatic conditions in the region, the outcome of farmer selection for traits such as panicle length, tillering, plant height, yield, taste, swelling, and ease of threshing may possibly have contributed to the genetic differences between sub-clusters 4-1 and 4-2.

Why are interspecific farmer hybrids absent or rare in Ghana and Togo?

Farmer interspecific hybrids are less frequent or absent in our samples from Ghana and Togo (Togo Hills), an important region of co-occurrence of *O. glaberrima* and *O. sativa.* Conditions in the Togo Hills may be less favourable to in-field interspecific hybridisation due to cultural and geographical factors. The cultural significance of African rice seems to limit the amount of farmer hybridisation on the Ghana side of the Togo Hills. Rice cultivators in eastern Ghana grow *O. sativa* mainly as a commercial crop under relatively favourable conditions. These farmers maintain a strong interest in African rice, but for cultural reasons. African rice is prominent in traditional ceremonies and as an ethnic marker [32]. In such circumstances, a hybrid would be less suited because of its blurred morphology. Farmers in Togo (the Danyi plateau) grow African rice at higher altitudes, while *O. sativa* is planted at lower altitudes. This imposes a geographical barrier to interspecific hybridisation.

Concluding remarks

Our results strongly suggest that interspecific hybridisation in West African farmers' fields is a recurrent and continuing process, with spontaneous back-crossing events playing a crucial role, resulting in different groups of genetic diversity in different rice growing areas stimulated by differences in selection criteria and selection environments. This clear evidence for the emergence of farmer hybrids of African and Asian rice in West Africa has important implications for understanding crop development and human adaptation. Whether and how such hybridisation and backcrossing events have occurred for other crops may be a useful question to pursue, to achieve a better understanding of crop development and diversity. For example, it may help to identify the most plausible scenario for the development of maize (*Zea mays* L.). Our findings also suggest that adversity, such as dislocation by armed conflict and climatic change, has not hindered, and may have accelerated the rate at which interspecific hybrid rice varieties have spread [31]. Farmer interspecific hybrids of rice may complement those recently developed by formal scientific research. This points to potential value in linking science and local technology development by marginalised groups, better to address challenges of rapid adaptation in a world of increased socio-political and climatic uncertainty.

Supporting Information

Table S1: Overview of the 315 investigated rice samples and their assignment to the four observed clusters by the software Structure (see below).

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Author Contributions

Conceived and designed the experiments: EN RvT PS AM FO BT PR. Performed the experiments: EN RvT AM FO BT. Analysed the data: EN RvT. Contributed reagents/materials/analysis tools: EN RvT AM FO BT. Wrote the paper: EN RvT PS AM FO BT PR.

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Annexes

Table S1: *Overview of the 315 investigated rice samples and their assignment to the four observed clusters by the software Structure.*

Variety name	Origin	Taxonomy	P (Gla)	P (Ind)	P (Jap)	P (Cl4)
A. Farmer varieties						
Kaomo black	Ghana	*O. glaberrima*	1.00	0.00	0.00	0.00
Kaomo black (with awns)	Ghana	*O. glaberrima*	1.00	0.00	0.00	0.00
Kaomo krukutuwa	Ghana	*O. glaberrima*	1.00	0.00	0.00	0.00
Kaomo krukutuwa signaweh	Ghana	*O. glaberrima*	1.00	0.00	0.00	0.00
Kaomo signaweh	Ghana	*O. glaberrima*	1.00	0.00	0.00	0.00
Kaomo signaweh black	Ghana	*O. glaberrima*	1.00	0.00	0.00	0.00
Kaomo white	Ghana	*O. glaberrima*	1.00	0.00	0.00	0.00
Jangjango	Guinea Bissau	*O. glaberrima*	1.00	0.00	0.00	0.00
Jangjango	Guinea Bissau	*O. glaberrima*	1.00	0.00	0.00	0.00
Kurekimbeli	Guinea Bissau	*O. glaberrima*	1.00	0.00	0.00	0.00
Uassolondji	Guinea Bissau	*O. glaberrima*	1.00	0.00	0.00	0.00
Dixi Wansan Lot 1	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Saali Fire	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Saali Fore	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Saali Fore	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Saali Fore	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Saali Fore	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Saali Fore	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Siiga?	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Tombo Bokary	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Tombo Bokary	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Tombo Bokary	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Tombo Bokary	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Tombo Bokary	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Tombo Bokary	Guinea Conakry	*O. glaberrima*	1.00	0.00	0.00	0.00
Mani Musoo	Senegal	*O. glaberrima*	1.00	0.00	0.00	0.00
Mani Musoo	Senegal	*O. glaberrima*	1.00	0.00	0.00	0.00
Damba	Sierra Leone	*O. glaberrima*	1.00	0.00	0.00	0.00
Saliforeh	Sierra Leone	*O. glaberrima*	1.00	0.00	0.00	0.00
Mani Ba	The Gambia	*O. glaberrima*	1.00	0.00	0.00	0.00
Mani Ba	The Gambia	*O. glaberrima*	1.00	0.00	0.00	0.00
Mani Ba	The Gambia	*O. glaberrima*	1.00	0.00	0.00	0.00
Mani Ba	The Gambia	*O. glaberrima*	1.00	0.00	0.00	0.00
Awinto blanc	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Awinto yibo	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Danyi moli	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Danyi moli	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Kpakpalipke	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Xleti etoh (three months)	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Xleti eve	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Yibo riz	Togo	*O. glaberrima*	1.00	0.00	0.00	0.00
Kaomo signaweh white	Ghana	*O. glaberrima*	0.99	0.00	0.00	0.00
Saali Koute	Guinea Conakry	*O. glaberrima*	0.99	0.01	0.00	0.00
Tombo Bokary	Guinea Conakry	*O. glaberrima*	0.99	0.00	0.00	0.00
Mani Musoo	Senegal	*O. glaberrima*	0.99	0.01	0.00	0.00
Sanganyaa	Sierra Leone	*O. glaberrima*	0.99	0.00	0.00	0.01
Dixi Wansan Lot 2	Guinea Conakry	*O. glaberrima*	0.98	0.00	0.01	0.00

Safaary	Guinea Conakry	*O. glaberrima*	0.98	0.00	0.00	0.01
Siiga	Guinea Conakry	*O. glaberrima*	0.98	0.01	0.01	0.01
Tombo Bokary	Guinea Conakry	*O. glaberrima*	0.98	0.00	0.00	0.02
Gbankeyi	Guinea Conakry	*O. glaberrima*	0.97	0.01	0.00	0.02
Safaary	Guinea Conakry	*O. glaberrima*	0.96	0.01	0.02	0.01
Awinto blanc	Togo	*O. glaberrima*	0.93	0.03	0.00	0.03
Maalay	Sierra Leone	*O. glaberrima*	0.92	0.03	0.03	0.02
Saali Fore	Guinea Conakry	*O. glaberrima*	0.91	0.06	0.02	0.01
Saali Fore	Guinea Conakry	*O. glaberrima*	0.91	0.00	0.02	0.07
Mani Musoo	Senegal	*O. glaberrima*	0.82	0.14	0.00	0.04
Wansarang	Guinea Bissau	*O. glaberrima*	0.81	0.02	0.14	0.02
Siiga	Guinea Conakry	*O. glaberrima*	0.01	0.98	0.00	0.01
Dalifode	Guinea Conakry	*O. glaberrima*	0.10	0.67	0.01	0.22
Trimont (white)	Sierra Leone	*O. glaberrima*	0.00	0.00	0.00	1.00
Pa Trimont	Sierra Leone	*O. glaberrima*	0.00	0.00	0.00	0.99
Painy-pain	Sierra Leone	*O. glaberrima*	0.00	0.00	0.00	0.99
Pindie	Sierra Leone	*O. glaberrima*	0.00	0.00	0.00	0.99
Pa Trimont (red)	Sierra Leone	*O. glaberrima*	0.01	0.01	0.00	0.98
Saliforeh	Sierra Leone	*O. glaberrima*	0.00	0.01	0.03	0.96
Samba	Guinea Conakry	*O. sativa*	0.97	0.01	0.02	0.01
Adeisi	Ghana	*O. sativa*	0.00	1.00	0.00	0.00
Akpasseh	Ghana	*O. sativa*	0.00	1.00	0.00	0.00
Red saka	Ghana	*O. sativa*	0.00	1.00	0.00	0.00
Zomojo	Ghana	*O. sativa*	0.00	1.00	0.00	0.00
Bissau	Guinea Bissau	*O. sativa*	0.00	1.00	0.00	0.00
Sajar	Guinea Bissau	*O. sativa*	0.00	1.00	0.00	0.00
Kaniya	Guinea Conakry	*O. sativa*	0.00	1.00	0.00	0.00
Momodou male	Guinea Conakry	*O. sativa*	0.00	1.00	0.00	0.00
Saidou fire (red grain)	Guinea Conakry	*O. sativa*	0.00	1.00	0.00	0.00
Soumaila	Guinea Conakry	*O. sativa*	0.00	1.00	0.00	0.00
Ablie Koyo	Senegal	*O. sativa*	0.00	1.00	0.00	0.00
Fadass	Senegal	*O. sativa*	0.00	1.00	0.00	0.00
Kuboni	Senegal	*O. sativa*	0.00	1.00	0.00	0.00
Madina Koyo	Senegal	*O. sativa*	0.00	1.00	0.00	0.00
Buttercup	Sierra Leone	*O. sativa*	0.00	1.00	0.00	0.00
Yainky-Yanka	Sierra Leone	*O. sativa*	0.00	1.00	0.00	0.00
Akacha	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Barafita koyo	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Baraso	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Bendou	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Chinese short	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Derisa Mano	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Foni Mano	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Off-type (in Binta Sambou)	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Peking	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Peking	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Tensi	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Tombom	The Gambia	*O. sativa*	0.00	1.00	0.00	0.00
Adeta red rice	Ghana	*O. sativa*	0.00	0.99	0.00	0.01
Awonyo (two months)	Ghana	*O. sativa*	0.00	0.99	0.01	0.01
Bouake	Ghana	*O. sativa*	0.00	0.99	0.00	0.01
James rice	Ghana	*O. sativa*	0.00	0.99	0.00	0.01
Red saka	Ghana	*O. sativa*	0.00	0.99	0.00	0.00
Red saka (off-type?)	Ghana	*O. sativa*	0.00	0.99	0.00	0.01
Red variety	Ghana	*O. sativa*	0.00	0.99	0.00	0.00
Aninha de lugar	Guinea Bissau	*O. sativa*	0.00	0.99	0.00	0.01
Wankarang	Guinea Bissau	*O. sativa*	0.00	0.99	0.00	0.00

Saidou Fire	Guinea Conakry	*O. sativa*	0.00	0.99	0.00	0.00
Saidou Fire	Guinea Conakry	*O. sativa*	0.00	0.99	0.00	0.01
Saidou Gbeeli	Guinea Conakry	*O. sativa*	0.00	0.99	0.00	0.00
Saidou Gbeeli	Guinea Conakry	*O. sativa*	0.00	0.99	0.00	0.00
Jina Mano	Senegal	*O. sativa*	0.00	0.99	0.00	0.00
Kuboni Juuno	Senegal	*O. sativa*	0.00	0.99	0.00	0.00
Rok31	Sierra Leone	*O. sativa*	0.00	0.99	0.00	0.00
Bonti	The Gambia	*O. sativa*	0.00	0.99	0.00	0.01
Kadi Dabo	The Gambia	*O. sativa*	0.00	0.99	0.00	0.00
Mani Suntungo-1	The Gambia	*O. sativa*	0.00	0.99	0.00	0.01
Mani Suntungo-2	The Gambia	*O. sativa*	0.00	0.99	0.00	0.00
Muso Noringo	The Gambia	*O. sativa*	0.00	0.99	0.00	0.01
Peking	The Gambia	*O. sativa*	0.00	0.99	0.00	0.01
Sainey Kolly	The Gambia	*O. sativa*	0.00	0.99	0.01	0.01
Teiba	The Gambia	*O. sativa*	0.00	0.99	0.00	0.01
Awuie red	Togo	*O. sativa*	0.00	0.99	0.00	0.00
Awuie white	Togo	*O. sativa*	0.00	0.99	0.00	0.01
White saka	Ghana	*O. sativa*	0.00	0.98	0.00	0.02
Sambaconcon	Guinea Bissau	*O. sativa*	0.02	0.98	0.00	0.00
CK 21	Guinea Conakry	*O. sativa*	0.01	0.98	0.01	0.01
Pode 1	Guinea Conakry	*O. sativa*	0.00	0.98	0.01	0.01
Sorie Kunde	Sierra Leone	*O. sativa*	0.00	0.98	0.01	0.01
Chinese red	The Gambia	*O. sativa*	0.00	0.98	0.00	0.02
Saidou fire (white grain)	Guinea Conakry	*O. sativa*	0.01	0.97	0.01	0.01
Saidou Gbeeli	Guinea Conakry	*O. sativa*	0.01	0.97	0.02	0.00
Yaka (Rok3)	Sierra Leone	*O. sativa*	0.01	0.97	0.01	0.02
Viotto (off-type?)	Ghana	*O. sativa*	0.00	0.95	0.04	0.01
Zomojo	Ghana	*O. sativa*	0.01	0.95	0.04	0.01
Zomojo (off-type?)	Ghana	*O. sativa*	0.00	0.95	0.00	0.04
Baraso	The Gambia	*O. sativa*	0.00	0.95	0.00	0.04
Sarjo Keeba Mano	The Gambia	*O. sativa*	0.01	0.94	0.04	0.01
Yaka	Sierra Leone	*O. sativa*	0.00	0.93	0.01	0.07
Pa Bad-scent	Sierra Leone	*O. sativa*	0.06	0.92	0.01	0.01
Viono short	Ghana	*O. sativa*	0.00	0.91	0.08	0.00
Wonyonwonyon yi	Guinea Conakry	*O. sativa*	0.02	0.89	0.04	0.05
Terfatch	The Gambia	*O. sativa*	0.01	0.82	0.01	0.16
Damansah 1	Ghana	*O. sativa*	0.00	0.81	0.00	0.18
Mani Koyo	Senegal	*O. sativa*	0.00	0.74	0.01	0.25
Damansah 4	Ghana	*O. sativa*	0.00	0.62	0.06	0.31
Off-type (in Hombo Wulengo)	The Gambia	*O. sativa*	0.00	0.61	0.00	0.38
Bondiyaa Karejang	Senegal	*O. sativa*	0.00	0.54	0.00	0.46
Off-type (in Tabuyaa Mani Koyo)	Guinea Bissau	*O. sativa*	0.00	0.53	0.01	0.46
Aqua blue	Ghana	*O. sativa*	0.00	0.48	0.44	0.07
Aqua blue	Ghana	*O. sativa*	0.00	0.00	1.00	0.00
Aqua blue with awns	Ghana	*O. sativa*	0.00	0.00	1.00	0.00
Gokpui	Ghana	*O. sativa*	0.00	0.00	1.00	0.00
Mateggi	Ghana	*O. sativa*	0.00	0.00	1.00	0.00
Buba Njie	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Bumali	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Conakry	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Demba Ba	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Jahuun (sutungo)	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Kissidugô	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Nahawa	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Off-type (in Sefa Fingo)	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Sefa Fingo	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Senkiliba	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00

Toba	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Umobel	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Usefa Udjenel	Guinea Bissau	*O. sativa*	0.00	0.00	1.00	0.00
Conakry	Guinea Conakry	*O. sativa*	0.00	0.00	1.00	0.00
Bobordeen	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Boikortor	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Gbengben	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Gbengben	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Jobboi	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Jumukui	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Kondaylah	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Kortigbongoi	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Nduluwai	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Pamanneh	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Pla Gbon	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Sembehun nyaha	Sierra Leone	*O. sativa*	0.00	0.00	1.00	0.00
Hombo Wulengo	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Kukone	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Kukur	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Mani Tima	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Nerica koyo	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
off-type (in Hombo Wulengo)	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Off-type (in Sefa Koyo)	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Off-type (Samano?)	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Sefa Fingo	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Sefa Fingo (red)	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Sefa Koyo	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Sonna Mano	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Wesiwes	The Gambia	*O. sativa*	0.00	0.00	1.00	0.00
Aquablue	Togo	*O. sativa*	0.00	0.00	1.00	0.00
Ujogade	Guinea Bissau	*O. sativa*	0.01	0.00	0.99	0.00
Uyeey	Guinea Bissau	*O. sativa*	0.00	0.00	0.99	0.00
Bonyaha	Sierra Leone	*O. sativa*	0.01	0.00	0.99	0.00
Coffeegay..	Sierra Leone	*O. sativa*	0.00	0.00	0.99	0.00
Konowanjei	Sierra Leone	*O. sativa*	0.00	0.00	0.99	0.01
Nerica wulengo	The Gambia	*O. sativa*	0.00	0.00	0.99	0.00
Sefa Nunfingo	The Gambia	*O. sativa*	0.00	0.00	0.99	0.00
Sefa Nunfingo (white)	The Gambia	*O. sativa*	0.00	0.01	0.99	0.00
Wab 56-50	The Gambia	*O. sativa*	0.00	0.00	0.99	0.00
Aqua blue	Ghana	*O. sativa*	0.00	0.00	0.98	0.01
Off-type (in Kadidjango)	Guinea Bissau	*O. sativa*	0.00	0.01	0.98	0.01
Otcha	Guinea Bissau	*O. sativa*	0.00	0.01	0.98	0.00
Mabargie	Sierra Leone	*O. sativa*	0.00	0.01	0.98	0.01
Yonnie	Sierra Leone	*O. sativa*	0.01	0.00	0.98	0.01
Berengdinto Koyo	Guinea Bissau	*O. sativa*	0.00	0.01	0.97	0.01
Nerigay	Sierra Leone	*O. sativa*	0.00	0.02	0.97	0.01
Yabasie	Sierra Leone	*O. sativa*	0.01	0.02	0.97	0.00
Gbengben	Sierra Leone	*O. sativa*	0.00	0.00	0.96	0.04
Gbengben	Sierra Leone	*O. sativa*	0.03	0.00	0.96	0.01
Musugomie	Sierra Leone	*O. sativa*	0.02	0.01	0.96	0.01
Jetteh	Sierra Leone	*O. sativa*	0.00	0.04	0.95	0.00
Off-type (lost variety)	The Gambia	*O. sativa*	0.00	0.02	0.95	0.02
Jewule	Sierra Leone	*O. sativa*	0.04	0.01	0.94	0.02
Konko	Guinea Conakry	*O. sativa*	0.00	0.07	0.93	0.00
Ngiligortie	Sierra Leone	*O. sativa*	0.05	0.02	0.93	0.00
Red saka	Ghana	*O. sativa*	0.02	0.00	0.91	0.06
Off-type (lost variety)	The Gambia	*O. sativa*	0.00	0.01	0.90	0.09

Wapu	Guinea Bissau	*O. sativa*	0.00	0.04	0.89	0.07
Off-type (in Uyeeye)	Guinea Bissau	*O. sativa*	0.00	0.06	0.87	0.07
Kolosarr, original	Guinea Bissau	*O. sativa*	0.00	0.00	0.00	1.00
Daakulo Koyo	Senegal	*O. sativa*	0.00	0.00	0.00	1.00
Kumoi	The Gambia	*O. sativa*	0.00	0.00	0.00	1.00
M Mesengo	The Gambia	*O. sativa*	0.00	0.00	0.00	1.00
Mani Wulengo	The Gambia	*O. sativa*	0.00	0.00	0.00	1.00
Kolosarr, Bondiya	Guinea Bissau	*O. sativa*	0.00	0.01	0.00	0.99
Konsonkuto	Guinea Bissau	*O. sativa*	0.00	0.00	0.00	0.99
Maimuna	Guinea Bissau	*O. sativa*	0.00	0.00	0.00	0.99
Kissi Foundeyi	Guinea Conakry	*O. sativa*	0.00	0.00	0.00	0.99
Wonyonwonyon yi	Guinea Conakry	*O. sativa*	0.00	0.01	0.01	0.99
Ablie Mano	Senegal	*O. sativa*	0.00	0.00	0.00	0.99
Einu	Senegal	*O. sativa*	0.00	0.01	0.00	0.99
Madina Wulengo	Senegal	*O. sativa*	0.00	0.01	0.00	0.99
Kari Saba	The Gambia	*O. sativa*	0.00	0.01	0.00	0.99
Mani Mesendingo	The Gambia	*O. sativa*	0.00	0.01	0.00	0.99
Off-type (in Mani Wulendingo)	The Gambia	*O. sativa*	0.00	0.01	0.00	0.99
Kolosarr, M Wulendingo	Guinea Bissau	*O. sativa*	0.00	0.02	0.00	0.98
Mesemese	Guinea Bissau	*O. sativa*	0.00	0.02	0.00	0.98
Off-type (in Madina Wulengo)	Senegal	*O. sativa*	0.00	0.02	0.01	0.98
Binta Sambou	The Gambia	*O. sativa*	0.00	0.02	0.00	0.98
Mani Wulendingo	The Gambia	*O. sativa*	0.00	0.02	0.00	0.98
Off-type (in Madina Wulengo)	Senegal	*O. sativa*	0.00	0.01	0.03	0.95
Kong	Senegal	*O. sativa*	0.00	0.05	0.02	0.93
Moti	The Gambia	*O. sativa*	0.00	0.03	0.08	0.89
Off-type (in Madina Wulengo)	Senegal	*O. sativa*	0.00	0.02	0.11	0.88
Daakulo	Senegal	*O. sativa*	0.00	0.41	0.00	0.59
Trimonte	Guinea Conakry	Hybrid	0.00	1.00	0.00	0.00
Off-type (in Daakulo)	Senegal	Hybrid	0.00	0.99	0.00	0.00
Ataa	Ghana	Hybrid	0.00	0.71	0.00	0.28
Off-type (in WAB 56-50)	The Gambia	Hybrid	0.20	0.64	0.15	0.01
Aquablue awinto	Togo	Hybrid	0.00	0.00	1.00	0.00
Khaki	Togo	Hybrid	0.00	0.00	1.00	0.00
Aqua blue signaweh	Ghana	Hybrid	0.00	0.00	0.99	0.00
Pa Three Month2	Sierra Leone	Hybrid	0.00	0.01	0.99	0.01
Nerica 2 (off-type)	Ghana	Hybrid	0.00	0.01	0.94	0.04
Nerica 2	Ghana	Hybrid	0.12	0.00	0.87	0.00
Sewa	Guinea Conakry	Hybrid	0.00	0.13	0.86	0.00
Off-type (in WAB 56-50)	The Gambia	Hybrid	0.20	0.00	0.80	0.00
Dissi	Guinea Bissau	Hybrid	0.00	0.00	0.00	0.99
Jangjango	Guinea Bissau	Hybrid	0.00	0.00	0.00	0.99
Untufa	Guinea Bissau	Hybrid	0.00	0.00	0.01	0.99
Wansarang	Guinea Bissau	Hybrid	0.00	0.00	0.00	0.99
Tebeleh	Sierra Leone	Hybrid	0.01	0.00	0.01	0.98
Pa Three Month1	Sierra Leone	Hybrid	0.00	0.05	0.01	0.95
Pa Three Month3	Sierra Leone	Hybrid	0.00	0.01	0.10	0.88
Kaomo with awns	Ghana	unclear	1.00	0.00	0.00	0.00
Kolonkalan 1b	Sierra Leone	unclear	1.00	0.00	0.00	0.00
Off-type 1A	Sierra Leone	unclear	1.00	0.00	0.00	0.00
Pindie	Sierra Leone	unclear	1.00	0.00	0.00	0.00
Egomu	Ghana	unclear	0.97	0.01	0.01	0.01
Off-type 1B	Sierra Leone	unclear	0.96	0.02	0.00	0.02
Pugulu undef.	Ghana	unclear	0.00	0.99	0.00	0.01
Pugulu white	Ghana	unclear	0.00	0.99	0.00	0.00
Viono tall	Ghana	unclear	0.00	0.99	0.01	0.00
Pa Follah	Sierra Leone	unclear	0.00	0.99	0.00	0.00

Tema	Togo	unclear	0.00	0.97	0.00	0.03
Pugulu red	Ghana	unclear	0.00	0.95	0.02	0.03
Pla-Camp	Sierra Leone	unclear	0.01	0.87	0.02	0.11
Damansah 3	Ghana	unclear	0.01	0.60	0.03	0.35
Pugulu undef.	Ghana	unclear	0.00	0.00	1.00	0.00
Gbondobai	Sierra Leone	unclear	0.00	0.00	1.00	0.00
Pugulu undef.	Ghana	unclear	0.00	0.00	0.99	0.00
Jebbeh-komie	Sierra Leone	unclear	0.01	0.00	0.98	0.00
Bogootie	Sierra Leone	unclear	0.00	0.02	0.96	0.02
Pindi-pabai 1a red	Sierra Leone	unclear	0.00	0.00	0.00	1.00
Pa DC	Sierra Leone	unclear	0.00	0.00	0.00	0.99
Pa Yariken	Sierra Leone	unclear	0.00	0.00	0.00	0.99
Pa DC	Sierra Leone	unclear	0.01	0.01	0.00	0.98
Trimont (white)	Sierra Leone	unclear	0.01	0.00	0.05	0.95
B. Modern varieties						
I Kong Pao	CIRAD	*O. sativa*	0.00	1.00	0.00	0.00
CCA	NARI	*O. sativa*	0.00	1.00	0.00	0.00
Parasana	NARI	*O. sativa*	0.00	1.00	0.00	0.00
Se 302 G (IRAT 11)	CIRAD	*O. sativa*	0.00	0.99	0.00	0.01
Se 319 G (IRAT 12)	CIRAD	*O. sativa*	0.00	0.99	0.00	0.01
IR66-23	IRRI	*O. sativa*	0.00	0.99	0.00	0.00
DJ 12-519	ISRA	*O. sativa*	0.00	0.99	0.00	0.00
DJ 8-341	ISRA	*O. sativa*	0.00	0.99	0.01	0.00
Off-type (in DJ-11-307)	NARI	*O. sativa*	0.00	0.99	0.00	0.00
RC18-3	IRRI	*O. sativa*	0.00	0.98	0.01	0.01
DJ-11-307	NARI	*O. sativa*	0.00	0.97	0.00	0.03
RC10-43	IRRI	*O. sativa*	0.00	0.94	0.01	0.05
IR36-63	IRRI	*O. sativa*	0.00	0.76	0.01	0.23
IRAT 10	CIRAD	*O. sativa*	0.00	0.00	1.00	0.00
IRAT 110	WARDA	*O. sativa*	0.00	0.00	1.00	0.00
IRAT 112	WARDA	*O. sativa*	0.00	0.00	1.00	0.00
OS 6 (Faro 11)	WARDA	*O. sativa*	0.00	0.00	1.00	0.00
WAB 365-B-2-H3-HB	WARDA	*O. sativa*	0.00	0.00	0.99	0.00
WAB 450-I-B-P-163-4-1	WARDA	Hybrid	0.00	0.00	1.00	0.00
WAB 450-I-B-P-105-HB	WARDA	Hybrid	0.06	0.00	0.93	0.00
Nerica 1	MOFA	Hybrid	0.08	0.02	0.77	0.14
C. Wild and semi-wild material						
*O. barthi*i black	The Gambia	*O. barthi*i	1.00	0.00	0.00	0.00
*O. barthi*i white	The Gambia	*O. barthi*i	1.00	0.00	0.00	0.00
Devil rice	Guinea Conakry	*O. barthi*i	0.97	0.01	0.01	0.01
Ngafa bei	Sierra Leone	*O. barthi*i	0.84	0.10	0.01	0.06
Ngewobei	Sierra Leone	*O. barthi*i	0.75	0.19	0.02	0.04

CHAPTER FIVE

Robustness and strategies of adaptation among farmer varieties of African rice (Oryza glaberrima) and Asian rice (Oryza sativa) across West Africa

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Abstract

This study offers evidence of the robustness of farmer rice varieties (*Oryza glaberrima* and *O. sativa*) in West Africa. Our experiments in five West African countries showed that farmer varieties were tolerant of sub-optimal conditions, but employed a range of strategies to cope with stress. Varieties belonging to the species *Oryza glaberrima* - solely the product of farmer agency - were the most successful in adapting to a range of adverse conditions. Some of the farmer selections from within the *indica* and *japonica* subspecies of *O. sativa* also performed well in a range of conditions, but other farmer selections from within these two subspecies were mainly limited to more specific niches. The results contradict the rather common belief that farmer varieties are only of local value. Farmer varieties should be considered by breeding programmes and used (alongside improved varieties) in dissemination projects for rural food security.

Keywords: *Oryza glaberrima*, *Oryza sativa*, robustness, adaptation, farmer varieties, West Africa

Introduction

It is often supposed that crops should only be grown where conditions are favourable. This is not an option for farmers cultivating food crops with limited resources. They have to grow what they need with the conditions they have been given. In short, they have to cope with sub-optimality. For these farmers, adaptability of varieties under sub-optimal conditions is an essential requirement [1, 2]. Hypothetically, we should expect to find this adaptability among farmer varieties since these are to a large extent the product of farmer selection. This would mean that farmer varieties are the result of interplay between local ecological and social factors.

In large parts of West Africa small-scale farmers rely upon the cultivation of upland rice under low input conditions in a great diversity of micro-environments. The first rice farming in West Africa was based exclusively on African rice (*O. glaberrima* Steud.). The cultivation of African rice is entirely a result of farmer agency as African rice has never been disseminated by extension programmes. Asian rice (*Oryza sativa*) is a more recent introduction, perhaps during the period of the Atlantic Slave trade (beginning c. 1550), or earlier via trans-Saharan trade routes. Asian rice has two main subspecies: *Oryza sativa* var. *japonica* (short-grained, mainly grown as upland rice) and *O. sativa* var. *indica* (long-grained, mainly a lowland type).

Today, farmers in the region mainly grow the two types of Asian rice. Nevertheless in certain areas African rice remains an important crop type [2-6]. These areas all seem to have a shared history of rice cultivation taking place against a background of special difficulty, such as war, population displacement or harsh ecological conditions [7]. This suggests the species may be selected for its greater tolerance to sub-optimal conditions when compared to Asian rice. The logic of the present study, therefore, is to compare African and Asian rice, in farmer conditions, in order to understand the extent to which plasticity and adaptability are factors in farmer varietal choice. The overall aim of the study is to secure a better knowledge base for possible complementary strategies of variety promotion. These complementary strategies would give due consideration both to varieties developed through scientific research and varieties produced by farmer selection. The objective is to assess the case for protecting farmer varieties as an important aspect of local food security, in an environment in which development agencies seek more generally to expand the range of high-yielding cultivars to meet urban rice demand across the region. Our study reports on differences in response to varying environments of a large sample of farmer varieties across five West African countries in the high-rainfall coastal zone.

The study tests the hypothesis that African rice may be more robust than Asian rice in West African farmer conditions. Here robustness is seen as the ability of a variety or group of varieties to perform well in a diversity of cultivation conditions. The following research questions are posed:

1. Are farmer varieties of *O. glaberrima* better suited to sub-optimal agro-ecological conditions than varieties of the two subspecies of *O. sativa*?
2. Do farmer varieties of *O. glaberrima* adapt better to different environmental conditions than varieties of the two subspecies of *O. sativa*?
3. What are the physiological processes and social and eco-regional patterns underlying the adaptation of farmer varieties across environments?

In achieving robustness, varieties can respond to environmental conditions by showing phenotypic plasticity in a range of traits [8, 9]. Different varieties or groups of varieties achieve robustness by combining variability and stability of different traits, thus constituting different physiological strategies. Hence, this study investigates whether different botanical groups of rice, or certain groups of varieties within those botanical groups, have developed different physiological strategies to achieve adaptation.

The hypothesis that African rice might be more robust than Asian rice in West African conditions would make sense of a number of observations already reported. Richards [7] has offered some general evidence that African rice is an important food reserve for communities facing special difficulty (e.g. when displaced by war). Dingkuhn *et al*. [10] and Johnson *et al*. [11] showed evidence that *O. glaberrima* has a vegetative vigour superior to that of *O. sativa*, thus is better able to suppress weeds. Sumi and Katayama [12] provided evidence that African rice has a yield potential similar to Asian counterparts.

Definitions

For a proper understanding of the paper we offer the following definitions of concepts and notions.

Robustness: the persistence of a system's characteristic behaviour under sub-optimal conditions, implying stable performance across environments. In the context of this paper, robustness is taken to be the ability of a variety or a group of varieties to yield well across distinct environments.

Adaptability: the ability of a variety or a group of varieties to be robust. Adaptability implies significant Genotype (G) × Environment (E) interactions.

Plasticity: the physiological process through which varieties adjust their phenotypes in response to different environmental conditions [13]. A plastic response of this nature does not require changes in gene frequencies (i.e. evolution). Such phenotypic shifts can allow varieties to achieve adaptability [9].

Sub-optimal farming: characterised by no or limited mineral fertilisation, no or natural pest and disease control, rain fed moisture conditions, rarely mono cropping, and below an optimal or standard level of output.

Tolerance: the ability of a variety to survive adverse conditions with only a small reduction in performance.

Materials and Methods

Ethics statement

We confirm that no specific permits were required for the locations where the described field trials were conducted, that these locations were not protected in any way, and that none of these field studies involved endangered or protected species. We thank local authorities, NGOs, research institutions and farmers for their support.

Variety collection and selection

From June to December 2007 we carried out field work in seven countries of Coastal West Africa, i.e. The Gambia, Ghana, Guinea, Guinea Bissau, Senegal, Sierra Leone and Togo (Figure 1). The field work aimed at (1) listing rice varieties/accessions used by farmers, (2) observing the development/physiology of these varieties in farmers' fields, and (3) collecting varieties at harvest. A total of 231 accessions were collected in 2007. After seed collection we carried out molecular analysis (AFLP) on the collected varieties in February and March 2008. Output of this molecular analysis was combined with the output of an analysis of 84 accessions performed in 2002 [14]. We used Version 2.2 of the software package 'Structure' to analyse genetic population structure and to assign samples to populations and 'SplitsTree' to visualise phylogenetic relationships between the samples. For further details please refer to [15]. Based on the output of the molecular analysis, 24 commonly cultivated farmer varieties (*O. glaberrima* and *O. sativa*, including representatives of both the *indica* and *japonica* groups) were selected for further study (Table 1). These 24 varieties reflect the popular varieties grown in different parts of the region and therefore provide a subset of the large set of farmer varieties identified, with good local performance but not necessarily large robustness. All 26 varieties were included in all five experiments described in this paper.

***Figure 1**: Geographic overview of the West African study area. Reprinted from [15] under a CC BY license, with permission from Edwin Nuijten, copyright 2009. Original figure generated using Google Maps.*

Results of AFLP analysis suggested several clusters within the various botanical groups. These clusters were more or less coinciding with the regions where the varieties were collected. The *glaberrima* divided into a cluster from the Upper Guinea Coastal region (Glab_UpperCoast) and a cluster from the Lower Guinea Coastal region (Glab_LowerCoast) (Figure 2a). The *indica* divided into *indica* from Ghana (Ind_Gh) and *indica* from Guinea (Ind_Gc) (Figure 2b) and the *japonica* into *japonica* from Ghana and Guinea Bissau (Jap_GbGh) and *japonica* from Sierra Leone (Jap_SL) (Figure 2c). It is possible the differences in the *japonica* group reflect different histories of introduction (Portuguese trading connections linking the Ghana and Guinea Bissau group, and British sources supplying Sierra Leone in the late 18th/early 19th centuries [cf. 16]. We used these molecular clusters in the analysis of robustness and adaptability.

Table 1: *List of varieties used in the study*

Code	Name of variety	Molecular cluster	Country of collection	Ecology of cultivation
O. glaberrima				
333	Saali Firê	Glab_UpperCoast	Guinea	Upland
347	Safaary	Glab_UpperCoast	Guinea	Upland
334	Tombo Bokary	Glab_UpperCoast	Guinea	Upland
318	Saali Forê	Glab_UpperCoast	Guinea	Upland
420	Jangjango	Glab_UpperCoast	Guinea Bissau	Upland/transition
435	Kurekimbeli	Glab_UpperCoast	Guinea Bissau	Upland/transition
113	Kaomo black	Glab_LowerCoast	Ghana (Togo mountain ranges)	Upland
124	Xleti eve	Glab_LowerCoast	Togo (Togo mountain ranges)	Upland
135	Kpakpalipke	Glab_LowerCoast	Togo (Togo mountain ranges)	Upland
272	Saliforeh	Glab_UpperCoast	Sierra Leone	Transition/upland
249	Maalay	Glab_UpperCoast	Sierra Leone	Transition/upland
O. sativa type *indica*				
348	Saidou Firê	Ind_Gc	Guinea	Upland
349	Saidou Gbéli	Ind_Gc	Guinea	Upland
130	Zomojo	Ind_Gh	Ghana (Togo mountain ranges)	Upland/transition/lowland
128	Viono tall	Ind_Gh	Ghana (Togo mountain ranges)	Upland/transition/lowland
163	Ataa	Ind_Gh	Ghana (Togo mountain ranges)	Upland/transition
O. sativa type *japonica*				
407	Demba Ba	Jap_GbGh	Guinea Bissau	Upland
427	Uyeey	Jap_GbGh	Guinea Bissau	Upland
432	Usefa Udjenel	Jap_GbGh	Guinea Bissau	Upland
141	Aqua blue	Jap_GbGh	Ghana (Togo mountain ranges)	Upland/transition
274	Nduliwa	Jap_SL	Sierra Leone	Transition/upland
210	Gbengbeng	Jap_SL	Sierra Leone	Transition/upland
215	Jebbeh-komi	Jap_SL	Sierra Leone	Transition/upland
408	Buba Njie	Jap_GbGh	Guinea Bissau	Upland/transition

Transition: variety cultivated in transitional zone between lowland and upland. Ind_Gc= cluster of *indica* from Guinea. Ind_Gh= cluster of *indica* from Ghana. Jap_GbGh= cluster of *japonica* from Guinea Bissau and Ghana. Jap_SL= cluster of *japonica* from Sierra Leone. Glab_LowerCoast= cluster of *glaberrima* from Lower Guinea coast. Glab_UpperCoast= cluster of *glaberrima* from Upper Guinea coast.

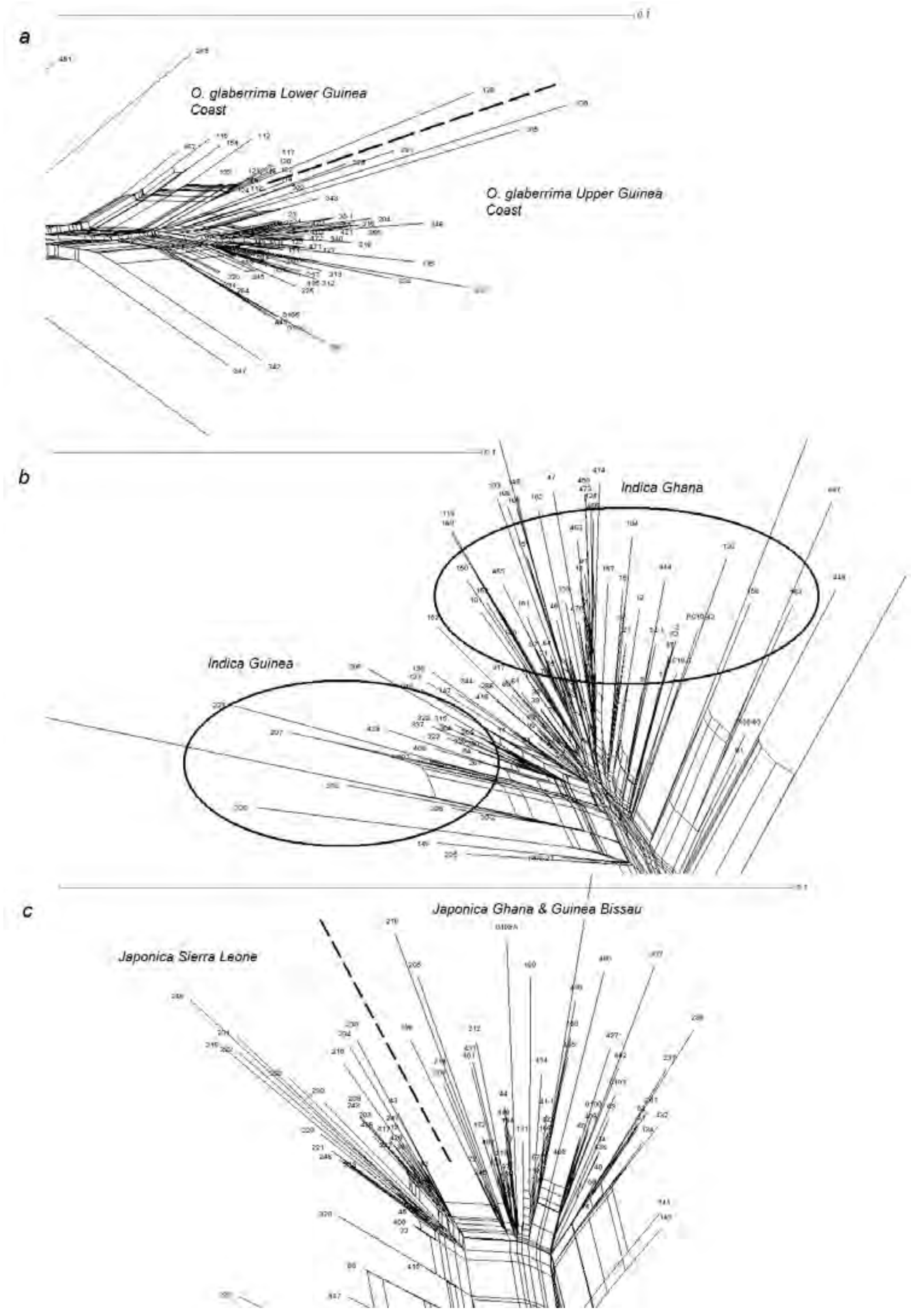


***Figure 2**: Phylogenetic relationships of glaberrima and its sub-clusters (a), indica and its sub-clusters (b), and japonica and its subclusters (c).*

Trials

Locations

Five trials were conducted in Guinea, Guinea Bissau, Ghana, Togo and Sierra Leone from June 2008 to January 2009. Table 2 summarises the characteristics of the experimental sites. Sites were selected to be representative for upland rice production on loamy soils. In all cases the experiments were planted after a fallow period.

***Table 2**: Characteristics of the experimental sites*

	Guinea	Guinea Bissau	Ghana	Togo	Sierra Leone
GPS coordinates	10.00275 N 12.91770 W 379 m asl	12.131734 N 15.93607 W 10 m asl	7.26429 N 0.46984 W 213 m asl	7.27028 N 0.71598 W 809 m asl	8.14917 N 11.90806 W 58 m asl
Ecology	Upland	Upland	Upland	Upland	Upland
Soil characteristics					
pH (water)	4.8	4.6	4.6	4.9	4.2
OC%	2.9	1.6	1.9	5.4	4.1
total N g kg^{-1}	0.9	0.2	0.7	0.9	0.6
ppm Meh P	8.1	0.6	7.8	7.0	5.5
sand%	69.0	81.3	63.0	65.0	16.0
clay%	13.7	12.8	8.0	19.0	7.0
silt%	11.1	5.3	28.0	10.0	70.0
soil type	Sandy loam	Loamy sand	Sandy loam	Sandy (clay) loam	Silty loam
Background of experiment sites	- One year fallow - Previous crops (successively): rice, groundnut (*Arachis hypogaea*), cassava (*Manihot esculenta*) - Presence of *Imperata cylindrica*	-At least 5 years of fallow	-5 year fallow -Previous crop: maize (*Zea mays*)	-3 years fallow -Previous crop: maize (*Zea mays*)	24 years fallow. Previous crops: rice mixed cropping (cropped with squash, cucumber (*Cucumis spp.*), eggplant (*Solanum spp.*), pepper (*Capsicum spp.*), sorrel (*Hibiscus spp.*), legumes, *Zea mays*, *Manihot esculenta*, *Ipomoea batatas*, *Arachis hypogaea*, etc. -Presence of *Pennisetum purpureum* -Home for natural pests: rodents, stems borers etc.
Average annual rainfall (mm)	2800-4000	1500	1500	1200	2100-3000
Duration rainfall (months)	6	4 to 5	7	7	6 to 7
General observation	Stress and plant mortality observed during crop establishment phase	Good germination and growth. The late maturing varieties suffered from drought and rodent damage	Most plants showed excellent germination and growth	Most plants showed some traces of acidity damage	-Excellent germination and growth -Low to moderate pest (rodents, termites, cut worms, stem borers) incidences were most specific to *O. sativa* japonica
Trial setup dates					
First sowing	28 June 2008	29 June 2008	16 July 2008	09 July 2008	12 June 2008
Second sowing	16 July 2008	13 July 2008	06 August 2008	30 July 2008	04 July 2008

The experiments were carried out in one growing season. By including different sowing times, we created diverse environmental conditions within each site. The growing seasons allowed normal performance of the crops, although the Guinea experiment experienced some stress during crop establishment and the Guinea Bissau experiment experienced late season drought affecting the late-maturing varieties only.

Experimental design

In each of the five trials, the varieties were sown in a randomised block design with two sowing dates and five replications, resulting in 24 × 2 × 5 = 260 plots. All 24 varieties were included in all experiments. Sowing dates were determined by following the farmers' practices in each region. The time between the first and the second sowing was two to three weeks. Each plot was 1.5 m × 2.1 m and contained 70 pockets, spaced 30 cm between rows and 15 cm within rows. Three to five grains were sown in each pocket and pockets were thinned to one plant within four weeks after sowing.

Measurements

Table 3 summarises the measured variables, the methodology of assessment and the trials in which they were recorded.

The percentage of canopy coverage was determined during the growing cycle using frames of 60 cm × 75 cm (in Togo and Ghana) and 60 cm × 45 cm in Guinea that were put in the plot and photographed from straight above. A series of about 20 photos representing a wide range of canopy cover values was analysed with Matlab 7 and DIP image [17], to allow calculation of the percentage green in a photo. Based on this calibration the percentages of canopy coverage were estimated for all photos.

Determination of the canopy cover development

For each plot, canopy coverage curves were made on the basis of 6 to 12 measurements. As curves for the different replications showed a large variation and a block effect was not found we decided to carry out curve fitting on the average values of the five replications.

To describe the canopy development we used a modified version of the model developed by Khan *et al*. [18] for potato. The model of Khan *et al*. distinguishes three development phases for potato: the build-up phase, the phase where the canopy cover remains constant and the decline phase. In our case, possibly because of stress the plants experienced, the canopy never

***Table 3**: Measured parameters and countries of measurement.*

Parameters	*indication on methods of measurement*	*Trials where parameters were measured*
Canopy cover	See below (section: Determination of the canopy cover development)	Ghana, Guinea and Togo
Plant height (cm)*	Measured from the base of the plant to the tip of the panicle of the main tiller	Ghana, Guinea, Guinea Bissau, Sierra Leone, Togo
Number of tillers*	Total number of tillers per plant	Ghana, Guinea, Guinea Bissau, Sierra Leone, Togo
Days to 50% flowering	The number of days between the sowing date and the date 50% of the plants flowered	Ghana, Guinea, Guinea Bissau, Sierra Leone, Togo
Number of panicles*	Total number of panicles per plants	Guinea, Guinea Bissau, Sierra Leone
Panicle length (cm)*	Measured from the base to the tip of the panicle of the main axis	Ghana, Guinea, Guinea Bissau, Sierra Leone, Togo
Panicle weight (g)	Weight of the grains of 14 panicles	Ghana and Togo
200 grain weight (g)	Weight of 200 filled grain. Unfilled and partially filled grains were excluded	Ghana, Guinea, Guinea Bissau, Togo
Plot yield (kg/ha)	Weight of the three inner rows	Ghana, Guinea Bissau, Sierra Leone, Togo

**Measured on 6 plants randomly selected from the inner rows.*

reached 100% coverage, nor did it reach a plateau level maintained for any period of time. This simplified the model because the time that the maximum canopy cover was reached (t_1) and the time it started to decline (t_2) coincided, resulting into a two-phase model:

Phase 1

$$v = v_{max}\left(1 + \frac{t_1 - t}{t_1 - t_{m1}}\right)\left(\frac{t}{t_1}\right)^{\frac{t_1}{t_1 - t_{m1}}} \text{ with } 0 \leq t \leq t_1 \qquad (1)$$

Phase 2

$$v = v_{max}\left(\frac{t_e - t}{t_e - t_1}\right)\left(\frac{t}{t_1}\right)^{\frac{t_1}{t_e - t_1}} \text{ with } t_1 \leq t \leq t_e \qquad (2)$$

where:

v = canopy cover (%)

v_{max} = maximum canopy cover (%)

t_{m1} = the inflexion point

t_1 = the time the maximum canopy cover is reached

t_e = the time when the canopy has declined to 0

t_{m1}, t_1, v_{max} and t_e were estimated using SAS.

The accumulated canopy cover A, represented by the sum of surfaces under the curves of phase 1 and 2, was estimated by using the following formulae:

Surface under the curve for phase 1 (A_1):

$$A_1 = v_{max}\left(\frac{2t_1(t_1 - t_{m1})}{3t_1 - 2t_{m1}}\right) \qquad (3)$$

Surface under the curve for phase 2 (A_2):

$$A_2 = \frac{v_{\max}(t_e - t_1)}{2t_e - t_1}\left(t_e\left(\frac{t_e}{t_1}\right)^{\frac{t_1}{t_e - t_1}} - 2t_1\right) \qquad (4)$$

Estimation of the accumulated canopy cover (A):

$$A = A_1 + A_2 \qquad (5)$$

Data analysis

G×E interactions

As different botanical groups and molecular clusters were compared, interactions between genotypes and environment were analysed through ANOVA (analysis of variance) to assess differences in responses to different environments within and between botanical groups. Significant G×E interactions point to the presence of such a variation in response and indicate that the botanical group or cluster contains varieties that respond differently to different environments, which can be considered an indicator of adaptability within a specific botanical group or cluster. We used the Tukey test to compare means.

Wide sense heritability estimates

H^2=100×Vg/(Vg+1/rsVgs+1/rlVgl+1/rslVgls+1/rVe)

where:

H^2 = wide sense heritability

Vg = genetic variance

Vgs = variance genetic × sowing interactions

Vgl = variance genetic × location interactions

Vgls = variance genetic × location × sowing interactions

Ve = error variance

r = number of replications (5)

s = number of sowings (2)

l = number of locations (2, 3, 5)

Descriptive statistics

Averages and standard deviations were calculated.

Results

In the following sections the parameters are investigated for each botanical group (*glaberrima*, *indica* or *japonica*) and molecular cluster (see section on Materials and Methods). The parameters are dealt with one by one and cross references are made among them to unravel strategies of adaptation. Graphs are used to compare performance of each parameter across environments. ANOVAs provided important information on adaptability, as they provided estimates of G×E interactions (Tables 4-13).

Table 14 shows the average performance of the studied genotypes (grouped into botanical groups and molecular clusters) for ten parameters used to analyse the vegetative growth and yield components: maximum canopy cover (V_{max}; %), accumulated canopy cover (A; %.day), plant height (cm), number of tillers per plant (# tillers), days to 50% flowering (50% flowering), number of panicles per plant (#panicles), panicle length (cm), panicle weight (g), 200 grain weight (g) and grain yield (kg/ha). Tables 14 and 15 show the yield and yield components for the five countries, wheras Table 16 shows the estimates of the wide sense heritability for the ten variables listed in Tables 4-14. Tables 17-25 show the Pearson correlations between the yield components.

Maximum canopy cover (V_{max}) and accumulated canopy cover (A)

V_{max} and A correlated positively (r = 0.984**) at 0.01 level. The same trend was observed for all botanical groups and molecular clusters in all environments (Tables 17-25; Figure 3). Accumulated canopy cover (A) can therefore represent V_{max} and vice versa. In all cases the surface under the canopy curves (A) can be conceived as a triangle with the cycle length (Te) as base and V_{max} as

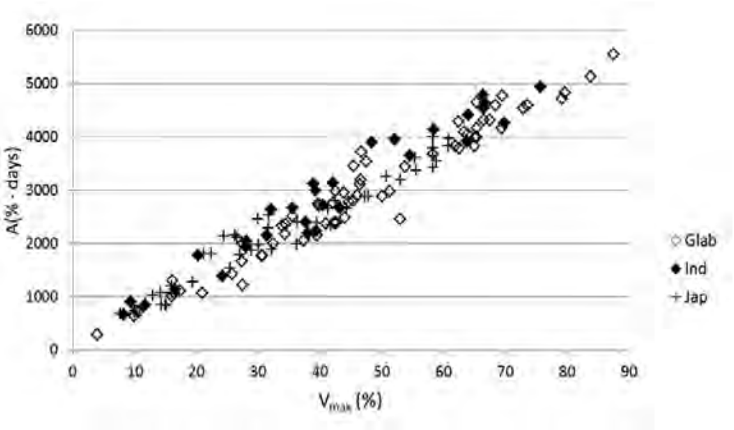


***Figure 3**: Relation between the accumulated canopy cover over the whole growing cycle (A; y-axis, in %.days) and the maximum canopy cover (Vmax; x-axis, in %) . Data refer to all combinations of location ×genotype × sowing time, whereas different symbols refer to different botanical groups (glaberrima, indica and japonica).*

***Tables 4-13**: Interaction effects of genotypes, sowing dates and trial locations (location) on maximum canopy development (Vmax), accumulated canopy (A), plant height, number of tillers per plant (#tillers), days to 50% flowering (50% flowering), number of panicles per plant (#panicles), panicle length, panicle weight, 200 grains weight and yield of 24 genotypes grouped according to their botanical groups and further on molecular clusters.*

Table 4: All botanical groups and clusters together

	Genotype	Sowing	Location	Genotype* Sowing	Genotype * Location	Sowing* Location	Genotype* Sowing* Location
V_{max} [d]	0.000***	0.758	0.026*	0.092	0.881	0.029*	-
A [d]	0.000***	0.435	0.027*	0.014*	0.444	0.001***	-
Plant height [f]	0.000***	0.922	0.002**	0.612	0.000***	0.000***	0.264
# Tillers[f]	0.000***	0.533	0.006**	0.043*	0.000***	0.000***	0.986
50% Flowering [f]	0.000***	0.011*	0.000***	0.008**	0.000***	0.003**	0.000***
# Panicles [a]	0.000***	0.334	0.112	0.005**	0.000***	0.000***	0.947
Panicle length [a]	0.000***	0.890	0.003**	0.023*	0.000***	0.000***	0.017*
Panicle weight [e]	0.000***	0.140	0.502	0.236	0.157	0.194	0.012*
200 grains weight [b]	0.000***	0.318	0.006**	0.069	0.018*	0.031*	0.850
Yield [c]	0.000***	0.070	0.042*	0.583	0.873	0.020*	0.000***

*Values in the table are p values (three-way ANOVA). *: Significant at 0.05 level. **: significant at 0.01 level. ***: Significant at 0.001 level. **a**: ANOVA performed for Guinea Bissau, Guinea and Sierra Leone. **b**: ANOVA performed for Guinea Bissau, Guinea, Ghana and Togo. **c**: ANOVA performed for Guinea Bissau, Ghana, Sierra Leone and Togo. **d**: ANOVA performed for Ghana, Guinea and Togo. **e**: ANOVA performed for Ghana and Togo. **f**: ANOVA performed for all five countries. -: not assessed*

Tables 4-13 continued:

Table 5: Glaberrima botanical group

	Genotype	Sowing	Location	Genotype* Sowing	Genotype* Location	Sowing* Location	Genotype* Sowing* Location
Vmax [d]	0.190	0.373	0.083	0.464	0.319	0.000***	-
A [d]	0.260	0.217	0.055	0.268	0.132	0.000***	-
Plant height [f]	0.000***	0.797	0.009**	0.471	0.001***	0.000***	0.469
# Tillers[f]	0.097	0.246	0.003**	0.268	0.000***	0.014*	0.612
50% Flowering [f]	0.000***	0.007**	0.001***	0.069	0.014*	0.024*	0.000***
# Panicles [a]	0.314	0.267	0.117	0.025*	0.000***	0.000***	0.998
Panicle length [a]	0.000***	0.810	0.001***	0.024*	0.004**	0.009**	0.024*
Panicle weight [e]	0.051	0.255	0.081	0.359	0.088	0.279	0.563
200 grains weight [b]	0.000***	0.457	0.003**	0.584	0.019*	0.103	0.940
Yield [c]	0.000***	0.458	0.254	0.619	0.981	0.002**	0.000***

Table 6: Cluster of Glaberrima from Lower Guinea coast (Glab_Lower Coast)

	Genotype	Sowing	Location	Genotype* Sowing	Genotype* Location	Sowing*L ocation	Genotype* Sowing* Location
Vmax [d]	0.137	0.737	0.176	0.330	0.877	0.172	-
A [d]	0.740	0.464	0.082	0.129	0.609	0.053	-
Plant height [f]	0.567	0.566	0.218	0.685	0.665	0.641	0.042*
# Tillers[f]	0.852	0.061	0.002**	0.638	0.026*	0.347	0.935
50% Flowering [f]	0.014*	0.001***	0.004**	0.086	0.061	0.534	0.022*
# Panicles [a]	0.840	0.243	0.086	0.145	0.091	0.008**	0.963
Panicle length [a]	0.582	0.164	0.178	0.144	0.791	0.441	0.393
Panicle weight [e]	0.274	0.081	0.370	0.641	0.330	0.926	0.517
200 grains weight [b]	0.056	0.421	0.119	0.654	0.325	0.258	0.218
Yield [c]	0.099	0.316	-	0.570	0.899	0.604	0.017*

Table 7: Cluster of Glaberrima from Upper Guinea coast (Glab_Upper Coast)

	Genotype	Sowing	Location	Genotype* Sowing	Genotype* Location	Sowing* Location	Genotype* Sowing* Location
Vmax [d]	0.589	0.276	0.076	0.973	0.178	0.001***	-
A [d]	0.545	0.170	0.055	0.667	0.184	0.002**	-
Plant height [f]	0.003**	0.702	0.027*	0.209	0.000***	0.000***	0.956
# Tillers[f]	0.664	0.397	0.031*	0.27	0.008**	0.056	0.145
50% Flowering [f]	0.000***	0.017*	0.005**	0.455	0.29	0.091	0.000***
# Panicles [a]	0.372	0.294	0.144	0.025*	0.000***	0.000***	0.982
Panicle length [a]	0.018*	0.919	0.010**	0.003**	0.000***	0.000***	0.439
Panicle weight [e]	0.309	0.300	0.242	0.322	0.128	0.221	0.454
200 grains weight [b]	0.202	0.581	0.001***	0.464	0.013*	0.329	0.98
Yield [c]	0.000***	0.519	0.412	0.344	0.902	0.001***	0.039*

*Values in the table are p values (three-way ANOVA). *: Significant at 0.05 level. **: significant at 0.01 level. ***: Significant at 0.001 level. **a**: ANOVA performed for Guinea Bissau, Guinea and Sierra Leone. **b**: ANOVA performed for Guinea Bissau, Guinea, Ghana and Togo. **c**: ANOVA performed for Guinea Bissau, Ghana, Sierra Leone and Togo. **d**: ANOVA performed for Ghana, Guinea and Togo. **e**: ANOVA performed for Ghana and Togo. **f**: ANOVA performed for all five countries. -: not assessed*

Tables 4-13 continued:

Table 8: Indica botanical group

	Genotype	Sowing.	Location	Genotype* Sowing	Genotype* Location	Sowing*L ocation	Genotype* Sowing* Location
Vmax [d]	0.017*	0.931	0.06	0.16	0.746	0.171	-
A [d]	0.031*	0.588	0.038*	0.177	0.508	0.055	-
Plant height [f]	0.089	0.591	0.000***	0.72	0.000***	0.010**	0.057
# Tillers[f]	0.553	0.998	0.001***	0.022*	0.001***	0.006**	0.979
50% Flowering [f]	0.027*	0.005**	0.000***	0.233	0.003**	0.432	0.120
# Panicles [a]	0.358	0.654	0.149	0.100	0.002**	0.315	0.829
Panicle length [a]	0.162	0.474	0.002**	0.595	0.063	0.377	0.047*
Panicle weight [e]	0.174	0.029*	0.230	0.377	0.271	0.732	0.457
200 grains weight [b]	0.001***	0.053	.	0.339	0.794	0.866	0.365
Yield [c]	0.001***	0.002**	0.358	0.630	0.441	0.916	0.000***

Table 9: Cluster of Indica from Ghana (Ind_Gh)

	Genotype	Sowing.	Location	Genotype* Sowing	Genotype* Location	Sowing* Location	Genotype* Sowing* Location
Vmax [d]	0.057	0.362	estimate.	0.229	0.943	0.756	-
A [d]	0.099	0.762	0.439	0.253	0.891	0.370	-
Plant height [f]	0.385	0.480	0.001 ***	0.798	0.022*	0.124	0.012*
# Tillers[f]	0.361	0.580	0.005 **	0.078	0.055	0.201	0.702
50% Flowering [f]	0.026*	0.026*	0.011*	0.245	0.172	0.539	0.019*
# Panicles [a]	0.448	0.548	0.864	0.222	0.038*	0.644	0.44
Panicle length [a]	0.158	0.872	0.081	0.475	0.170	0.287	0.139
Panicle weight [e]	-	0.119	-	-	-	-	-
200 grains weight [b]	-	-	-	-	-	-	-
Yield [c]	0.016*	0.062	0.061	0.385	0.192	0.342	0.000 ***

Table 10: Cluster of Indica from Guinea (Ind_Gc)

	Genotype	Sowing.	Location	Genotype* Sowing	Genotype* Location	Sowing* Location	Genotype* Sowing* Location
Vmax [d]	0.103	0.657	0.025*	0.242	0.074	0.033*	-
A [d]	0.052	0.439	0.017*	0.122	0.100	0.035*	-
Plant height [f]	0.962	0.957	0.000***	0.829	0.025*	0.008**	0.964
# Tillers[f]	0.634	0.440	0.018*	0.384	0.006**	0.031*	0.973
50% Flowering [f]	0.286	0.003**	0.029*	0.551	0.118	0.823	0.391
# Panicles [a]	0.500	0.189	0.114	0.774	0.038*	0.242	0.876
Panicle length [a]	0.781	0.369	0.021*	0.416	0.180	0.397	0.368
Panicle weight [e]	0.412	0.032*	0.377	0.336	0.358	0.761	0.540
200 grains weight [b]	0.272	0.481	0.350	0.535	0.573	0.494	0.302
Yield [c]	0.598	0.097	0.090	0.112	0.454	0.022*	0.501

*Values in the table are p values (three-way ANOVA). *: Significant at 0.05 level. **: significant at 0.01 level. ***: Significant at 0.001 level. **a**: ANOVA performed for Guinea Bissau, Guinea and Sierra Leone. **b**: ANOVA performed for Guinea Bissau, Guinea, Ghana and Togo. **c**: ANOVA performed for Guinea Bissau, Ghana, Sierra Leone and TogO. **d**: ANOVA performed for Ghana, Guinea and Togo. **e**: ANOVA performed for Ghana and Togo. **f**: ANOVA performed for all five countries. -: not assessed*

***Table 4-13** continued:*

Table 11: Japonica botanical group

	Genotype	Sowing.	Location	Genotype* Sowing	Genotype* Location	Sowing* Location	Genotype* Sowing* Location
Vmax [d]	0.047**	0.178	0.047**	0.703	0.468	0.011**	-
A [d]	0.176	0.318	0.065	0.818	0.285	0.002***	-
Plant height [f]	0.021*	0.562	0.000***	0.846	0.000***	0.001***	0.404
# Tillers[f]	0.000***	0.755	0.033*	0.965	0.008**	0.000***	0.963
50% Flowering [f]	0.001***	0.431	0.005**	0.108	0.007**	0.000***	0.012*
# Panicles [a]	0.010**	0.803	0.653	0.946	0.282	0.020*	0.121
Panicle length [a]	0.000***	0.86	0.038*	0.043*	0.000***	0.000***	0.784
Panicle weight [e]	0.182	0.158	0.405	0.813	0.608	0.368	0.022*
200 grains weight [b]	0.000***	0.197	0.085	0.178	0.936	0.216	0.660
Yield [c]	0.001***	0.006**	estimate.	0.644	0.987	0.884	0.000***

Table 12: Cluster of Japonica from Guinea Bissau and Ghana (Jap_GbGh)

	Genotype	Sowing.	Location	Genotype* Sowing	Genotype* Location	Sowing* Location	Genotype* Sowing* Location
Vmax [d]	0.331	0.116	0.030*	0.637	0.472	0.142	-
A [d]	0.355	0.205	0.028*	0.725	0.347	0.069	-
Plant height [f]	0.080	0.607	0.000***	0.693	0.004**	0.045*	0.229
# Tillers[f]	0.000 ***	0.764	0.035*	0.891	0.714	0.005**	0.661
50% Flowering [f]	0.857	0.574	0.007**	0.851	0.006**	0.000***	0.408
# Panicles [a]	0.027*	0.805	0.466	0.860	0.995	0.106	0.036*
Panicle length [a]	0.005 **	0.808	0.028*	0.014*	0.001***	0.000***	0.835
Panicle weight [e]	0.074	0.188	0.576	0.495	0.547	0.352	0.091
200 grains weight [b]	0.000 ***	0.571	0.129	0.339	0.917	0.278	0.705
Yield [c]	0.856	0.329	0.089	0.442	0.605	0.016*	0.039*

Table 13: Cluster of Japonica from Sierra Leone (Jap_SL)

	Genotype	Sowing.	Location	Genotype* Sowing	Genotype* Location	Sowing* Location	Genotype* Sowing* Location
Vmax [d]	0.433	0.293	0.097	0.526	0.461	0.133	-
A [d]	0.550	0.473	0.128	0.578	0.306	0.044*	-
Plant height [f]	0.072	0.568	0.003**	0.736	0.005**	0.005**	0.845
# Tillers[f]	0.062	0.747	0.049*	0.775	0.072	0.023*	0.949
50% Flowering [f]	0.067	0.305	0.002**	0.044*	0.069	0.037*	0.052
# Panicles [a]	0.199	0.812	0.218	0.88	0.125	0.088	0.816
Panicle length [a]	0.032*	0.988	0.229	0.251	0.006**	0.02*	0.637
Panicle weight [e]	0.977	0.634	-	0.917	0.673	0.728	0.082
200 grains weight [b]	0.328	1.000	-	0.735	0.948	0.925	0.067
Yield [c]	0.114	0.082	0.619	0.516	0.943	0.422	0.000***

*Values in the table 1-10 are p values (three-way ANOVA). *: Significant at 0.05 level. **: significant at 0.01 level. ***: Significant at 0.001 level. a: ANOVA performed for Guinea Bissau, Guinea and Sierra Leone. b: ANOVA performed for Guinea Bissau, Guinea, Ghana and TogO. c: ANOVA performed for Guinea Bissau, Ghana, Sierra Leone and TogO. d: ANOVA performed for Ghana, Guinea and TogO. e: ANOVA performed for Ghana and TogO. f: ANOVA performed for all five countries. -: not assessed* height. Variations in cycle length (Te), inflexion point (Tm1) and the time V_{max} was reached (T1) appear to confirm that A is linearly related to V_{max}.

None of the botanical groups or molecular clusters showed G×E interactions for A or V_{max} (Tables 5-13). This means that within all botanical groups and molecular clusters the varieties responded comparably for A and V_{max} across environments.

However, for all three botanical groups significant sowing × location interactions were found, in particular for *glaberrima* and *japonica*. Sowing × location interactions were highly significant for the *glaberrima* botanical group and Glab_UpperCoast but not significant for the Glab_LowerCoast cluster. Glab_LowerCoast therefore maintained better A and Vmax across environments, since its genotypes reacted in a similar way to different environments. However, the developed canopy did not turn into a yield increase as Glab_UpperCoast yielded more than Glab_LowerCoast (Table 14).

Of the *indica* group, it was only in the Ind_Gc cluster that significant sowing × location interactions were found for A and V_{max}. The *indica* group showed a significant location effect for A. No significant effects were found for the Ind_Gh cluster. This indicates that the Ind_Gh maintained better V_{max} and A than the Ind_Gc but often failed to yield (Figures 4 and 5).

The *japonica* group showed significant sowing × location interactions, suggesting that (for the two *japonica* clusters) A and V_{max} varied across environments. At cluster level significant sowing × location interactions were found for Jap_SL for V_{max} only, while for the Jap_GbGh cluster the location effects were significant for both A and V_{max}. This suggests that Jap_SL maintained A across environments better than Jap_GbGh. However Jap_SL showed considerable yield variation (Figure 5), suggesting that the relative stability observed for A did not contribute to yield stability.

Generally, the highest A was observed in Ghana followed by Togo and Guinea (Figure 4).

Yield

The analyses of variance performed for all genotypes and at botanical group level showed a highly significant three-way interaction for yield (Tables 4-13). This suggests that the studied rice varieties generally responded differently in yield across environments and sowing dates. The yield variability studied at cluster level also revealed significant G×E interactions (Tables 3, 4, 6, 9 and 10) with the exception of the *indica* cluster from Guinea (Ind_Gc) (Table 10). The yield therefore varied in a similar manner across environments for genotypes of Ind_Gc.

The *glaberrima* botanical group showed the highest yields across all environments (Table 14 and Figure 5). “Zero” yields (complete crop failure) occurred only with *indica* and *japonica*.

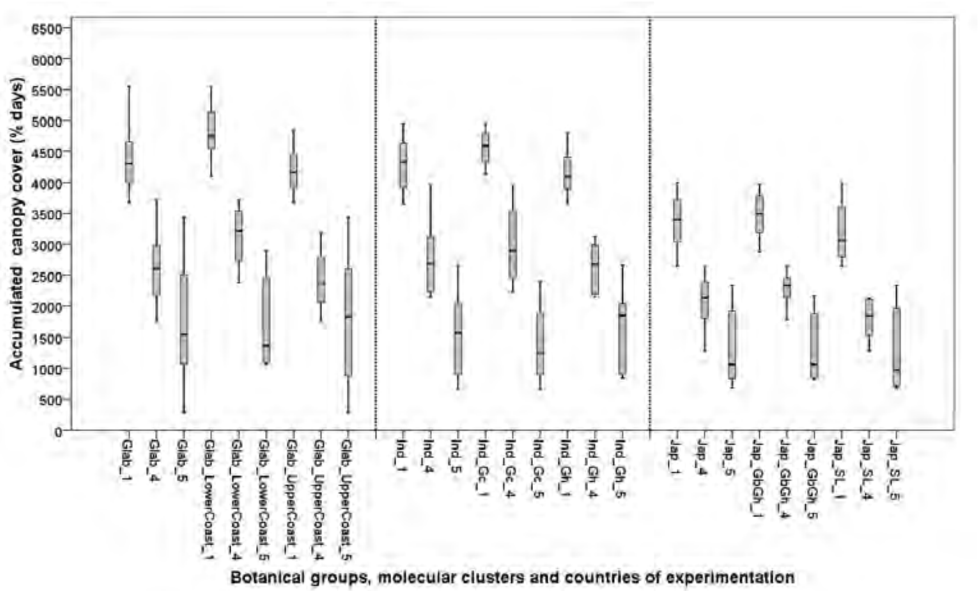


Figure 4: *Box plots for accumulated canopy cover (A; %.days) of 24 varieties in three experimental sites: Ghana (1); Togo (4) and Guinea (5). See materials and methods section for coding of the botanical groups and molecular clusters.*

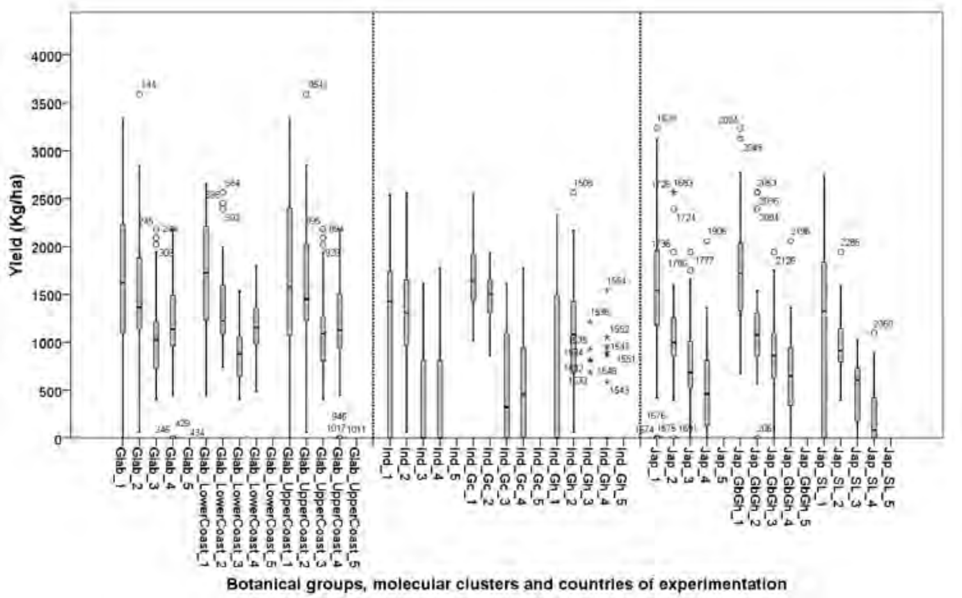


Figure 5: *Box plots for grain yield (in kg/ha) of 24 varieties in four experimental sites: 1: Ghana; 2: Sierra Leone; 3: Guinea Bissau; and 4: Togo; in 5: Guinea yield was not measured. See materials and methods section for coding of the botanical groups and molecular clusters*

At cluster level, *glaberrima* from upper Guinea coast (Glab_UpperCoast) showed the highest yield. *Glaberrima* from the Lower Guinea coast (Glab_LowerCoast) had the same yield range as *japonica* from Guinea Bissau and Ghana (Jap_GbGh) and Ind_Gc. Ind_Gh and Jap_SL showed the lowest average yield.

A comparison of the botanical groups on the yield across environments (Figure 5) shows that, within the same environment, *glaberrima* yielded more than *indica* and *japonica*. In Ghana where the average plot yield was generally high, some *indica* varieties showed “zero” yield. Zero yield occurred for *japonica* only in Guinea Bissau and Tog*O*. These are the two countries where the overall yield was generally lowest.

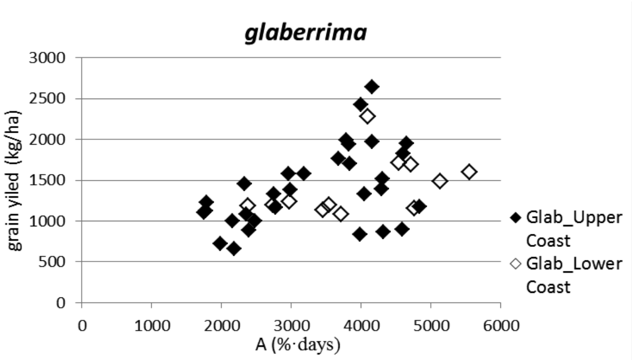
Figures 6a-c show the graphical representations of the relationships between yield and A for each botanical group. At cluster level different relationships were observed. The relation between yield and A was similarly low for Glab_LowerCoast and Glab_UpperCoast (r = 0.451 and r = 0.476** respectively). This shows that *glaberrima* can yield well even when relatively low accumulated canopy cover is produced.

For the *indica* and *japonica* clusters clear differences in the relationship between grain yield and A were found. A significant relationship between yield and A was found for Ind_Gc (r = 0.857**) but not for Ind_Gh (r = 0.137). Also a significant Pearson correlation coefficient was found for Jap_GbGh (r = 0.848**) but not for Jap_ SL (r = 0.497). These findings suggest that Ind_Gc and Jap_GbGh increased their yields by producing a correspondingly dense canopy. The absence of significant correlation values for Ind_Gh and Jap_SL was caused by a number of crop failures that could be related to them being narrowly adapted to Sierra Leone only (Figures 6b and 6c).

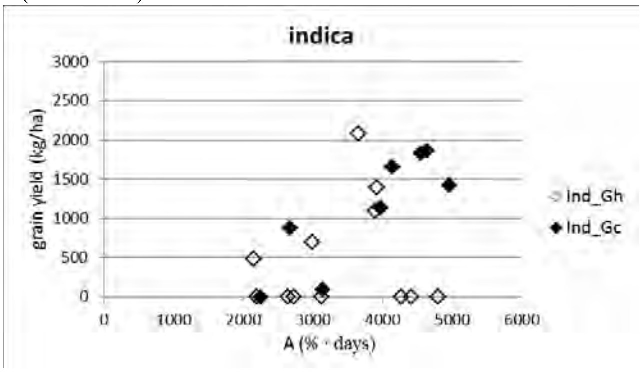
A minimum A is indispensable for yield formation, as shown by the various associations between A and yield observed for the various clusters. But from our observation only the *glaberrima* clusters were able to yield well with low canopy development.

Plant height

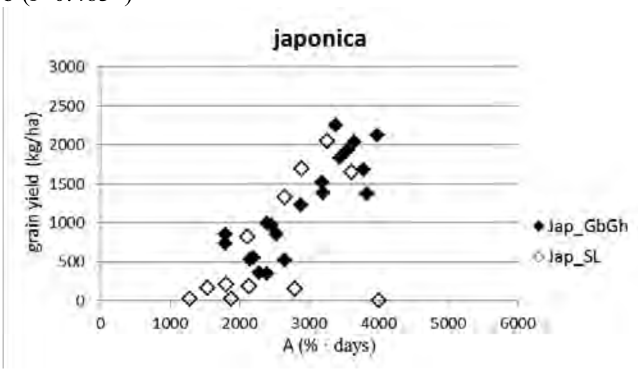
Significant G×E interactions for plant height were observed for all botanical groups and their respective clusters. This implies that across environments genotypes within botanical groups and clusters responded differently in plant height, suggesting the existence of varied strategies of adaptation for the different botanical groups and clusters. This finding confirms that plant height is in general sensitive to environmental conditions.



a (r=0.476**)



b (r=0.483*)



c (r=0.706**)

***Figure 6**: The relation between yield (in kg/ha; y-axis) and accumulated canopy cover (A in %.days; x-axis) for three botanical groups. Different symbols refer to different molecular clusters. Values presented are averages of 5 replications. Correlation coefficients are: a (varieties belonging to glaberrima): r=0.476 (P<0.01); b (varieties belonging to indica): r=0.483 (P<0.05); c (varieties belonging to japonica): r=0.706 (P<0.01).*

A decreasing trend was observed for plant height from countries with higher yield to countries with lower yield (Figure 7). The *O. glaberrima* group showed significantly greater average plant height than the *indica* and *japonica* groups (Table 14). At cluster level, we found that Glab_UpperCoast had

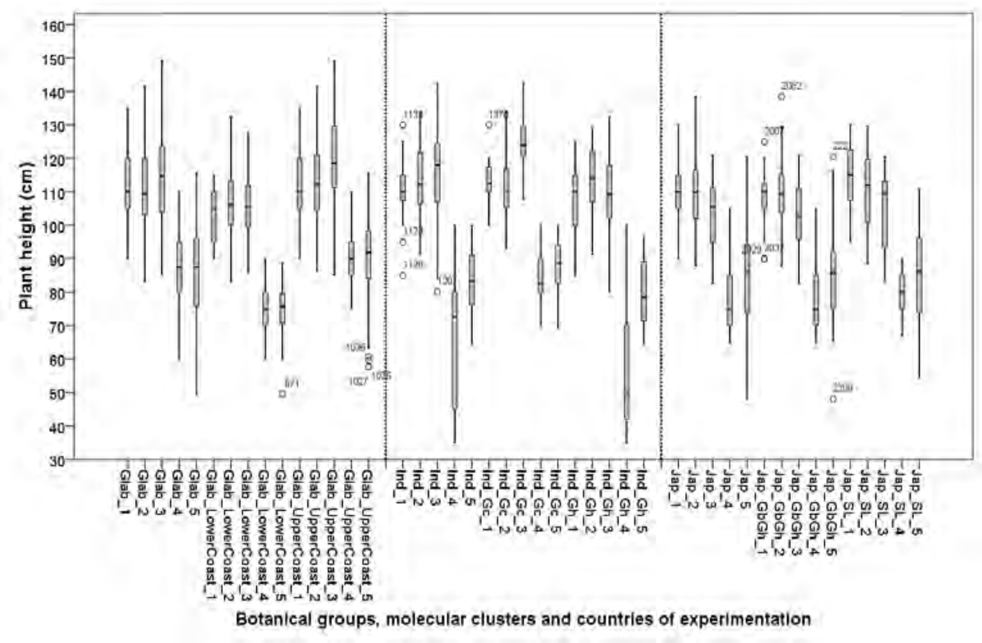


Figure 7*: Box plots for plant height (in cm) of 24 varieties in five experimental sites: 1: Ghana; 2: Sierra Leone; 3: Guinea Bissau; 4: Togo and 5: Guinea. See materials and methods section for coding of the botanical groups and molecular clusters*

taller plants than Glab_LowerCoast and that Ind_Gc had taller plants than Ind_Gh. The *japonica* clusters did not show significant differences for plant height (Table 14).

The relation between plant height and A is more strongly positive for Glab_UpperCoast (r = 0.826**, Figure 8a) than for Glab_LowerCoast. This difference is, however, absent when considering the relation between plant height and yield (Figure 8b), confirming that when more canopy was produced Glab_LowerCoast no longer invested in its height but rather in the number of its tillers, which was significantly higher for Glab_LowerCoast than for Glab_UpperCoast (Table 14, Figure 9). This suggests two distinct strategies adopted by the Glab_LowerCoast cluster and the Glab_UpperCoast cluster to arrive at similar A, and V_{max}: the second cluster produces higher plants and fewer tillers and the first cluster produces shorter plants but more tillers.

Within *indica*, the cluster Ind_Gc had the tallest plants and showed a highly significant relationship between plant height and A (r = 0.784**). These observations, together with observations of high V_{max} and A for Ind_Gc, imply that Ind_Gc had a better vegetative growth compared to Ind_Gh. Cluster Ind_Gc also displayed the same average plant height as Glab_UpperCoast.

Japonica clusters did not show significant differences for plant height (Table 14) nor for the relationship between plant height and A: r = 0.635** and r = 0.640** for Jap_GbGh and Jap_SL, respectively.

Number of panicles

The *glaberrima* and *indica* groups showed significant G×E interactions for number of panicles, while the *japonica* group did not (Tables 5, 8 and 11). At cluster level Glab_UpperCoast, Ind_Gc Ind_Gh and Jap_GbGh showed significant G×E interactions (Tables 7, 9, 10, 12). There was no such interaction for genotypes of the clusters Glab_LowerCoast and Jap_SL (Tables 6 and 13)

The *glaberrima* group showed the highest average number of panicles. Cluster Ind_Gc showed a significantly higher average number of panicles than Ind_Gh and performed similar to the *glaberrima* group (Table 14). Within the *japonica* group, the highest number of panicles was observed with Jap_SL cluster in Sierra Leone, the origin of the cluster. For all botanical groups and variety clusters, the number of panicles was relatively low in Sierra Leone and Guinea Bissau and highest in Guinea (Figure 10). An opposite trend was observed only with Jap_SL. This cluster showed more panicles in Sierra Leone. This underlines our observation that Jap_SL is specifically adapted to conditions in Sierra Leone.

The *japonica* group showed the lowest numbers of panicles throughout the whole range of A and yield values (Figures 8c and 8d) and across locations (Figure 10). The number of panicles in relation to A and yield hardly overlapped for *glaberrima* and *japonica* (Figures 8c and 8d) and differed significantly (Table 14). The *glaberrima* group showed a decreasing trend in panicle number as yield values increased (r = -0.453**). For the *japonica* and *indica* groups no such decreasing trend was observed. For the *indica* group, the relation between panicle number and yield seemed to be intermediate between the tendencies for the *glaberrima* and *japonica* groups (Figure 8d), thus confirming its group distinctiveness (Table 14).

Number of tillers

The three botanical groups showed significant G×E interactions for the number of tillers produced per plant. This means that, in general, genotypes composing the three botanical groups followed different strategies in tiller production across environments (Figure 11). At cluster level, G×E interactions were also found for the two *glaberrima* clusters and for the Ind_Gc cluster, but were absent for the Ind_Gh cluster and the two clusters of *japonica*. This implying that within the *japonica* clusters and the Ind_Gh cluster genotypes all vary tiller production in a similar way across environments.

***Table 14**: Average performance of several clusters of rice (including three botanical groups and six related molecular clusters) for main crop characteristics, including maximum canopy development (Vmax), accumulated canopy (A), plant height, number of tillers per plant (# Tillers), days to 50% flowering (50% Flowering), number of panicles per plant (# Panicles), panicle length, panicle weight, 200 grains weight and yield in five West African countries.*

Botanical groups and Clusters*	V_{max} (%)	A (%d)	Plant height (cm)	# Tillers	50% Flowering (d)	# Panicles	Panicle length (cm)	Panicle weight (g)	200 grains weight (g)	Yield (kg/ha)
Glaberrima	46.1 C	2908 B	101.1 B	6.8 B	97.1 A	6.4 C	23.4 B	2.0 A	4.3 A	1349 C
Indica	41.7 B	2889 B	97.8 A	7.6 C	108.9 C	5.5 B	22.1 A	1.9 A	4.1 A	757 A
Japonica	35.0 A	2269 A	97.2 A	4.0 A	101.8 B	2.8 A	22.5 A	3.1 B	4.3 A	967 B
Glab_UpperCoast	44.5 bcd	2794 bcd	104.2 de	6.5 c	96.7 b	6.2 cd	23.9 b	2.1 b	4.1 ab	1376 cd
Glab_LowerCoast	50.2 d	3214 d	92.7ab	7.5 d	98.4 bc	7.2 d	21.9 a	1.8 ab	4.9 c	1265 bcd
Jap_GbGh	36.8 ab	2320 ab	97.0 abc	4.4 b	101.9 c	3.1 a	22.7 ab	2.9 c	4.6 bc	1095 bc
Jap_SL	31.1 a	2085 a	98.7 cd	3.3 a	107.8 d	2.2 a	22.0 a	2.9 c	3.9 a	691 a
Ind_Gc	44.2 bcd	2984 cd	104.2 de	7.7 d	110.0 d	6.2 cd	21.6 a	1.7 ab	4.5 bc	1064 b
Ind_Gh	40.0 bc	2826 cd	91.8 a	7.4 d	110.7 d	4.8 b	22.4 a	1.5 a	3.7 a	551 a

Means in a column followed by the same letter are not significantly different from each other at 0.05% (based on Tukey tests for the botanical groups and clusters separately).

** See materials and methods section for coding of the clusters.*

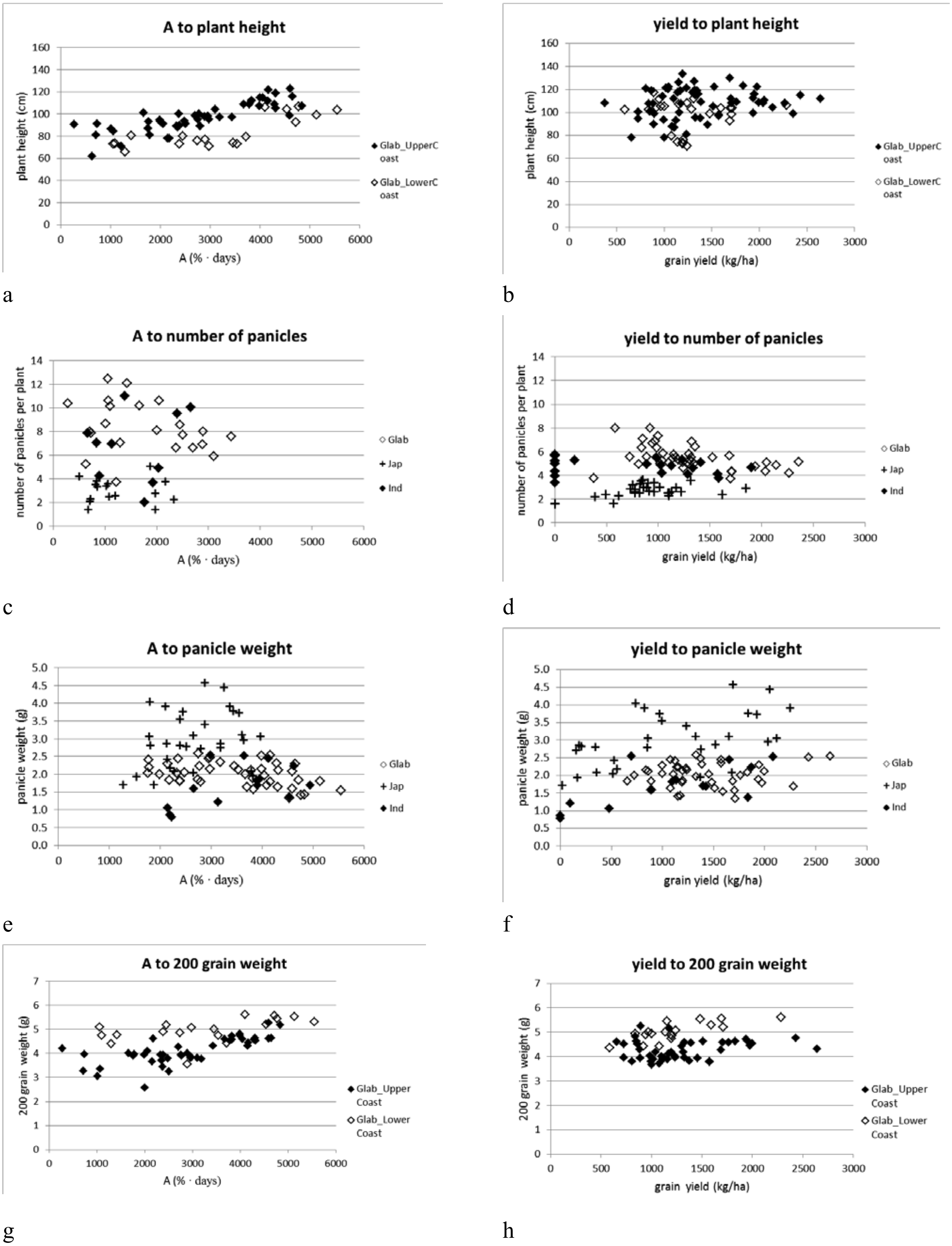


Figure 8: *Relation between accumulated canopy cover (A; in %.days; x-axis of a, c, e, g) or grain yield (in kg/ha; b, d, f, h) and plant height (a, b), number of panicles (c, d), panicle weight (e, f) and 200 grain weight (g, h). Different symbols refer to different botanical groups or molecular clusters within the glaberrima botanical group. Values presented are averages of 5 replications. See materials and methods section for coding of the botanical groups and molecular clusters*

Indica as well as *glaberrima* showed intensive tillering (Table 14). An increase in tiller number was observed from more favourable (Sierra Leone and Ghana) to less favourable environments (Guinea, Togo and Guinea Bissau) for the *indica* cluster (Figure 11). One of the underlying mechanisms facilitating the increase of tillers under less favourable conditions is that generally (for all botanical groups and clusters) under less favourable conditions (Guinea and Togo) the time to flowering is longer than under more favourable conditions (Sierra Leone and Ghana) (Figure 12). It seems particularly the case that the *indica* group uses this time to produce tillers while the *japonica* and *glaberrima* groups responded in various other ways.

Figures 9b and 9e indicate that for the *indica* group there is a positive relationship between canopy cover and tillering in Guinea and Togo, while tillering remains constant at high A in Ghana (Figures 9b). However the positive relation in Guinea and Togo does not match with the relation between number of tillers and yield at low A because tillering remained high even when the crop failed to yield (Figure 9e).

Japonica showed a positive relationship between number of tillers and A (r = +0.604**, Figure 9c), but not for number of tillers and yield (Figure 9f). The two *japonica* clusters showed a similar positive relation between A and number of tillers. The Jap_GbGh cluster clearly produced more tillers than the Jap_SL cluster (Table 14). This higher number of tillers contributed to a higher panicle number (although not significantly higher) which in turn might be linked to the significantly higher yield observed for Jap_GbGh.

Time to 50% flowering

We observed that at low yield levels the time to 50% flowering was consistently higher for all genotypes than at higher yield levels (Figure 12). This suggests that under less favourable conditions genotypes generally delayed their flowering.

Panicle weight

Significant G×E interactions were found only for *japonica*. Sowing effects were observed for *japonica* group (as part of the three way interaction between sowing, location and genotype), for the *indica* botanical group, and for the Ind_Gc cluster. Of the clusters only Ind_Gc showed variations of panicles weight by sowing dates. The panicle weight and yield highly correlated positively for Ind_Gc (r = 0.755*) and Jap_SL (r = 0.824**). For other clusters no significant relations were observed between panicle weight and yield. These observations suggest that the *japonica* and *indica* groups were more sensitive to sowing date (less robust) than the *glaberrima* group and its clusters.

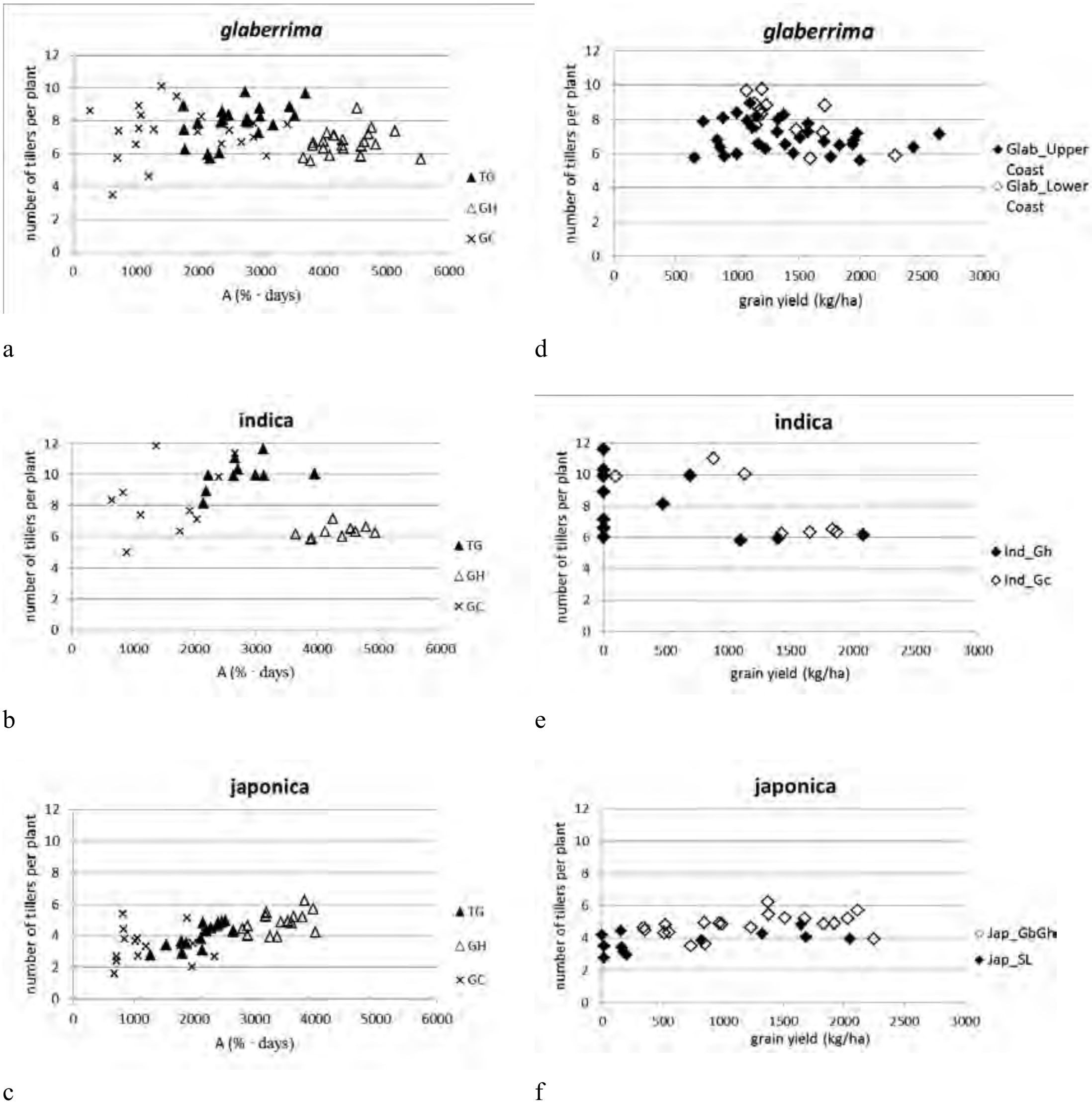


***Figure 9**: The relation between accumulated canopy cover (A; in %.days; x-axis of a, b, c) or grain yield (in kg/ha; x-axis of d, e, f) and the number of tillers per plant for each of the three botanical groups and their respective molecular clusters. Series TG, GH and GC respectively indicate observations from Togo, Ghana and Guinea. Values presented are averages of 5 replications for each of the two sowing dates. See materials and methods section for coding of the botanical and molecular clusters.*

Panicle weight for *glaberrima* and *indica* was significantly lower than for *japonica* (Table 14). When yield and A increased, panicle weight also increased, for the *indica* group (0.549*). For the *japonica* group there was no relation between panicle weight and A. However, an increasing trend in panicle weight was observed when yield increased (0.601**) (Figures 8e and 8f). Such trends were not observed for the *glaberrima* group, suggesting that panicle weight of *glaberrima* was more stable. No significant differences or trends were found, for clusters within the *glaberrima*, *japonica* and *indica* groups, for panicle weight, with the exception of Jap_SL, which showed a positive relation with A (r = 0.674*). Panicle weight for cluster Jap_GbGh showed no relation with A.

Panicle length

Significant G×E interactions were found for all botanical groups. The Glab_UpperCoast, Jap_GbGh and Jap_SL clusters all showed significant G×E interactions. There was a tendency towards short panicle production in Ghana and Sierra Leone, the countries where the yields were generally high (Figure 13). The cluster Glab_UpperCoast produced significantly longer panicles than all other clusters except for Jap_GbGh. The fact that the Glab_UpperCoast cluster had a panicle weight similar to that of Glab_LowerCoast implies that Glab_UpperCoast produced more grains of smaller size per panicle than Glab_LowerCoast. The cluster Glab_UpperCoast also showed a rather slight negative correlation between panicle length and yield (r = -0.332**), A (r = -0.335*) and a somewhat stronger negative correlation with the 200 grain weight (r = -0.427**). This means that for Glab_UpperCoast cluster production of short panicles corresponded with high A, yield and grain weight. This implies that under stress conditions (i.e. low yield and low A) Glab_UpperCoast invested more in panicle length (Figure 13). The negative relation between yield and panicle length was also observed, somewhat more strongly, for Glab_LowerCoast (r = -0.708**), Ind_Gc (r = -0.850**), Ind_Gh (r = -0.664**) and Jap_GbGh (r = -0.450**). Jap_SL did not show any relation between yield and panicle length.

200 grain weight

Significant G×E interactions were found for 200 grain weight for the *glaberrima* group and the Glab_UpperCoast cluster, suggesting that the genotypes composing the Glab_UpperCoast cluster responded differently across environments for 200 grain weight. This might be a factor in observed robustness in yield for this cluster. The absence of G×E interactions within the other botanical groups suggests that the 200 grain weight is genetically determined. The high estimate of wide sense heritability (H^2 = 80%; Table 16) confirms this general trend for *indica*. However, the relatively low wide sense heritability estimate for *japonica* (H^2 = 32%; Table 16) as compared to other botanical groups indicates that environmental conditions might have some considerable impact on the 200 grain weight of *japonica*. However, it is only with the *glaberrima* group, and not for *japonica* or *indica*, that a significant location effect was found.

Significant genotype effects were observed for the *japonica* group and Jap_GbGh cluster. No significant genotype effect was observed for the varieties of the Jap_SL cluster, suggesting little variation for 200 grain weight in the Jap_SL cluster and large genotypic variation in the Jap-GbGh cluster. The *indica* group also showed a significant genotype effect. Not enough data were available for an ANOVA of the Ind_Gh group.

The botanical groups showed little variation for 200 grain weight, but the average 200 grain weight varied significantly among the clusters of each botanical group. Within the *glaberrima* group the Glab_UpperCoast average was lower than that of the Glab_Lower coast cluster. The average 200 grain weight for the Jap_GbGh cluster was higher than that of the Jap_SL cluster and the Ind_Gc cluster average was higher than that of Ind_Gh cluster.

Japonica showed a fairly strong positive correlation between A and 200 grain weight: r = 0.70**, against r = 0.596** and r = 0.581** for the *glaberrima* and *indica* groups, respectively. At low values of A, the Ind_Gh cluster and *japonica* group tended to produce more empty or poorly developed grains, as represented in Figure 14. This is consistent with our summary finding under the section on tillering that extra tillers were produced at lower levels of A and yield contained more empty grains. The trends observed between A and 200 grain weight were also observed between 200 grains weight and yield, but only with the *indica* and *japonica* groups.

A clear divide was observed for the 200 grain values for Glab_UpperCoast and Glab_LowerCoast (Figures 8g, 8h). Figures 8g and 8h show that when canopy cover decreased the 200 grain weight for the Glab_UpperCoast cluster decreased more than the 200 grain weight for the Glab_LowerCoast cluster. Therefore, it can be concluded that the Glab_LowerCoast cluster was less susceptible to variation in environment. The 200 grain weight for clusters within *indica* and *japonica* decreased in a similar way when A and yield decreased. These clusters were similarly sensitive to the environment. In general, all *glaberrima* clusters (and also Ind_Gc) maintained their grain weight across environments even at low yield (Figure 8h, 14). This is contrary to the Ind_Gh and two *japonica* clusters, for which the empty grains increased at lower yield levels. This underscores the claim we make for the robustness of farmer varieties of *glaberrima* and Ind_Gc, and the consequent ability of these types consistently to produce good grains throughout a range of difficult environments.

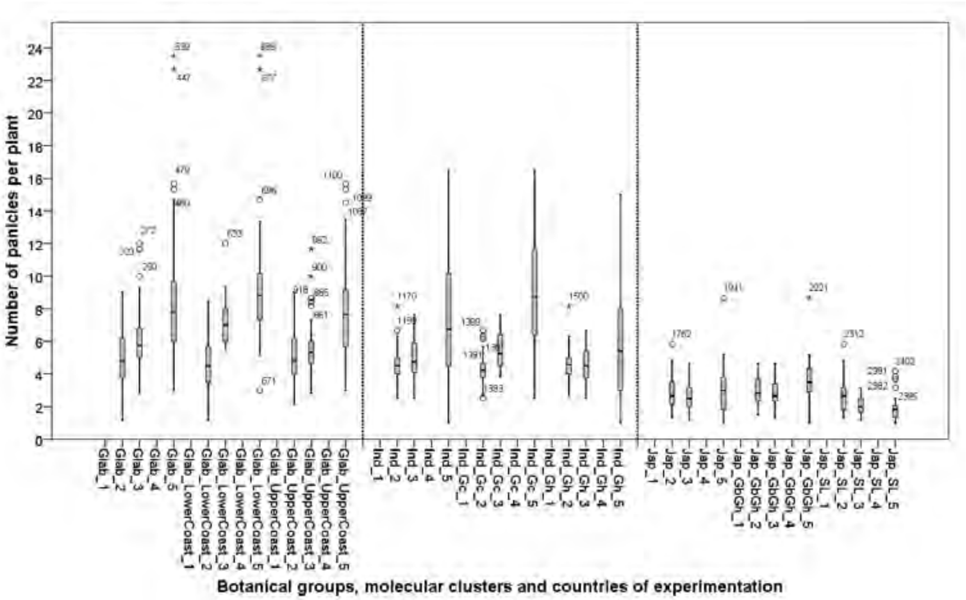


***Figure 10**: Box plots for number of panicles of 24 varieties in five experimental sites: 1: Ghana; 2: Sierra Leone; 3: Guinea Bissau; 4: Togo and 5: Guinea. See materials and methods section for coding of the botanical groups and molecular clusters.*

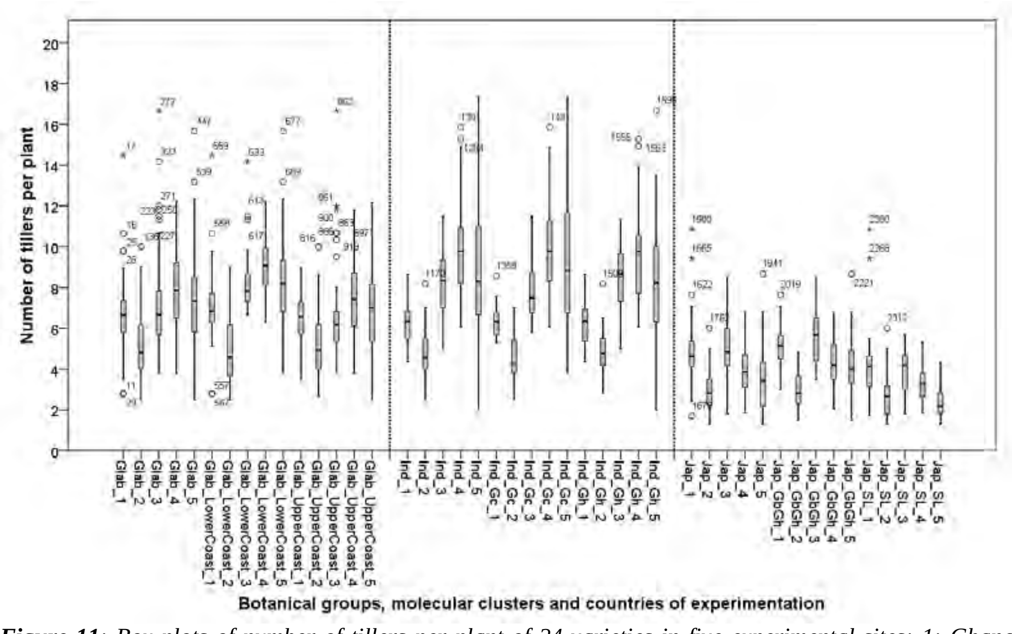


***Figure 11**: Box plots of number of tillers per plant of 24 varieties in five experimental sites: 1: Ghana; 2: Sierra Leone; 3: Guinea Bissau; 4: Togo and 5: Guinea. See materials and methods section for coding of the botanical and molecular clusters.*

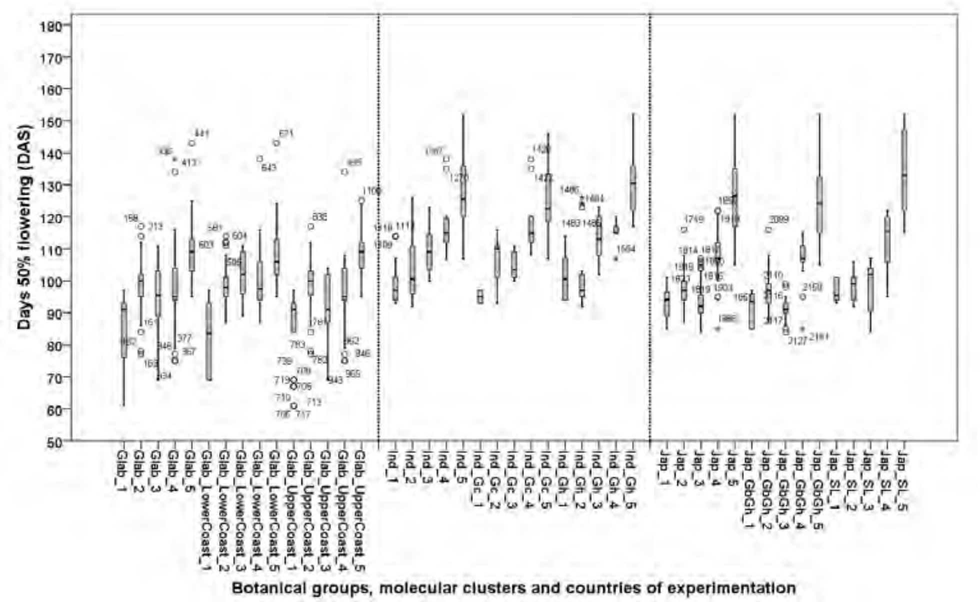


***Figure 12**: Box plots for days to 50% flowering of 24 varieties in five experimental sites: 1: Ghana; 2: Sierra Leone; 3: Guinea Bissau; 4: Togo and 5: Guinea. See materials and methods section for coding of the botanical groups and molecular clusters.*

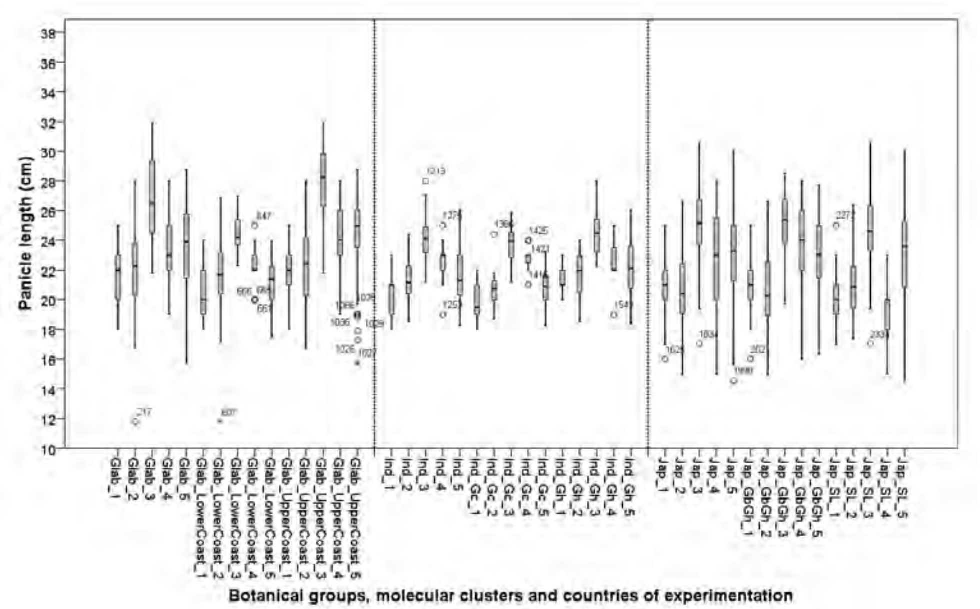


***Figure 13**: Box plots for panicle length of 24 varieties in five experimental sites: 1: Ghana; 2: Sierra Leone; 3: Guinea Bissau; 4: Togo and 5: Guinea. See materials and methods section for coding of the botanical groups and molecular clusters.*

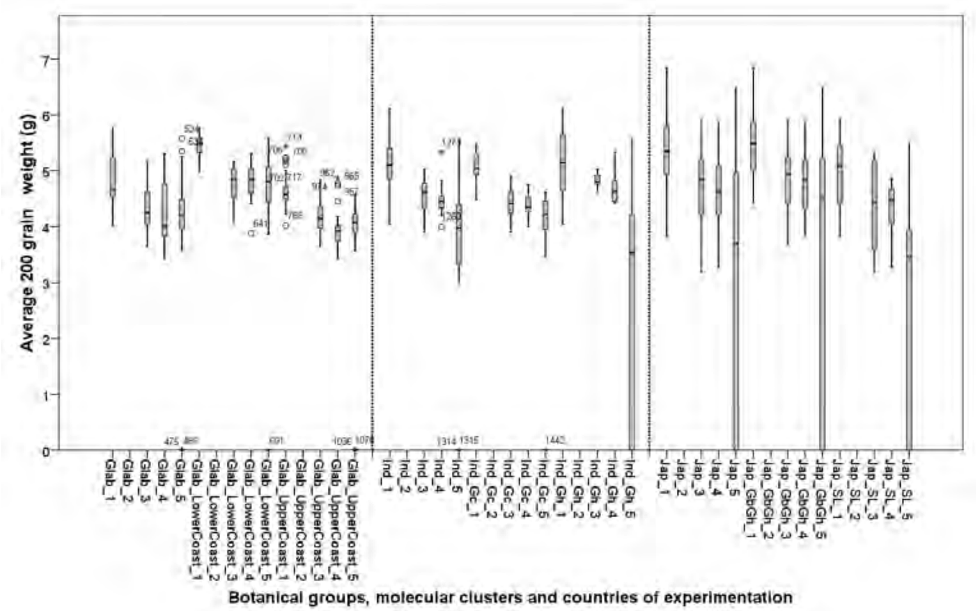


Figure 14*: Box plots for average 200 grain weight of 24 varieties in five experimental sites: 1: Ghana; 2: Sierra Leone; 3: Guinea Bissau; 4: Togo and 5: Guinea. See materials and methods section for coding of the botanical groups and molecular clusters.*

Discussion

Figure 5 showed that the two clusters of the *glaberrima* group maintained a minimum yield of 660 kg/ha in all environments. We observed that in trials in two countries where yields were relatively high (Ghana and Sierra Leone) the *indica* sourced from Guinea maintained a yield level close to that of *glaberrima*. But in the Guinea Bissau and Togo trials, the likelihood of crop failure was high overall. This might be due to the relatively short rainy season in Guinea Bissau and to the acidity of the soil in Togo. In contrast, varieties in the Ind_Gh cluster yielded only in Sierra Leone and to a lesser extent in Ghana, with a high frequency of zero yield. In Ghana and Sierra Leone Jap_GbGh showed a yield level similar to that of the *glaberrima* clusters. In Guinea Bissau and Togo, Jap_GbGh had a low yield but still reached at least 320 kg/ha.

In contrast, Jap_SL only showed a good yield level (without zero yield) in Sierra Leone. In Guinea Bissau the yield for Jap_SL dropped to 200 kg/ha and the frequency of crop failure increased in Togo and Ghana. Jap_SL thus seemed to be specifically well adapted to the ecology of Sierra Leone. Like Jap_SL, Ind_Gh produced only in Sierra Leone. This might be attributed to the characteristics of the varieties (Viono tall and Zomojo). These varieties from Ghana are mostly cultivated in the lowlands but have proven to suit certain specific upland niches in Ghana for which the conditions were apparently not met in the Ghana trial but were approached best in Sierra Leone. Okry *et al*. [19] also reported on such transfer of varieties across agro-ecologies. They provided a case where farmers were trying CK 21, a typical lowland variety in the upland in the region of Guinea known as Guinea Maritime. Given that farmers have decided, for their own reasons, to shift this variety from the recommended domain, it could be counted as an instance of G×E×S (society) interaction.

These findings on the yield show that clusters differed in yield performance across environments. Glab_Upper coast, Glab_Lower coast, Jap_GbGh and Ind_Gc were best able to maintain their yield across environments. Farmers often look for varieties that assure minimum yield in environments with variable and stressful conditions. These varieties seemingly satisfy such objectives of farmers.

Observations of average performance at cluster level revealed that canopy development and yield scenarios differed between and within botanical groups. Glab_UpperCoast and Glab_LowerCoast showed the highest values for V_{max}, A and yield. The two clusters of *indica*, Ind_Gh and Ind_Gc, showed similar values for V_{max} and A, although the latter significantly outperformed the former in yield. Moreover, Ind_Gc had a canopy development (V_{max} and A) and yield similar to Glab_LowerCoast and Jap_GbGh. Whereas Jap_GbGh and Jap_SL did not significantly differ in V_{max} or A, Jap_GbGh had a significantly higher yield than Jap_SL. Additionally, Jap_GbGh - although displaying low values of V_{max} and A - showed an average yield similar to that of *glaberrima* and Ind_Gc. The clusters Jap_SL and Ind_Gh developed a smaller canopy and also had the lowest yield. From these findings we infer that lower A can be associated with higher yield, and high canopy growth can be associated with lower yields. These associations are strongest for Ind_Gh (lower yield with higher A) and Jap_GbGh (higher yield with lower A).

Looking at the overall averages in Table 14 the ratio number of panicles over number of tillers was highest for *glaberrima* (0.94), followed by *indica* (0.72) and *japonica* (0.70), suggesting that the tillers of *glaberrima* produced more panicles. Particularly under less favourable conditions (e.g. Guinea Bissau) a difference was observed between botanical groups in the ratio of the number of panicles and tillers (Table 15). Of the botanical groups, only the clusters of the *indica* group varied, with tillers of Ind_Gc producing more panicles than those of Ind_Gh (0.8 and 0.65 respectively). However, looking at the averages per country for each botanical group and molecular cluster we observed that the increase in tillering for the *indica* group resulted in increased panicle production: the ratio of number of panicles over number of tillers remained stable or even increased at lower

Table 15: *Yield and yield components for different botanical groups and countries: Average yield (kg/ha) in descending order from left to right, number of panicles per plant, number of tillers per plant and ratio between the number of panicles and the number of tillers across countries. The values for Guinea are put in the uttermost right column as the yield was not assessed.*

Botanical groups and clusters*		Ghana	Sierra Leone	Togo	Guinea Bissau	Guinea
Glaberrima	Yield	1660	1510	1164	1034	-
	Panicles	-	5.0	-	5.9	8.0
	Tillers	6.6	5.0	7.9	6.9	7.2
	Ratio		1.00		0.86	1.11
		Ghana	Sierra Leone	Guinea Bissau	Togo	Guinea
Japonica	Yield	1513	1061	759	504	-
	Panicles	-	2.9	2.6	-	3.0
	Tillers	4.9	2.9	5.1	4.0	3.5
	Ratio		0.98	0.52		0.86
		Sierra Leone	Ghana	Togo	Guinea Bissau	Guinea
Indica	Yield	1248	1132	329	317	-
	Panicles	4.5	-	-	4.9	7.2
	Tillers	4.7	6.3	9.3	8.2	8.3
	Ratio	0.96			0.60	0.88
		Ghana	Sierra Leone	Togo	Guinea Bissau	Guinea
Glab_UpperCoast	Yield	1664	1568	1160	1100	-
	Panicles	-	5.1	-	5.5	7.8
	Tillers	6.5	5.1	7.5	6.4	6.9
	Ratio		1.01		0.86	1.13
		Ghana	Sierra Leone	Togo	Guinea Bissau	Guinea
Glab_LowerCoast	Yield	1651	1356	1174	872	-
	Panicles	-	4.7	-	7.0	8.6
	Tillers	6.7	4.7	9.0	8.1	8.2
	Ratio		1.00		0.87	1.06
		Ghana	Sierra Leone	Guinea Bissau	Togo	Guinea
Jap_SL	Yield	1127	958	525	242	-
	Panicles	-	2.7	2.1	-	2.0
	Tillers	4.4	2.8	4.0	3.3	2.4
	Ratio		0.98	0.51		0.81
		Ghana	Sierra Leone	Guinea Bissau	Togo	Guinea
Jap_GbGh	Yield	1741	1123	869	662	-
	Panicles	-	2.9	2.9	-	3.6
	Tillers	5.1	3.0	5.5	4.4	4.1
	Ratio		0.98	0.52		0.88
		Sierra Leone	Ghana	Togo	Guinea Bissau	Guinea
Ind_Gh	Yield	1096	742	196	153	-
	Panicles	4.6	-	-	4.5	5.7
	Tillers	4.9	6.3	9.2	8.5	7.9
	Ratio	0.95			0.53	0.72
		Ghana	Sierra Leone	Guinea Bissau	Togo	Guinea
Ind_Gc	Yield	1699	1476	553	529	-
	Panicles	-	4.4	5.4	-	8.8
	Tillers	6.4	4.6	7.8	9.4	8.7
	Ratio		0.96	0.69		1.02

- : not measured. *See materials and methods section for coding of the clusters yield (Table 15). The combination of the high number of tillers and panicles for Ind_Gh together with low yield suggests that its panicles have a large percentage of non-formed (i.e. empty) grains.

In general the number of tillers correlated (r = 0.800**) with the number of panicles per plant which in turn correlated with A. The fact that the relationship between the number of tillers and A was not clear for all botanical groups might imply that other variables such as the size of the tillers, leaf width, leaf length and leaf blade angle, which were not measured in these experiments, might account for the overall poor relationships we observed between A and the number of tillers per plant. Vigour-related variables are known to vary between rice species, *O. glaberrima* being often more vigorous than *O. sativa* [10-12].

The longest average period until 50% flowering was observed with the *indica* group. The *glaberrima* group showed the shortest period until 50% flowering, suggesting that this group had a shorter vegetative cycle. The result agrees with farmers' assertions that *glaberrima* (e.g. farmer varieties Malaa and Jangjango) are often earlier than other traditional *sativa* varieties and thus are used to beat the pre-harvest hunger gap [20].

Comparing the negative relationship between time to 50% flowering and A it can be said that this relation is most clear for *japonica* and *indica* (r = -0.880** and r = -0.855** respectively). The same relation was observed at cluster level for these two botanical groups. The *glaberrima* group and its clusters showed lower correlations between 50% flowering and A (r = -0.538** for the botanical group). This might imply that the environmental conditions determining accumulated canopy cover (A) affected 50% flowering of the *glaberrima* and its clusters less than that of the other varieties. This suggests that *glaberrima* is more stable in terms of time to 50% flowering. An advantage of such stability would be that even under high stress conditions farmers do not run the risk that the crop will delay its flowering beyond the scope of the rainy season. This is more likely the case for the varieties from Upper Guinea Coast. Varieties from Lower Guinea Coast usually experience a short dry period 2 to 4 weeks after planting. In such conditions it is important for the rice crop not to flower too early. The stability in flowering time for the *glaberrima* group takes care of that.

When summarising the relation between the yield and yield determining parameters, our study has shown that a large number of farmer varieties are able to adapt to large variations in environment. Our findings on tillering, yield, A, flowering and number of panicles suggest the existence of three different physiological strategies of adaptability for each of the botanical groups, which we now attempt to summarise.

Glaberrima

Across environments *O. glaberrima* consistently showed the highest values for maximum canopy, plant height, number of panicles and yield. Also remarkable was the absence of crop failure for the *glaberrima* group; this helps explain why it makes a more reliable and secure choice for sub-optimal farming or situations of special difficulty. In addition, the *glaberrima* group showed the shortest time to 50% flowering, a useful property for farmers affected by a pre-harvest hunger gap [20].

Overall, accumulated canopy, maximum canopy cover and yield were similar for Glab_LowerCoast and Glab_Upper coast clusters. But the two clusters differed in their strategy of canopy building: Glab_LowerCoast invested more in tiller production while Glab_UpperCoast produced taller plants. When A decreased, Glab_LowerCoast was better able to maintain its grain weight than Glab_UpperCoast and therefore appears to be more stable in grain weight. Under stress conditions (i.e. low yield and low A) Glab_UpperCoast invested more in panicle length. Also *glaberrima* from the lower coast showed higher values for 200 grain weight and the decrease of the 200 grain weight at lower yield levels was also less. However, the panicle weight for Glab_LowerCoast was less than that of the cluster Glab_UpperCoast. This also applies to panicle length and plant height. The Glab_LowerCoast varieties thus tended to invest more in grain weight, whereas Glab_UpperCoast varieties produced more grains per panicle. These two distinct strategies led to similar yields for these two clusters.

In sum, among the studied genotypes, those of *O. glaberrima* developed different strategies of adaptation, but interestingly, these strategies led to similar performance throughout the range of environments tested, demonstrating the robustness of this group of rices when compared to other botanical groups. These strategies relate to the area of collection of the varieties and also coincide with molecular groupings [15].

The *glaberrima* showed more G×E interactions than *indica* and *japonica*. This is worthy of note, since it is sometimes assumed that *O. glaberrima* is genetically less diverse than *indica* and *japonica*. Molecular analysis conducted by Nuijten *et al*. [15] showed that *glaberrima* and *japonica* were roughly similar in terms of genetic diversity: (H_e = 0.034; n = 66) and (H_e = 0.045; n = 87), respectively).

Indica

In less favourable environments varieties of the *indica* group produced more tillers than in the more favourable environments. The underlying mechanism seems to be that under less favourable conditions flowering is delayed and at the same time the tillering period is prolonged. The result is that at higher yield levels *indica* produced fewer tillers. At lower yield levels *indica* seemed less vigorous, as the increase in number of tillers did not lead to an increase in A. These tillers were, however, productive because an increase in tillering led to an increase in panicle production. The fact that an increase in panicle production did not lead to an increase in yield is a product of the crop failure observed for many plots in the less favourable environments, and the many panicles with unfilled grains.

The cluster Ind_Gc showed the highest plant height. This observation together with observations of high V_{max} and A for Ind_Gc implies that Ind_Gc is more vigorous compared to Ind_Gh. This vigour tuned into higher yield for Ind_Gc. The Ind_Gc cluster also displayed the same average plant height as the Glab_Upper coast cluster.

This shows that the Ind_Gc cluster, like *glaberrima,* is able to maintain its yield. At lower yield levels, however, it follows a different physiological strategy of adaptation than *glaberrima,* as it produced the largest number of tillers. But compared to *glaberrima*, these tillers contributed less to A and contributed also less to yield maintenance, as there were high numbers of unfilled grains.

In sum, the *indica* from Guinea resembled the *glaberrima* group in several ways. Like *glaberrima* it was able to maintain its number of tillers and also increased its number of panicles at low yield levels. Like *glaberrima*, it showed significant G×E interactions that helped to stabilise A and V_{max}.

Japonica

Low canopy cover and limited tiller and panicle production seem typical for the *japonica* group. At a high level of A, *japonica* consistently produced more tillers. This relation seemed linear, as was the relation between yield and accumulated canopy, thus suggesting that an increase in tillering contributes to canopy formation and yield. In addition, *japonica* slightly increased its panicle number while tillering, A and V_{max} were not maintained at low yield levels. Instead of investing in high tiller number *japonica* invested more in panicle weight: when compared with *glaberrima* and *indica* panicle weight was approximately 50% to 100% higher.

The Jap_GbGh cluster maintained a yield across environments similar to that of the *glaberrima* group and *indica* cluster from Guinea, although it failed to maintain A at lower yield level. In contrast, varieties in the Jap_SL cluster only yielded well in Sierra Leone. This might suggest that these *japonica* varieties were highly adapted to a specific niche. In Sierra Leone, however, varieties in the *japonica* group are often found bridging an ecological gradient from lowland to upland [20].

Observed behaviour of the studied genotypes in relation to the area of collection

Glab_LowerCoast: Farmers in the Togo Hills (Togo mountain ranges) in Ghana and Togo traditionally used these varieties mainly on stony hills and slopes with poor soil because political conflict and war drove them into mountainous areas, since life on the plains was too dangerous. Reliability of yield was very important in these conditions and rice was probably once the main carbohydrate crop. The data for this cluster indeed show that they are highly reliable in relation to yield. Nowadays these varieties are cultivated on the Ghanaian slopes of the Togo Hills only for ceremonial reasons, because lowland farming has been added to the local farming repertoire since the 1960s, and other crops like cassava and maize are now more important than previously [21]. Occasionally African rice is used on the Ghanaian slopes and in the lowlands of the Togo Hills when farmers are very late with sowing rice. African rice is used because of its short cycle. Farmers in the Togo Hills (Danyi Plateau) grow only African rice, which is an important secondary crop. They said they have tried other varieties but nothing works as well in the hills as the rices of the Glab_LowerCoast cluster.

Glab_UpperCoast: The upper West African coast includes two secondary centres of domestication and diversity for *O. glaberrima* [22], so we might not expect a great deal of similarity in the behaviour of genotypes collected from this region (on a transect from Senegal to Sierra Leone). When comparing the Glab_LowerCoast to Glab_UpperCoast in our experiments the differences observed within and between clusters appear to reflect the fact that rice farmers on the Upper Coast grow rice as their main staple, and work a much broader range of environments (and thus exercise a larger range of selection pressures) than the farmers in the Togo Hills. Farmers experience quite different constraints in their farming systems. In the semi-arid zone of the upper coast (Senegal, Gambia and Guinea Bissau), a short rainy seasons (3 to 4 months) may have forced farmers to select for short duration *glaberrima* types better adapted to their conditions. In these conditions, farmers appear to have selected taller plants with longer panicles and fewer tillers.

In the forest belt of Sierra Leone and Guinea, with a much longer rainfall period (6 to 7 months) the environment is favourable for longer duration crops. However, farmers still cultivate *O. glaberrima* to some extent because of its adaptability to poor, eroded soils and tolerance to drought at the beginning and end of the rainy season. In the forest belt farmers report many weed problems [20], particularly in areas with short fallow periods. Selecting for tall plants could also help in suppressing weed. In addition farmers seem to have selected *glaberrima* types that were less photoperiod sensitive, facilitating the planting of short-duration types to be sown in late April and used as hunger breaker crops.

Ind_Gc: These varieties appeared to be stable in yield and in that way resemble *O. glaberrima* and Jap_GbGh. The Ind_Gc types are widely cultivated in the area of collection, under typical upland conditions on poor soils. Farmers state that rices in the Ind_Gc cluster resemble *O. glaberrima* in being well adapted to poor soils. They are also drought tolerant when compared to other *O. sativa* varieties (e.g. Samba, Dalifodé, Podê) and also yield well under good conditions (as well as well enough, under poor conditions). They dominate upland rice cultivation in their area of collection because, as farmers state, *O. glaberrima* lodges at complete maturity, as frequently mentioned as a drawback by a number of rice researchers [7, 23, 24]. Farmers claim this results in low yields, especially when they lack sufficient labour for a timely harvest.

Ind_Gh: These are varieties that performed relatively poorly in our experiments, except in Sierra Leone. In addition to cultivation under upland conditions (in the Ghanaian Togo Hills) these varieties are also cultivated very successfully in the adjacent lowlands. Since the 1960s lowland cultivation has been added to the farming systems of the different minority groups living at the foot of the Togo Hills. Ever since that time farmers have been experimenting with lowland varieties in the upland area and vice versa. The varieties in the Ind_Gh cluster are probably adapted to very specific upland conditions in the Ghanaian Togo mountain ranges, conditions apparently replicated in experimental conditions at the foot of the Sierra Leonean escarpment (Kamajei Chiefdom).

Jap_GbGh: These varieties are commonly planted under upland conditions. They are equal in yield to the two *O. glaberrima* clusters and the Ind_Gc cluster. Farmers grow them for their white pericarp, good taste and the fact that they fit the rainy season calendar very well, being not too short, and not too long. Farmers visiting the trial in Guinea Bissau were very impressed with the growth of some varieties of this *japonica* cluster, and indicated they would like to grow these varieties in the following season. However, upon realising the pericarp colour was red these farmers lost interest, as they have a strong preference for white seed colour. Elsewhere (in Ghana and Sierra Leone, for example) farmers actually prefer varieties with red pericarp. This underlines the importance of taking into account cultural factors in crop development [4].

Jap_SL: These varieties seem to be very specifically adapted to Sierra Leonean conditions. They are widely cultivated in this area of collection. Farmers who are conversant with them typically look for toposequences to allow flexible planting up and down slopes, taking account of the stage of the season. They are thus adapted to a mid-slope planting scenario, between wetland and upland varieties. The mid-slope niche is very common in an undulating, well-watered country such as Sierra Leone, but is less common in the other areas in which we carried out experiments. This may explain why this particular group only seemed to do well in its zone of collection. It has been selected for robustness in a niche.

Conclusion

It can be concluded, that the *glaberrima* group as a whole, and the *indica* cluster from Guinea and *japonica* from Guinea Bissau and Ghana, were more plastic than other rices in the study, allowing them to be more constant in yield, A, and in number of tillers and panicles. Seemingly, farmer selection in Guinea has created a group of Asian rices that resemble in performance the highly adapted African rices of the region.

This paper has presented evidence that farmer rice varieties in coastal West Africa are, for the most part, highly robust, and well-adapted to a range of sub-optimal farming conditions. A case has been made that much of this robustness is a product of adaptation. An implication is that many farmer varieties will maintain their performance across a range of low-input conditions, and thus might be very useful to farmers in neighbouring countries. More efforts should be made to conserve, evaluate and distribute farmer-selected rice planting materials in the region. Farmers themselves should be consulted about the best way to develop relevant modalities of dissemination, and involved directly in any such activity.

***Table 16**: Wide sense heritability estimates (for all genotypes together and per botanical group).*

	V_{max}	A	Plant height	# Tillers	50% Flowering	# Panicles	Panicle length	Panicle weight	200 grains weight	Yield/ha
All genotypes	60	45	60	79	86	77	67	75	49	76
Glaberrima	35	12	68	17	86	1	61	48	65	43
Indica	50	55	61	0	64	5	30	56	80	90
Japonica	76	63	45	62	59	56	69	48	32	59

Table 17: *Pearson correlations between yield components and days to 50% flowering*

Cluster	Plant height (cm)	Panicle length (cm)	Number of tillers	Number of panicles	Panicle weight (g)	200 grain weight (g)	Plot yield (kg/ha)	Canopy cover A (%)
All	- 0.390**	0.073	- 0.018	0.045	0.101	-0.581**	-0.298**	-0.661**
Glab	- 0.194*	0.211*	0.111	0.304*	0.464**	- 0.515**	0.080	- 0.538**
Ind	- 0.693**	0.115	0.413**	0.355	- 0.306	- 0.839**	-0.316	- 0.855**
Jap	- 0.593**	0.138	- 0.432**	- 0.029	- 0.237	- 0.716**	-0.511**	- 0.880**
Glab_Upper Coast	- 0.113	0.272*	0.043	0.385**	0.641**	- 0.705**	0.266*	- 0.482**
Glab_Lower Coast	- 0.335	0.189	0.193	0.099	0.245	- 0.714**	-0.428*	- 0.668**
Ind_Gc	- 0.751**	0.119	0.497*	0.589*	- 0.416	- 0.878**	-0.403	- 0.854**
Ind_Gh	- 0.649**	0.073	0.370	0.262	- 0.221	- 0.862**	-0.273	- 0.873**
Jap_GbGh	- 0.699**	0.058	- 0.274	0.459*	- 0.054	- 0.685**	-0.559**	- 0.896**
Jap_SL	- 0.548**	0.289	- 0.619**	- 0.449	- 0.611	- 0.702**	-0.342	- 0.877**

Table 18: *Pearson correlations between yield components and plant height (cm)*

Cluster	Days to 50% flowering	Panicle length (cm)	Number of tillers	Number of panicles	Panicle weight (g)	200 grain weight (g)	Plot yield (kg/ha)	Canopy cover A (%)
All	- 0.390**	0.225**	- 0.206**	- 0.168*	0.179	0.301**	0.346**	0.596**
Glab	- 0.194*	0.337**	- 0.384**	- 0.530**	- 0.067	0.051	0.168	0.671**
Ind	- 0.693**	0.274	- 0.495**	- 0.113	0.580*	0.631**	0.392*	0.555**
Jap	- 0.593**	0.034	0.093	- 0.017	0.442*	0.348**	0.420**	0.621**
Glab_UpperCoast	- 0.113	0.290**	- 0.191	- 0.408**	- 0.098	0.438**	0.181	0.826**
Glab_LowerCoast	- 0.335	0.152	- 0.550**	- 0.677**	- 0.788**	0.359	0.020	0.796**
Ind_Gh	- 0.649**	0.450*	- 0.520**	0.143	0.674	0.682*	0.393	0.485
Ind_Gc	- 0.751**	0.123	- 0.583**	- 0.673*	0.670	0.615*	0.228	0.784**
Jap_GbGh	- 0.699**	- 0.139	0.061	- 0.134	0.229	0.359*	0.482**	0.635**
Jap_SL	- 0.548**	0.323	0.300	0.254	0.727*	0.368	0.452*	0.640**

Table 19*: Pearson correlations between yield components and panicle length (cm)*

Cluster	Days to 50% flowering	Plant height (cm)	Number of tillers	Number of panicles	Panicle weight (g)	200 grain weight (g)	Plot yield (kg/ha)	Canopy cover A (%)
All	0.073	0.225**	0.182**	0.120	0.102	- 0.187*	- 0.293**	- 0.256**
Glab	0.211*	0.337**	0.107	0.023	0.731**	- 0.542**	- 0.338**	- 0.355**
Ind	0.115	0.274	0.484**	0.124	-0.128	0.240	- 0.767**	- 0.132
Jap	0.138	0.034	0.192	- 0.085	0.065	- 0.159	- 0.338**	- 0.317*
Glab_Upper Coast	0.272*	0.290**	0.220	0.130	0.728**	- 0.427**	- 0.332**	- 0.335*
Glab_Lower Coast	0.189	0.152	0.338	0.099	0.525	- 0.319	- 0.708**	- 0.362
Ind_Gc	0.119	0.123	0.463*	- 0.145	-0.488	- 0.328	- 0.850**	- 0.227
Ind_Gh	0.073	0.450*	0.600**	0.485*	0.868	0.511	- 0.664**	0.040
Jap_GbGh	0.058	-0.139	0.335*	0.091	0.087	- 0.136	- 0.450**	- 0.319
Jap_SL	0.289	0.323	-0.142	- 0.353	0.465	- 0.379	- 0.313	- 0.479

Table 20*: Pearson correlations between yield components and number of tillers*

Cluster	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of panicles	Panicle weight (g)	200 grain weight (g)	Plot yield (kg/ha)	Canopy cover A (%)
All	- 0.018	- 0.206**	0.182**	0.800**	- 0.562**	0.147	- 0.125	0.165*
Glab	0.111	- 0.384**	0.107	0.815**	0.025	0.145	- 0.328**	- 0.130
Ind	0.413**	- 0.495**	0.484**	0.677**	- 0.361	0.089	- 0.573**	- 0.314
Jap	- 0.432**	0.093	0.192	0.518**	- 0.018	0.564**	0.239	0.604**
Glab_Upper Coast	0.043	- 0.191	0.220	0.768**	0.232	-0.137	- 0.272*	- 0.087
Glab_Lower Coast	0.193	- 0.550**	0.338	0.857**	0.296	-0.389	- 0.446*	- 0.512*
Ind_Gc	0.497*	- 0.583**	0.463*	0.895**	- 0.527	-0.488	- 0.616*	- 0.532
Ind_Gh	0.370	- 0.520**	0.600**	0.525*	- 0.110	0.211	- 0.594**	- 0.170
Jap_GbGh	- 0.274	0.061	0.335*	0.301	- 0.357	0.394*	0.042	0.608**
Jap_SL	- 0.619**	0.300	- 0.142	0.420	0.446	0.705**	0.236	0.784**

***Table 21**: Pearson correlations between yield components and number of panicles*

Cluster	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of tillers	Panicle weight (g)	200 grain weight (g)	Plot yield (kg/ha)	Canopy cover A (%)
All	0.045	-0.168*	0.120	0.800**	.[a]	0.282*	0.150	0.122
Glab	0.304*	- 0.530**	0.023	0.815**	.[a]	0.083	- 0.453**	- 0.280
Ind	0.355	- 0.113	0.124	0.677**	.[a]	0.638*	- 0.201	0.137
Jap	- 0.029	- 0.017	- 0.085	0.518**	.[a]	0.207	0.474**	- 0.009
Glab_Lower Coast	0.099	- 0.677**	0.099	0.857**	.[a]	0.159	- 0.824**	- 0.521
Glab_Upper Coast	0.385**	- 0.408**	0.130	0.768**	.[a]	-0.335	- 0.281	- 0.228
Ind_Gc	0.589*	- 0.673*	- 0.145	0.895**	.[a]	-0.002	- 0.677	0.478
Ind_Gh	0.262	0.143	0.485*	0.525*	.[a]	0.707	- 0.022	0.314
Jap_GbGh	0.459*	- 0.134	0.091	0.301	.[a]	-0.116	0.038	0.076
Jap_SL	- 0.449	0.254	- 0.353	0.420	.[a]	0.321	0.717**	- 0.034

[a]: non estimated

***Table 22**: Pearson correlations between yield components and panicle weight (g)*

Cluster	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of tillers	Number of panicles	200 grain weight (g)	Plot yield (kg/ha)	Canopy cover A (%)
All	0.101	0.179	0.102	-0.562**	.[a]	0.231*	0.228*	- 0.225*
Glab	0.464**	- 0.067	0.731**	0.025	.[a]	- 0.625**	0.109	- 0.417**
Ind	- 0.306	0.580*	- 0.128	-0.361	.[a]	0.716**	0.701**	0.503
Jap	- 0.237	0.442*	0.065	-0.018	.[a]	0.379*	0.563**	0.251
Glab_Upper Coast	0.641**	- 0.098	0.728**	0.232	.[a]	- 0.553**	0.243	- 0.268
Glab_Lower Coast	0.245	- 0.788**	0.525	0.296	.[a]	- 0.299	- 0.347	- 0.551
Ind_Gc	- 0.416	0.670	- 0.488	- 0.527	.[a]	0.778*	0.755*	0.623
Ind_Gh	- 0.221	0.674	0.868	- 0.110	.[a]	0.617	0.702	0.574
Jap_GbGh	- 0.054	0.229	0.087	- 0.357	.[a]	0.563**	0.382	- 0.046
Jap_SL	- 0.611	0.727*	0.465	0.446	.[a]	0.320	0.824**	0.674*

[a]: non estimated

***Table 23**: Pearson correlations between yield components and 200 grain weight (g)*

Cluster	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of tillers	Number of panicles	Panicle weight (g)	Plot yield (kg.ha^{-1})	Canopy cover A (%)
All	- 0.581**	0.301**	- 0.187*	0.147	0.282*	0.231*	0.369**	0.568**
Glab	- 0.515**	0.051	- 0.542**	0.145	0.083	- 0.625**	0.218	0.596**
Ind	- 0.839**	0.631**	0.240	0.089	0.638*	0.716**	0.809**	0.581**
Jap	- 0.716**	0.348**	- 0.159	0.564**	0.207	0.379*	0.621**	0.692**
Glab_Upper Coast	- 0.705**	0.438**	- 0.427**	- 0.137	- 0.335	- 0.553**	0.223	0.725**
Glab_Lower Coast	- 0.714**	0.359	- 0.319	- 0.389	0.159	- 0.299	0.766**	0.499*
Ind_Gc	- 0.878**	0.615*	- 0.328	- 0.488	- 0.002	0.778*	0.902**	0.834**
Ind_Gh	- 0.862**	0.682*	0.511	0.211	0.707	0.617	0.861*	0.612*
Jap_GbGh	- 0.685**	0.359*	- 0.136	0.394*	- 0.116	0.563**	0.600**	0.708**
Jap_SL	- 0.702**	0.368	- 0.379	0.705**	0.321	0.320	0.599*	0.628*

***Table 24**: Pearson correlations between yield components and plot yield (kg/ha)*

Cluster	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of tillers	Number of panicles	Panicle weight (g)	200 grain weight (g)	Canopy cover A (%)
All	- 0.298**	0.346**	- 0.293**	- 0.125	0.150	0.228*	0.369**	0.478**
Glab	0.080	0.168	- 0.338**	- 0.328**	- 0.453**	0.109	0.218	0.450**
Ind	- 0.316	0.392*	- 0.767**	- 0.573**	- 0.201	0.701**	0.809**	0.483*
Jap	- 0.511**	0.420**	- 0.338**	0.239	0.474**	0.563**	0.621**	0.706**
Glab_Upper Coast	0.266*	0.181	- 0.332**	- 0.272*	- 0.281	0.243	0.223	0.476**
Glab_Lower Coast	- 0.428*	0.020	- 0.708**	- 0.446*	- 0.824**	- 0.347	0.766**	0.451
Ind_Gc	- 0.403	0.228	- 0.850**	- 0.616*	- 0.677	0.755*	0.902**	0.857**
Ind_Gh	- 0.273	0.393	- 0.664**	- 0.594**	- 0.022	0.702	0.861*	0.137
Jap_GbGh	- 0.559**	0.482**	- 0.450**	0.042	0.038	0.382	0.600**	0.848**
Jap_SL	- 0.342	0.452*	- 0.313	0.236	0.717**	0.824**	0.599*	0.497

***Table 25**: Pearson correlations between yield components and canopy cover A (%)*

Cluster	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	Number of tillers	Number of panicles	Panicle weight (g)	200 grain weight (g)	Plot yield (kg/ha)
All	- 0.661**	0.596**	- 0.256**	0.165*	0.122	- 0.225*	0.568**	0.478**
Glab	- 0.538**	0.671**	- 0.355**	- 0.130	- 0.280	-0.417**	0.596**	0.450**
Ind	- 0.855**	0.555**	- 0.132	- 0.314	0.137	0.503	0.581**	0.483*
Jap	- 0.880**	0.621**	- 0.317*	0.604**	- 0.009	0.251	0.692**	0.706**
Glab_Lower Coast	- 0.668**	0.796**	- 0.362	- 0.512*	- 0.521	- 0.551	0.499*	0.451
Glab_Upper Coast	- 0.482**	0.826**	- 0.335*	- 0.087	- 0.228	- 0.268	0.725**	0.476**
Ind_Gc	- 0.854**	0.784**	- 0.227	- 0.532	0.478	0.623	0.834**	0.857**
Ind_Gh	- 0.873**	0.485	0.040	- 0.170	0.314	0.574	0.612*	0.137
Jap_GbGh	- 0.896**	0.635**	- 0.319	0.608**	0.076	- 0.046	0.708**	0.848**
Jap_SL	- 0.877**	0.640**	- 0.479	0.784**	- 0.034	0.674*	0.628*	0.497

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Author contributions

Supervised the research: EN HM PR PCS. Conceived and designed the experiments: AM EN FO BT HM PR PCS. Performed the experiments: AM EN FO BT. Analysed the data: AM EN FO BT. Contributed reagents/materials/analysis tools: AM EN FO BT. Wrote the paper: AM EN FO BT HM PR PCS.

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CHAPTER SIX

Processes underpinning development and maintenance of diversity in rice in West Africa: Evidence from combining morphological and molecular markers

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Abstract

We assessed the interplay of artificial and natural selection in rice adaptation in low-input farming systems in West Africa. Using 20 morphological traits and 176 molecular markers, 182 farmer varieties of rice (*Oryza* spp.) from 6 West African countries were characterised. Principal component analysis showed that the four botanical groups (*Oryza sativa* ssp. *indica*, *O. sativa* ssp. *japonica*, *O. glaberrima*, and interspecific farmer hybrids) exhibited different patterns of morphological diversity. Regarding *O. glaberrima,* morphological and molecular data were in greater conformity than for the other botanical groups. A clear difference in morphological features was observed between *O. glaberrima* rices from the Togo hills and those from the Upper Guinea Coast, and among *O. glaberrima* rices from the Upper Guinea Coast. For the other three groups such clear patterns were not observed. We argue that this is because genetic diversity is shaped by different environmental and socio-cultural selection pressures. For *O. glaberrima*, recent socio-cultural selection pressures seemed to restrict genetic diversity while this was not observed for the other botanical groups. We also show that *O. glaberrima* still plays an important role in the selection practices of farmers and resulting variety development pathways. This is particularly apparent in the case of interspecific farmer hybrids where a relationship was found between pericarp colour, panicle attitude and genetic diversity. Farmer varieties are the product of long and complex trajectories of selection governed by local human agency. In effect, rice varieties have emerged that are adapted to West African farming conditions through genotype × environment × society interactions. The diversity farmers maintain in their rice varieties is understood to be part of a risk-spreading strategy that also facilitates successful and often serendipitous variety innovations. We advocate, therefore, that farmers and farmer varieties should be more effectively involved in crop development.

Key words: adaptation, farmer varieties, genetic diversity, morphological characterisation, *Oryza*, rice, seed systems

Introduction

West African farmers have cultivated two species of rice *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) for several centuries. Over much of the West African coastal zone, resource-poor farmers cultivate the two species as rainfed varieties in a range of ecologies, from lowland to upland. According to one view, Asian rice was introduced into coastal West Africa by Portuguese traders in the 16th century [1]. Another view is that it may have arrived earlier (perhaps around the beginning of the Common Era) via trans-Saharan trade routes and trade links between East Africa and India [2]. African rice (*O. glaberrima*) is thought to have been first domesticated in the swampy basins of the upper Niger River delta 3000-4000 years ago [3, 4]. Since its introduction into West Africa, Asian rice has tended to replace African rice, particularly in wetland cultivation. From the late 18th century onwards a second wave of introductions occurred from Asia and America, including both *O. sativa* ssp. *indica* and *O. sativa* ssp. *japonica*. This boosted the rate at which *O. sativa* replaced *O. glaberrima* [3], now including in dryland rice farming conditions. This accelerated replacement, alongside the enduring cultivation of *O. glaberrima* in certain pockets, is often explained as resulting from local variations in socio-cultural, political, ecological and geographical factors influencing farmers and their work [5-9]. *O. glaberrima* is widely believed to be well adapted to low-input farming conditions [10].

Oryza glaberrima has never been improved by agronomists or plant breeders. Professional opinion has been that the species has little to offer and that yields are invariably low. More recently, *O. glaberrima* has been seen as a useful genetic resource to improve *O. sativa* varieties [11, 12]. The two rice species are genetically isolated from each other by an F1 sterility barrier [13-17, amongst others], although gene exchange can occur in the field [15, 17-21]. Recent research confirms that varieties with an interspecific background, resulting from introgressions, are regularly to be found in farmer fields along the Upper Guinea Coast from The Gambia down to Sierra Leone [22, 23]. Because backcrossing to either parent (to produces fertile progeny) results in parental phenotypical resemblance, it is difficult to detect hybrid derivatives; they look like either *sativa* or *glaberrima* [17, 23]. This means that four botanical clusters can be identified as co-existing in West Africa: these are *O. sativa* ssp. *indica*, *O. sativa* ssp. *japonica*, *O. glaberrima* and interspecific farmer varieties [23].

A recurrent idea in the literature is that although farmer varieties look very diverse morphologically, they are actually genetically rather uniform at gene pool level because of continuous selection on qualitative traits in the same gene pool [24] and because most farmer varieties are the result of recombination of existing farmer varieties [25]. A common, different view is that farmer varieties are made up of different genotypes, making them genetically quite diverse. Both views do not seem to apply to rice in West Africa. The first idea is countered by a study conducted by Nuijten *et al*. [23], and the second view may apply to other crops, but not to rice [6]. In West Africa the coexistence of Asian and African rice has resulted in an enlarged gene pool and the development of interspecific farmer varieties [23, 26, 27]. The main underlying factors are farmer selection and gene flow through cross pollination and seed exchange [6]. From seemingly isolated hamlets seed can travel long distances, through informal seeds networks, mostly based on extended family ties, and can diffuse across countries [7, 28]. These processes of seed diffusion have been traced over several centuries [29]. The time-depth and durability of this process prepares us to understand the finding that farmer varieties can embody greater levels of genetic diversity than formal varieties [30], challenging an assumption often made by plant breeders that the reverse is true on account of the access enjoyed by breeders to a world-wide spectrum of genetic resources [31]. The existence of farmer varieties with an interspecific background clearly shows that farmer crop development has more potential value as a complement to scientific breeding than is often assumed [23]. The value of these activities, by farmers in West African conditions, is further reinforced by recent research showing that farmer rice varieties can be adapted to a wide range of agro-ecological conditions [10].

Country-specific studies have been conducted to unravel the genetic variability of rice in West Africa (e.g. for Sierra Leone, Guinea and The Gambia, see [22, 30, 32, 33]). Nuijten *et al*. [23] then offered a regional perspective by analysing a large set of farmer varieties collected from seven countries across coastal West Africa, using molecular markers. To obtain a more complete understanding of the processes underlying the development and maintenance of genetic diversity, the present study now combines molecular and morphological characterisation with socio-economic information concerning four botanical groups of rice from six West African countries. The aim is to explain how farmer practices have combined with environmental pressures to shape rice diversity in the case study countries. Reference to historical and socio-cultural data is made in order to better understand region-specific morphological traits.

Analysis directs attention to underlying processes regulating the development of genetic diversity in crops in low-input farming systems - processes not yet well understood. An important issue is to grasp the scope of the interplay of artificial and natural selection in crop adaptation. Our findings suggest (Figure 1) that there are multiple pathways for natural and artificial (farmer) selection to influence molecular and morphological markers. Correlations between morphological and molecular data may also vary among the botanical groups because of differences in genetic background, robustness and differential response to human or environmental selection pressures.

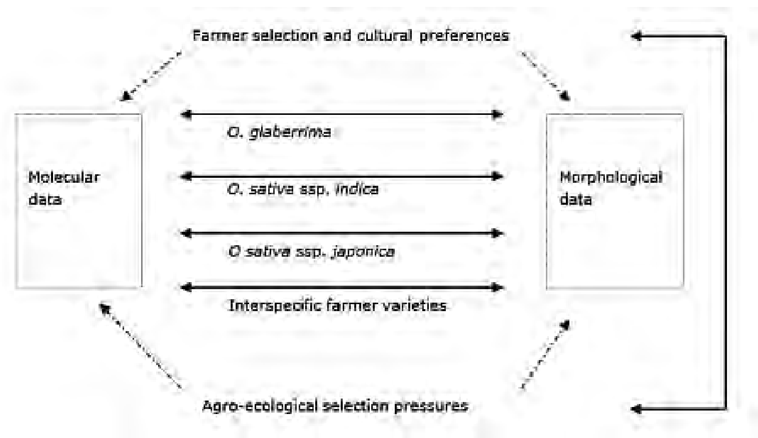


***Figure 1**: Schematic representation of the main aspects of our research and their interlinkages.*

Our analysis confirms that rice varieties in West Africa are adapted to their conditions as a result of genotype × environment × society interactions. The rice diversity farmers appeared to maintain is probably part of a risk-spreading strategy that facilitates innovations in variety development.

Materials and Methods

Ethics statement

We confirm that no specific permit was required for using the location where the field trial was conducted. The location was not protected in any way. The field study never involved endangered or protected species. Approval for the collection of socio-economic data using in-depth interviews and questionnaires was obtained from the Social Sciences Ethical Committee (SSEC) of Wageningen University. The research was carried out by researchers living in the country for at least several years and approved by village elders and farmer communities. Individual participants provided their verbal informed consent to participate in the interviews as part of the interview protocol. Written consent was not possible as most of the interviewees were illiterate. The SSEC approved this consent procedure. We thank the village elders, farmers and the land holding family at Fala Junction Kowa Chiefdom, Sierra Leone.

Variety collection and molecular analysis

Variety collection was carried out from June to December 2007 in seven countries of Coastal West Africa: The Gambia, Ghana, Guinea, Guinea Bissau, Senegal, Sierra Leone and Togo (Figure 2). The purpose was to collect varieties of *O. glaberrima* and *O. sativa* cultivated by farmers in regions where *O. glaberrima* was known to be cultivated. In each country varieties were collected in a number of case study villages. In exceptional cases, varieties in other villages were collected if they had a clear relationship to the main case study villages, if there was an important 'story' related to them, or if they were morphologically intermediate between *O. sativa* and *O. glaberrima*. At harvest time a total of 231 accessions were collected. In February and March 2008 these accessions were analysed molecularly using AFLP markers. In the research by Nuijten *et al*. [23] these data were then added to the 84 accessions analysed by Nuijten and Van Treuren [30]. With the software package 'Structure' (version 2.2), materials with a probability equal to or higher than 91% were assigned to four clusters (*glaberrima*, *indica*, *japonica* and farmer hybrids (see Table 1). Materials assigned with a value lower than $p = 0.91$ were considered outliers. Farmer hybrids are farmer varieties of interspecific origin [23].

Choice and types of farmer varieties

In this paper we consider only the materials that were assigned with a probability equal to or larger than 91% to the botanical groups *O. glaberrima*, *O. sativa* ssp. *japonica*, *O. sativa* ssp. *indica* and the farmer interspecific hybrids (Cluster 4). The focus of this study was on upland varieties. Apart from pure upland varieties also varieties from the upper part of the lowland-upland continuum were included. Typical lowland varieties were left out.

In addition, the number of materials collected from The Gambia in 2007 was too limited for a meaningful comparison and were left out. Because for some materials not enough seeds were available for the morphological analysis, we worked with a total of 182 varieties.

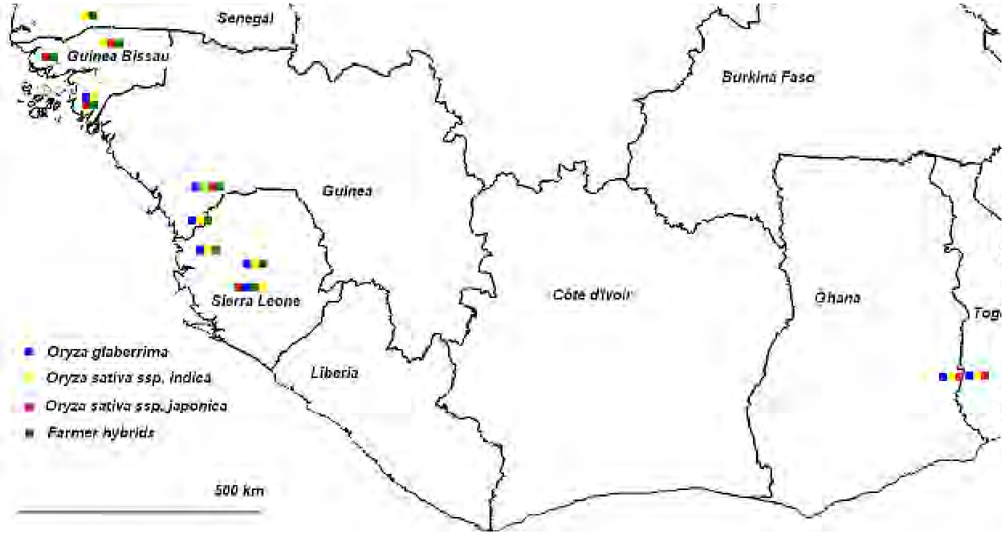


Figure 2*: Case study areas are indicated by colours representing the most commonly cultivated botanical groups in those areas.*

Table 1*: Number of materials used in the molecular and morphological analysis according to their botanical group and their areas of collection.*

Botanical group	Senegal (Casamance)	Guinea Bissau	Guinea (Kindia and Forecariah)	Sierra Leone (Central-N/West)	Ghana (Togo Hills, Volta region)	Togo (Togo Hills, Danyi plateau)	Total
O. glaberrima	3	4	19	6	8	9	49
O. sativa ssp. *indica*	7	4	13	5	15	2	46
O. sativa ssp. *japonica*	0	18	2	28	5	3	56
Farmer hybrids*	7	10	2	12	0	0	31
Total	17	36	36	51	28	14	182

*Interspecific farmer varieties with a combined background of *O. glaberrima* and *O. sativa*

Trial set-up

Field evaluations were carried out in Sierra Leone from June to December 2008. The trial was set up under upland rain-fed conditions at Fala Junction, Kowa Chiefdom (8.14917 N, 11.90806 E, 58 m asl), in Moyamba District. The period of field evaluation corresponded to the cropping season. The average annual rainfall is between 2100-3000 mm and the rainy season lasts for 6 to 7 months. The selected site was flat. The soil was cleared and deeply plowed after 24 years of bush fallow. The soil was silt loam (Mende: *tumui*).

***Table 2**: The 20 traits measured on the rice genotypes in a field trial in Sierra Leone in 2008. Ratings were based on five at randomly chosen plants per plot.*

Characteristic	Description and scale or unit	Type of determination	Stage of measurement
Agronomic traits			
Culm length	Average length, from ground level to the base of the panicle, in cm	Numerical	Physiological maturity
Plant height	Average height, from soil surface up to the tip of the tallest panicle, in cm	Numerical	Physiological maturity
Leaf length	Average length of peninsulate leaf (leaf below flag leaf), from collar to tip of leaf, in cm	Numerical	Physiological maturity
Leaf width	Average width of peninsulate leaf (leaf below flag leaf), widest portion of the leaf, in cm	Numerical	Physiological maturity
Panicle length	Average length, of main panicle, from panicle base to tip, in cm,	Numerical	Physiological maturity
Panicle number	Average number of panicles per plant	Numerical	Physiological maturity
Number of tillers	Average number of tiller(s) per plant	Numerical	Physiological maturity
Rattoon potential	Assessed after harvests: 0 = None; 1 = Low; 3 = Medium; 5 = Vigorous; 7 = Very vigorous	Scale.	After harvest
Grain length	Average length of grain length, from base of lowermost sterile lemma to tip of fertile lemma or palea, in mm.	Numerical	Post-harvest
Grain width	Average width, measured at the widest portion, in mm.	Numerical	Post-harvest
100-grain weight	Average weight of 100 filled seeds at 13% moisture content.	Numerical	Post-harvest
Botanical traits			
Leaf blade colour	0 = No green visible due to anthocyanin; 3 = Light green; 5 = Medium green; 7 = Dark green	Visual assessment	Physiological maturity
Leaf blade pubescence	1 = Glabrous (smooth); 2 = Intermediate; 3 = Pubescent	Ocular inspection and then fingertip rub to class hairiness	Physiological maturity
Ligule length	Average length, on peninsulate leaf of main stem, from the base of the collar to the tip, in mm	Numerical	Physiological maturity
Ligule shape	0 = Absent; 1 = Truncate; 2 = Acute to acuminate; 3 = 2-cleft	Visual assessment	Physiological maturity
Panicle attitude of main axis (PAMA)	1 = Upright; 2 = Semi-upright; 3 = Slightly drooping; 4 = Strongly drooping	Visual assessment of the main axis of the panicle	Physiological maturity
Panicle attitude of primary branches (PAB)	1 = Erect (compact panicle); 3 = Semi erect, semi-compact panicle; 5 = Spreading (open panicle); 7 = Horizontal; 9 = Drooping	Visual assessment	Physiological maturity
Awn length	0 = None (awn less); 1 = Very short (<5 mm); 3 = Short (~8 mm); 5 = Intermediate (~15 mm); 7 = Long (~30 mm); 9 = Very long (>40 mm)	The awn was measured from base to the tip, then translated in scales	Post-harvest
Husk (lemma and palea) colour	1 = White; 2 = Straw; 3 = Gold and gold furrows; 4 = Brown (tawny); 5 = Brown spots; 6 = Brown furrows; 7 = Purple; 8 = Reddish to light purple; 9 = Purple spots; 10 = Purple furrows; 11 = Black	Visual assessment	Post-harvest
Seed coat colour / pericarp colour	1= White; 2 = Light brown; 3 = Speckled brown; 4 = Brown; 5 = Red; 6 = Variable purple; 7 = Purple	Visual assessment	Post-harvest

The seeds of each accession were sown in a randomised block design. Each plot was 1.5 m × 2.1 m and contained 70 pockets, spaced 30 cm between rows and 15 cm within rows. Three grains were sown in each pocket and pockets were thinned to one plant within four weeks after sowing. Sowing date was determined by following the farmer practices in the region. Excellent germination and growth were observed with low to moderate pest (rodent, termites, cut worms, stem borers) incidences, mostly with *O. sativa* ssp. *japonica* varieties. Traditional fencing and mesh wire were used to prevent damage by rodents. No fertiliser was applied.

Measurements

A total of 20 traits were measured (Table 2). Most traits were measured in all four replications, except a few qualitative traits which were measured only on the first replication, as these traits were not influenced by microenvironment. Measurements were done on five plants chosen randomly in each plot excluding the border rows. The accessions were characterised according to the descriptor list by Bioversity International (2007) [34] with the exception of rattooning potential.

Socio-economic data collection

Besides the collection of farmer accessions, socio-economic data were collected on all 182 varieties using in-depth interviews and questionnaires which mainly covered (i) household data, (ii) number of varieties grown, (iii) ecology of cultivation, (iv) the area under cultivation, (v) farmer reasons for growing the variety, (vi) seed source, (vii) on-farm seed management practices from harvest to sowing and farmer knowledge related to variety use.

Data analysis

Principal component analysis (PCA) was used to describe the morphological data measured through a reduced number of variables shown in biplot as vectors. The genetic implications can be assessed from the eigenvalues ascribed to the different traits [35]. The values of the principal components per genotype correspond to a combination of traits explaining the variability. The closer the distance between genotypes in the biplots with the different principal components the closer the genotypes are related with respect to the traits represented by the principal components. PCA was conducted using SPSS/ PASW Statistics 18.

The morphological data were also analysed with the software Splitstree [36]. The measured data were translated into dummy variables. For the data with ordinal scales: for each value a column was created. For the numerical data, the number of categories was determined based on the difference between the maximum and minimum value divided by the standard deviation. The width of a category was determined by dividing the range by the number of categories multiplied with the factor 1.5. These data and the molecular data were analysed with the software Splitstree using the same method followed by Nuijten *et al*. [23].

Results and Discussion

Rice diversity in West Africa at the molecular level

Figure 3 illustrates the phylogenetic relationships of materials studied in the field trial, as assessed during molecular analysis [cf. 23]. Four clusters are shown in detail. Three of these clusters correspond to the botanical groups *O. glaberrima*, *O. sativa* ssp. *japonica* and *O. sativa* ssp. *indica*. In between *O. glaberrima* and *O. sativa* ssp. *indica* is situated the group of interspecific farmer varieties sharing the genetic background of both *O. glaberrima* and *O. sativa* (see [23], hereafter referred to as Cluster 4).

The genotypes comprising each cluster also tend to separate in sub-clusters (Figure 3). The genotypes of the *O. glaberrima* cluster split into *O. glaberrima* from the lower Guinea Coast and *O. glaberrima* from the upper Guinea Coast. The *indica* group splits into several sub-clusters in a complex way. Some sub-clusters only consist of genotypes from one country (*indica* from Ghana), while other sub-clusters are constituted by materials from different countries. The *japonica* cluster splits into one sub-cluster with *japonica* mainly from Sierra Leone and a sub-cluster with *japonica* mainly from Ghana and Guinea Bissau. The cluster of the farmer hybrids splits into one sub-cluster with genotypes that display erect and semi-erect panicles and a second sub-cluster with droopy panicles. Genotypes of the first sub-cluster (Cluster 4-1) were found in Sierra Leone, Guinea and Guinea Bissau while genotypes of the second sub-cluster were found in Guinea Bissau and Senegal (Cluster 4-2). The following sections explore the morphological diversity of the respective sub-clusters to see how they are related to the observations at molecular level and farming system level. Various historical and contextual explanations for these clusterings are discussed in Nuijten *et al*. [23] and Mouser *et al*. [29]. For example, the Ghana-Guinea Bissau *japonica* cluster could be interpreted as indicating a pathway of rice introduction from the East Indies via the important and long-established Portuguese coastal trading stations at Elmina (Ghana) and Cacheu (Guinea Bissau).

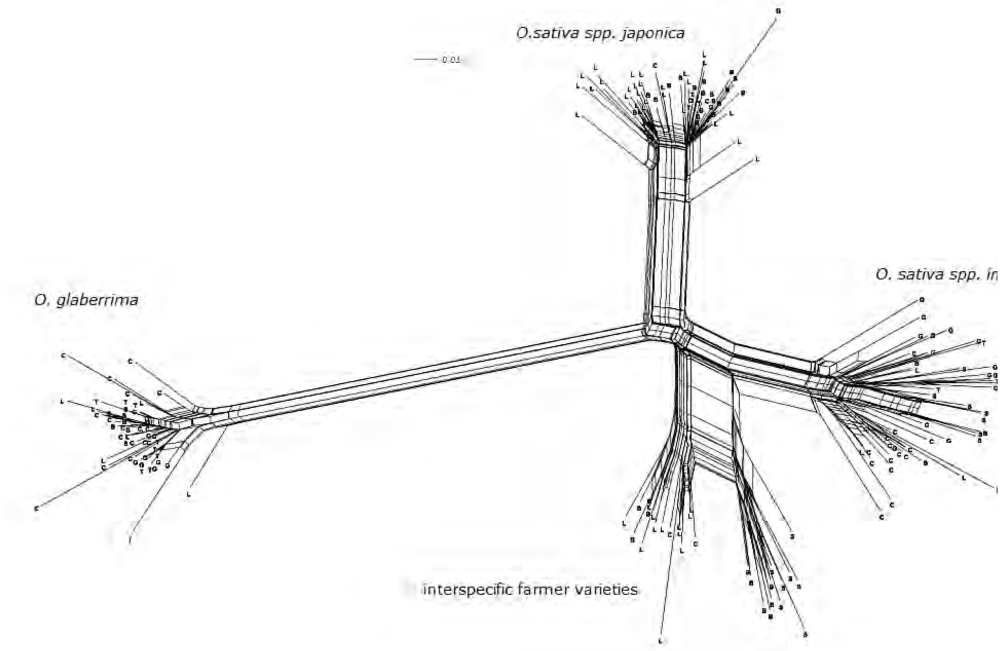


***Figure 3**: Phylogenetic relationships based on molecular markers of the 182 materials included in the morphological analysis. Country of collection is indicated by letters: B = Guinea Bissau, C = Guinea Conakry, G = Ghana, L = Sierra Leone, S = Senegal, T = Togo.*

Morphological diversity

Out of 17 principal components (PCs), the first four accounted for 73.57% of the variance among the traits studied (Table 3). The fifth component was not used in the biplots (Figures 4, 5, 6, 7, 8, and 9) because it had very little explanatory value for most traits. Table 4 presents the rotated principal components matrix and shows how traits contributed to the PCs. Traits commonly used to distinguish *O. glaberrima* from *O. sativa* contributed most to PC 1: ligule shape and length, panicle attitude of main axis (PAMA), and leaf blade pubescence. Traits that contributed most to PC 2 were leaf width, seed width, number of tillers and number of panicles. Traits that contributed most to PC 3 were culm length, plant height, panicle length and leaf length. Seed length contributed clearly to PC 4. Tables 5 and 6 show average values, standard deviations and coefficients of variation for 10 agronomic traits, by botanical groups and sub-groups.

***Table 3**: Initial eigenvalues and rotation sums of squared loadings of 17 principal components based on 17 morphological traits measured on 182 rice accessions.*

Principal	Initial eigenvalues			Rotation sums of squared loadings		
Component	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	5.98	35.17	35.17	5.51	32.38	32.38
2	3.13	18.38	53.55	2.98	17.51	49.90
3	2.20	12.94	66.49	2.65	15.57	65.47
4	1.20	7.08	73.57	1.29	7.58	73.04
5	1.00	5.90	79.47	1.09	6.43	79.47
6	0.88	5.16	84.63			
7	0.64	3.79	88.42			
8	0.58	3.42	91.84			
9	0.36	2.09	93.93			
10	0.29	1.70	95.63			
11	0.23	1.38	97.01			
12	0.21	1.22	98.23			
13	0.12	0.71	98.94			
14	0.08	0.47	99.41			
15	0.06	0.34	99.76			
16	0.04	0.24	100.00			
17	0.00	0.00	100.00			

Extraction Method: Principal Component Analysis.

Comparison between botanical groups

Figures 4, 5, 6, 7, 8, and 9 represent the morphological diversity using different combinations of PC 1, 2, 3 and 4. The graphical representation of genotypes using PC 1 and 2 (53.6%) shows two clouds of genotypes (Figure 4), separating *glaberrima* distinctly from the other three groups. *O. glaberrima* has a rounded and short ligule, erect panicle, erect primary branches, generally displays little leaf blade pubescence and tends to have a rather light leaf blade colour. This separation agrees with separations achieved through the molecular analysis.

By contrast, the three other botanical groups are not as clearly separated as they are in the molecular analysis. The clusters *japonica*, and *indica* form two connected clouds distributed along PC 2. The japonicas produce fewer tillers and panicles, and wider leaves and seed compared to the indicas. The farmer hybrids overlap mostly with the indicas. The molecular analysis also suggested that farmer hybrids are more closely related to indicas than to japonicas (see Figure 3). Most of the farmer hybrids that are clearly separate from the indicas

***Table 4**: Rotated Principal Components (PCs) of 17 morphological rice traits.*

Trait	Components				
	1	2	3	4	5
Leaf blade colour	0.65	0.50	-0.04	-0.10	-0.05
Leaf blade pubescence	0.90	0.02	0.01	-0.16	0.07
Culm length	-0.09	0.05	0.88	-0.15	0.24
Plant height	-0.09	0.02	0.95	-0.10	0.12
Panicle length	-0.04	-0.09	0.70	0.17	-0.40
Leaf length	0.25	0.37	0.60	0.14	0.20
Leaf width	-0.37	0.80	0.25	0.05	0.12
Ligule length	0.90	-0.22	0.05	-0.02	-0.01
Ligule shape	0.97	0.07	-0.07	-0.00	0.02
# tillers / plant	-0.42	-0.79	-0.05	-0.07	0.11
# panicles / plant	-0.44	-0.79	-0.00	-0.08	0.07
Panicle attitude of main axis (PAMA)	0.88	0.16	-0.09	0.28	-0.07
Panicle attitude of branches (PAB)	0.77	0.28	-0.07	0.17	-0.04
Seed length	0.10	-0.07	-0.05	0.93	0.09
Seed width	-0.05	0.71	-0.05	-0.36	0.19
Collar colour	0.05	0.03	0.17	0.09	0.81
Rattoon potential	0.74	0.15	0.08	0.23	0.27

* Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization.

belong to Sub-cluster 4-1 (Sierra Leone and Guinea Bissau) and only a few to Sub-cluster 4-2 (Guinea Bissau).

The combination of PC 1 and 3 (Figure 5) shows a larger overlap between japonicas, indicas and the farmer hybrids along the third component while the *glaberrima* cluster is pulled apart along the third component. The genotypes of *glaberrima* studied here are thus highly differentiated from each other on traits represented by PC 3 (plant height, culm length, panicle length and leaf length). The genotypes from Togo and Ghana tend to sit toward the lower part of the cloud and those from Guinea and Sierra Leone sit in the upper part.

When combining PC 2 and 3 (31.3%) all botanical groups form a single cloud (Figure 6). Whereas PC 1 is based on traits that separate *glaberrima* from the other botanical groups, PC 2 and 3 are based on a majority of the agronomic traits included in this study. The glaberrimas, indicas and most of the farmer hybrids, except for most of those from Senegal, are situated towards the left of the scatter, while the japonicas are positioned towards the right. Also, Figure 6 shows that *glaberrima* varieties differ more in height-related traits and panicle length than in number of panicles and tillers and leaf and seed width.

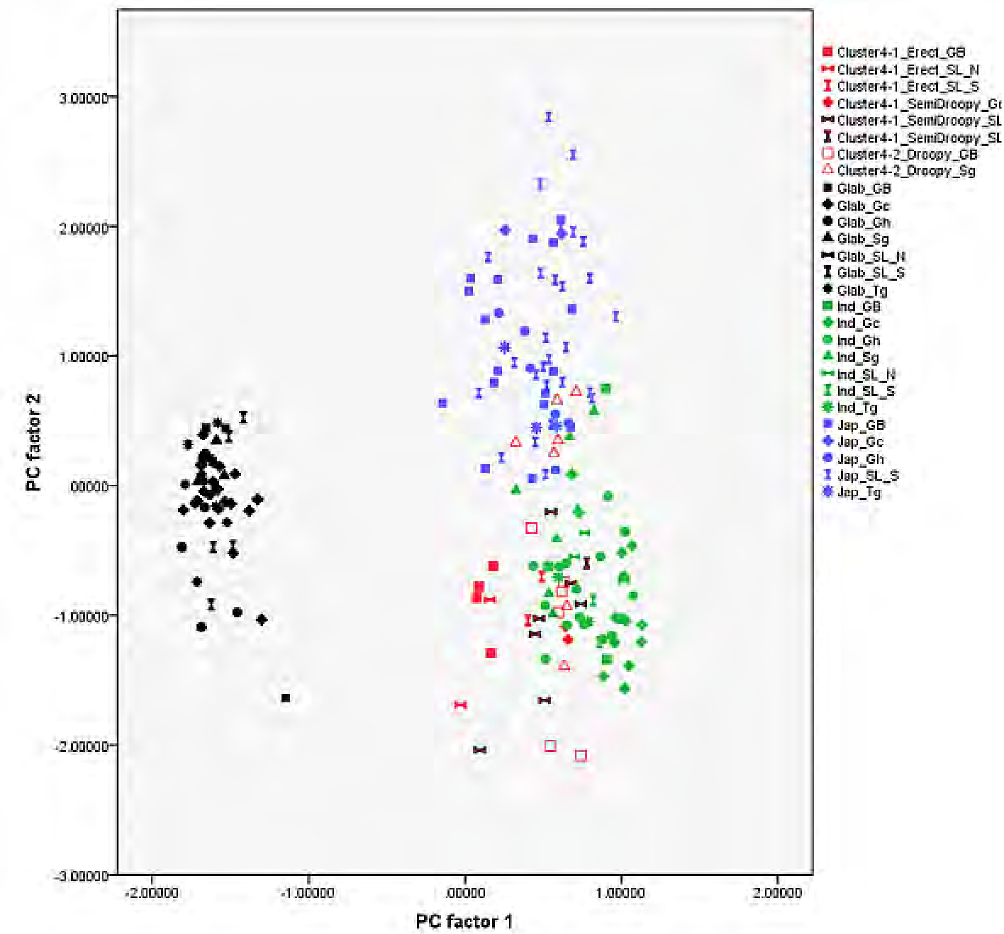


Figure 4*: Graphical repartition of materials based on morphological data of PC 1 and 2.*
Component 1*: Ligule shape (0.97)*, Leaf blade pubescence (0.90), Ligule length (0.90), PAMA** (0.88), PAB*** (0.77), Rattoon potential (0.74), Leaf blade colour (0.65)*
Component 2*: Leaf width (0.80), # tillers per plant (-0.79), # panicles per plant (-0.79), Seed width (0.71), Leaf blade colour (0.50) Glab: glaberrima, Ind: indica, Jap: japonica, Clusters 4-1 and 4-2: farmer hybrids, GB: Guinea Bissau, SL: Sierra Leone (north: N south: S), Gc: Guinea Conakry, Sg: Senegal, Gh: Ghana, Tg: Togo.*
**(): value of the correlation of the trait with the component*
***: Panicle Attitude of Main Axis*
****: Panicle Attitude of Branches*

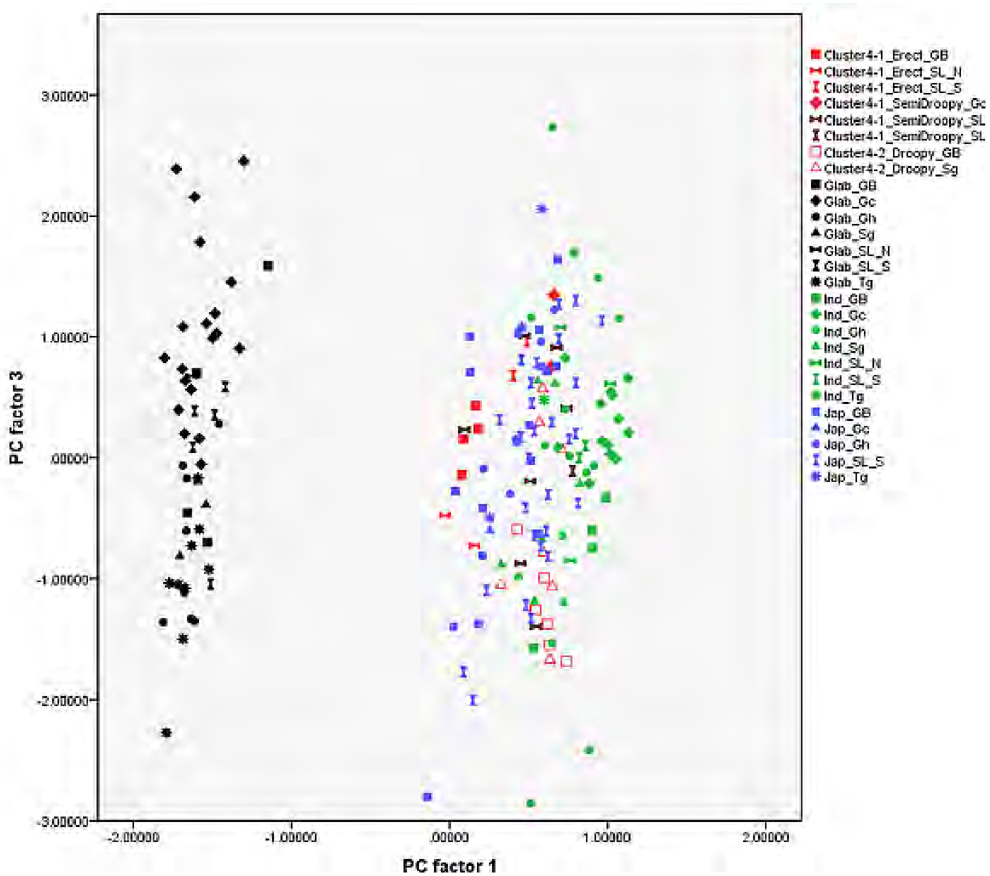


Figure 5*: Graphical repartition of materials based on morphological data of PC 1 and 3*
Component 1*: Ligule Shape (0.97)*, Leaf blade pubescence (0.90), Ligule length (0.90), PAMA** (0.88), PAB*** (0.77), Rattoon potential (0.74), Leaf blade colour (0.65)*
Component 3*: Plant height (0.95), Culm length (0.88), Panicle length (0.70), Leaf length (0.60)*
GB: Guinea Bissau, SL: Sierra Leone (north: N south: S), Gc: Guinea Conakry, Sg: Senegal, Gh: Ghana, Tg: Togo.
**(): value of the correlation of the trait with the component*
***: Panicle Attitude of Main Axis*
****: Panicle Attitude of Branches*

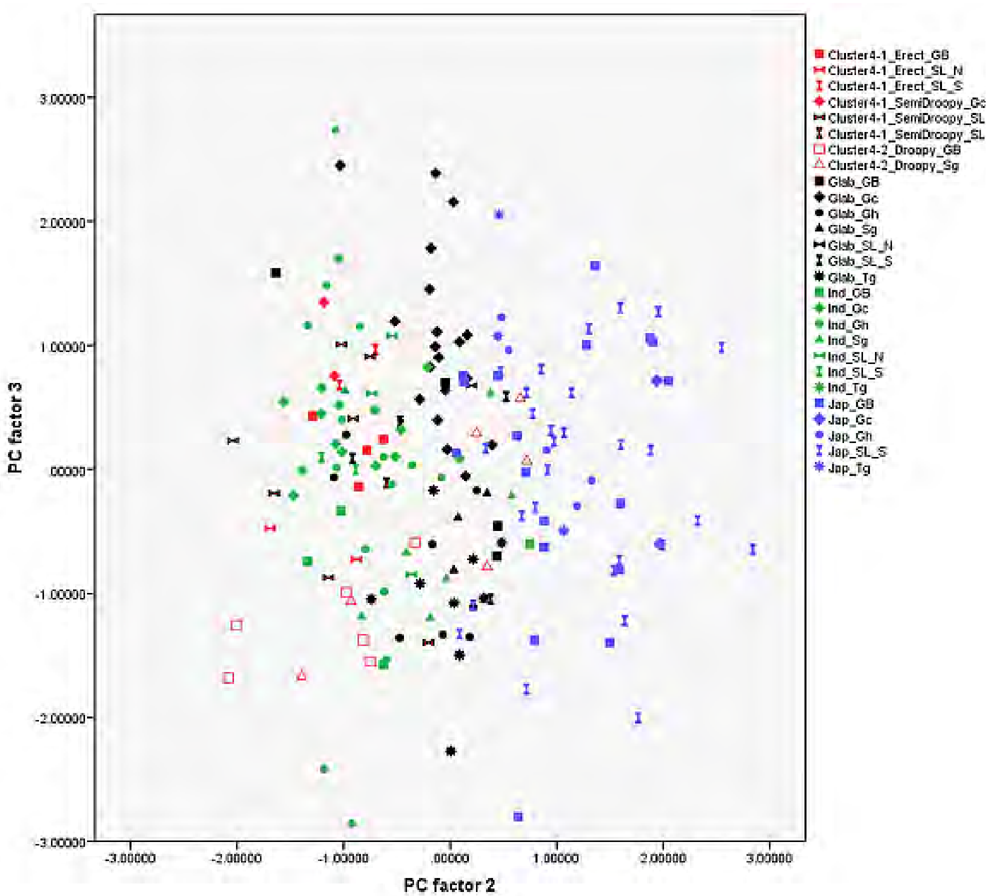


***Figure 6**: Graphically repartition of materials based on morphological data of PC 2 and 3*
***Component 2**: Leaf width (0.80)*, # tillers / plant (-0.79), # panicles/plant (-0.79), Seed width (0.71), Leaf blade colour (0.50)*
***Component 3**: Plant height (0.95), Culm length (0.88), Panicle length (0.70), Leaf length (0.60)*
GB: Guinea Bissau, SL: Sierra Leone (north: N south: S), Gc: Guinea Conakry, Sg: Senegal, Gh: Ghana, Tg: Togo.
**(): value of the correlation of the trait with the component*

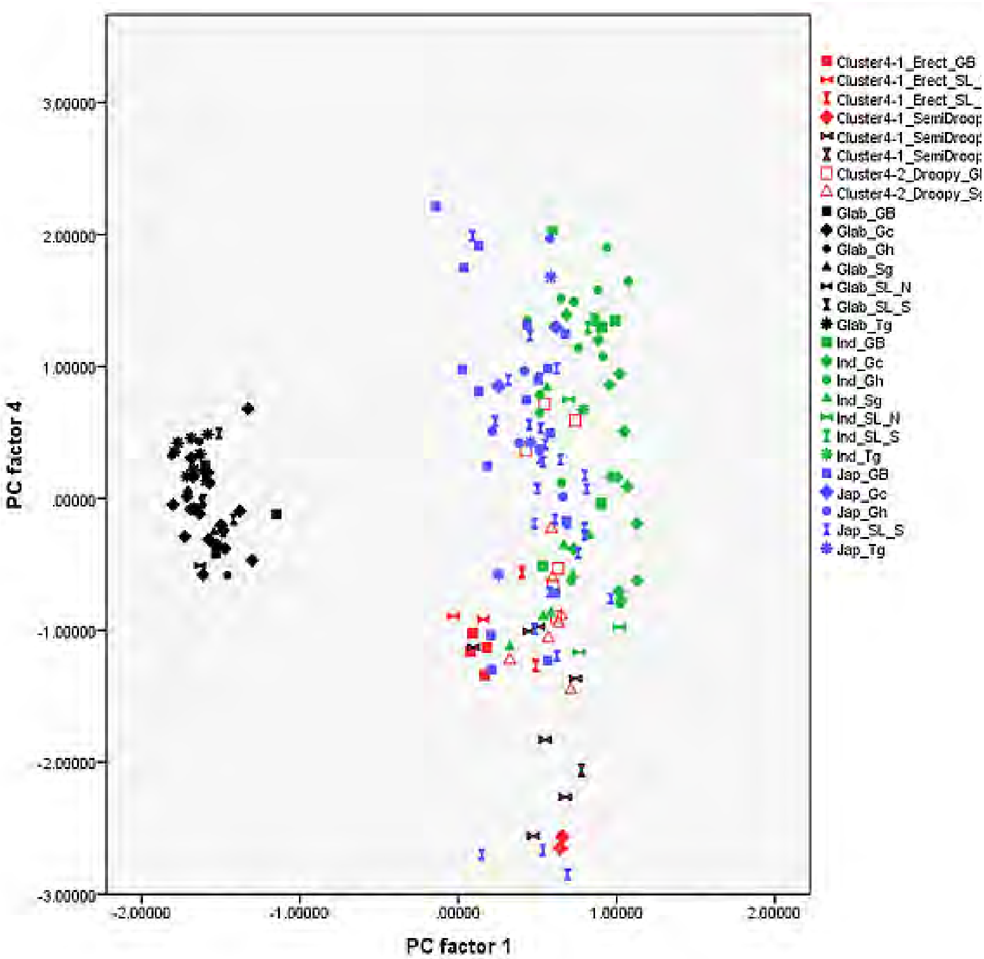


***Figure 7**: Graphically repartition of materials based on morphological data of PC 1 and 4*

Component 1**: Ligule Shape (0.97)*, Leaf blade pubescence (0.90), Ligule length (0.90), PAMA** (0.88), PAB (0.77), Rattoon potential (0.74), Leaf blade colour (0.65)*

***Component 4**: Seed length (0.93), Seed width (-0.36)*

GB: Guinea Bissau, SL: Sierra Leone (north: N south: S), Gc: Guinea Conakry, Sg: Senegal, Gh: Ghana, Tg: Togo.

**(): value of the correlation of the trait with the component*

***: Panicle Attitude of Main Axis*

****: Panicle Attitude of Branches*

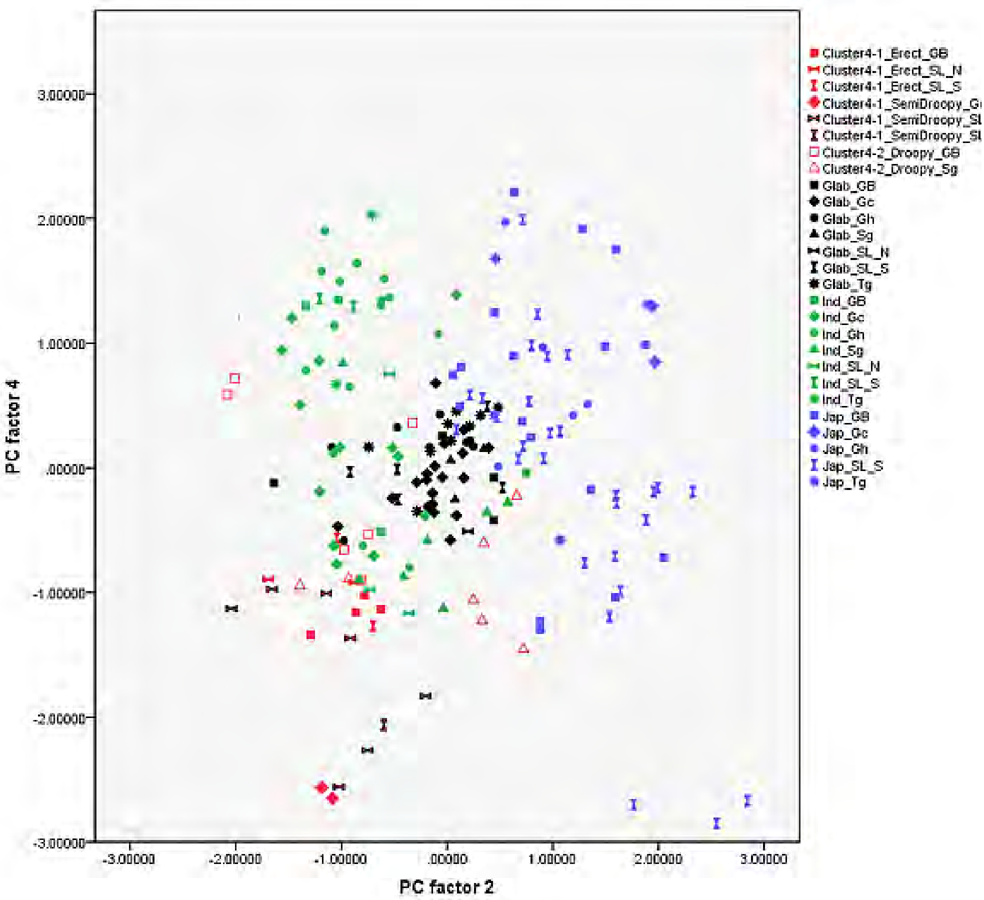


***Figure 8**: Graphically repartition of materials based on morphological data of PC 2 and 4*
***Component 2**: Leaf width (0.80)*, # tillers / plant(-0.79), # panicles/plant (-0.79), Seed width (0.71), Leaf Blade Colour (0.50)*
***Component 4**: Seed length (0.93), Seed width (-0.36) GB: Guinea Bissau, SL: Sierra Leone (north:N south: S), Gc: Guinea Conakry, Sg: Senegal, Gh: Ghana, Tg: Togo.*
.(): value of the correlation of the trait with the component*

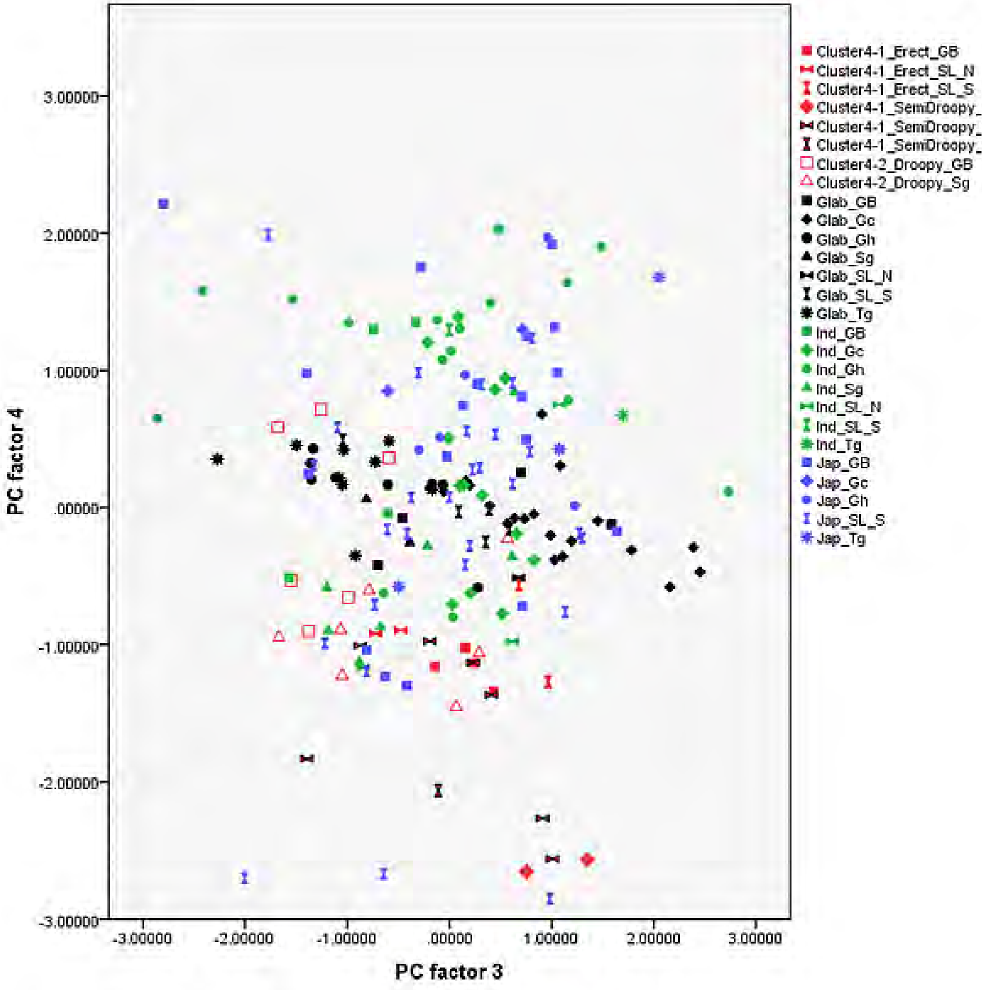


***Figure 9**: Graphically repartition of materials based on morphological data of PC 3 and 4*
***Component 3**: Plant height (0.95)*, Culm length (0.88), Panicle length (0.70), Leaf length (0.60)*
***Component 4**: Seed length (0.93), Seed width (-0.36)*
GB: Guinea Bissau, SL: Sierra Leone (north: N, south: S), Gc: Guinea Conakry, Sg: Senegal, Gh: Ghana, Tg: Togo.
**(): value of the correlation of the trait with the component*

Through combination of PC 1 and 4 (Figure 7) the *glaberrima* group is bunched into a concentrated cluster showing a large degree of uniformity in related traits. The *indica* and *japonica* genotypes, however, show an equally large range for seed length. The farmer hybrids (mostly the erect and semi-droopy types) are situated at the lower part of the shared cloud with indicas and japonicas, showing relatively short grain length.

Comparison within botanical groups.

When combining PC 1 and 3 (Figure 5) the *O. glaberrima* varieties from the Upper Guinea Coast are found in the upper part of the cloud, with those from Guinea right at the top, and those from the Lower Guinea Coast further down. The glaberrimas from the Upper Guinea Coast are taller and have longer culms and panicles but have similar leaf length and ligule length, when compared to the glaberrimas from the Lower Guinea Coast (Table 5). Among the Upper Guinea Coast glaberrimas, the varieties from Guinea seem to constitute a special group, being taller, with longer culms, panicles and leaves (Table 6). This was also observed in several trials conducted in five countries by Mokuwa *et al*. [29]. That some *glaberrima* varieties from Senegal and Guinea Bissau sit with those from Ghana and Togo when combining PC1 and 2 (Figure 4) might imply a process of adaptation to agro-ecological conditions, such as amount of rainfall, since this is comparable in the two regions.

Table 5 shows that glaberrimas from the Lower Guinea Coast have longer and heavier seeds than those from the Upper Guinea Coast. The differences in seed and plant height-related traits might be ascribed to a process of adaptation to specific ecological and/or socio-cultural factors. Farmers on the Danyi Plateau in the Togo Hills stated that glaberrimas used to thrive well on relatively poor and acid soils, in which the availability of vital nutrients is restricted. The cultivation of rice under these acid conditions might have led to selection for shorter plants that produce heavier and longer grains. Roy *et al*. [37] showed that larger seeds germinate better and produce more vigorous seedlings than smaller seeds and are able to produce a deeper initial root system. Also farmers on the Danyi plateau indicated that larger seed is clearly preferred for culinary reasons (B. Teeken, unpublished data: Chapter 3).

A few *glaberrima* varieties from Ghana, Sierra Leone, Guinea and Guinea Bissau separate (downwards) from the core *glaberrima* cluster (Figure 4). These varieties have more tillers and panicles but have narrower leaves and smaller seed width compared to the other glaberrimas. For these traits, these *glaberrima* varieties resemble the *indica* group.

Unlike the case for *O. glaberrima*, no separate clustering can be observed for *O. sativa* ssp. *indica* from the Upper and Lower Guinea Coast (Figures 4, 5, 6, 7, 8, and 9), nor are significant differences observed for the agronomic traits (Table 5). At molecular level, some indicas from Sierra Leone and the Maritime region of Guinea tend to cluster together. Likewise, the materials from Senegal and the Togo hills cluster. However, at the morphological level a different tendency can be observed. Within the *indica* group (Figure 4) those from Guinea are situated towards the right, and those from Senegal are situated in the upper part, of a cloud. The indicas from Togo, Ghana, Sierra Leone and Guinea Bissau sit together in the centre of the cloud. The indicas show similarity with the farmer hybrids, particularly the semi-droopy hybrids from Sierra Leone and Guinea, and the droopy hybrids from Guinea Bissau.

Within Figures 4, 5, and 6, the indicas from Guinea closely bunch together whereas those from Ghana and other countries are very scattered. One explanation is that the materials collected in Guinea represent a small range of *indica* varieties, whereas a wide range of *indica* varieties was collected from rather diverse ecologies (ranging from hydromorphic soils to pure upland ecologies) in Ghana. Only when combining PC 1 and 4 (Figure 7) and PC 2 and 4 (Figure 8) is the Guinea material pulled apart, reflecting diversity on seed width and length, but not on other traits. The Guinea materials do not differ from the other *indica* varieties from the upper Guinea Coast on agronomic traits, except slightly for leaf length (Table 6).

Our findings at morphological level suggest that farmers in Ghana, Guinea Bissau, Sierra Leone and Senegal tend to select *indica* varieties with a range of morphological features while farmers in Guinea have been selecting narrowly, favouring a particular group of indicas. In the rather difficult upland conditions of the Guinea case-study areas (adjacent to the Bena hills) only a limited range of *indica* varieties has proven to be locally well adapted.

As is the case with *O. glaberrima, O. sativa* ssp. *japonica* from the Togo hills tends to have heavier seeds than the *japonica* from the Upper Guinea Coast region, but unlike *glaberrima* the *japonica* from the Togo hills are taller plants (Table 5). Considering PC 1 and 2 (Figure 4) the genotypes from the Upper Guinea Coast (mostly from Sierra Leone and Guinea Bissau) are found throughout the whole of the *japonica* cluster, while genotypes from the Lower Guinea Coast (materials from Ghana and Togo) are only found in the lower part of the cluster. *Japonica* varieties situated in the upper part of the cluster have broader leaves, fewer panicles and tillers, broader seeds and darker leaves. Materials from Sierra Leone and Guinea Bissau showed equal (high) levels of variation for these traits (see also Table 6). The japonicas from Sierra Leone were only collected from the south of the country meaning that farmers in a specific area deal with a highly diverse set of japonicas. At molecular level the japonicas from Sierra Leone tend to cluster separately from those from the other countries. Such separation does not show clearly in Figures 4, 5, 6, 7, 8, and 9.

***Table 5**: Means, standard deviation (SD), coefficient of variation (CV) and t-test results (P, in bold) for the agronomic morphological traits for the different botanical groups from the Lower Guinea Coast (Lower) and the Upper Guinea Coast (Upper).*

Botanical group		*Glaberrima*		*Indica*		*Japonica*		Average
Region		Lower	Upper	Lower	Upper	Lower	Upper	all groups
Trait	N	17	32	29	17	8	48	151
Culm length (cm)	Mean	79.1	86.3	81.0	82.5	89.2	82.4	83.4
	SD	5.10	6.52	8.37	6.25	5.09	5.72	6.18
	CV (%)	6.45	7.55	10.33	7.57	5.71	6.94	7.43
	P		**0.000**		**0.528**		**0.003**	
Plant height (cm)	Mean	99.1	109.7	103.3	104.7	110.2	103.9	105.2
	SD	5.22	7.09	9.21	6.17	6.27	6.52	6.75
	CV (%)	5.27	6.46	8.91	5.89	5.68	6.27	6.41
	P		**0.000**		**0.561**		**0.014**	
Panicle length (cm)	Mean	20.1	23.4	22.3	22.2	21.1	21.5	21.8
	SD	1.01	1.29	1.44	1.01	1.95	2.23	1.49
	CV (%)	5.03	5.50	6.46	4.55	9.24	10.37	6.86
	P		**0.000**		**0.800**		**0.611**	
Leaf length (cm)	Mean	41.4	42.3	43.1	42.8	48.7	46.3	44.1
	SD	2.80	2.52	4.17	2.65	3.22	3.91	3.21
	CV (%)	6.77	5.96	9.66	6.19	6.62	8.45	7.28
	P		**0.234**		**0.761**		**0.107**	
Leaf width	Mean	1.44	1.46	1.04	1.06	1.50	1.58	1.34
	SD	0.07	0.12	0.10	0.14	0.08	0.20	0.12
	CV (%)	5.04	8.14	9.62	13.17	5.62	12.57	9.03
	P		**0.140**		**0.572**		**0.261**	
# tillers / plant	Mean	5.2	4.8	4.3	4.6	3.3	3.1	4.2
	SD	0.80	0.80	0.58	0.64	0.46	0.59	0.65
	CV (%)	15.48	16.46	13.32	14.05	14.11	19.12	15.42
	P		**0.599**		**0.208**		**0.485**	
# panicles / plant	Mean	4.5	4.4	3.8	4.0	2.7	2.7	3.7
	SD	0.56	0.70	0.52	0.60	0.30	0.47	0.53
	CV (%)	12.51	16.19	13.98	15.05	10.89	17.39	14.34
	P		**0.621**		**0.123**		**0.738**	
Average 200 seed weight (g)	Mean	4.63	4.17	4.67	4.77	5.29	4.82	4.73
	SD	0.19	0.41	0.38	0.44	0.33	0.73	0.41
	CV (%)	4.10	9.83	8.07	9.12	6.29	15.08	8.75
	P		**0.000**		**0.421**		**0.082**	
Seed length (mm)	Mean	8.69	8.40	9.13	9.03	9.25	8.66	8.86
	SD	0.16	0.29	0.68	0.60	0.49	0.82	0.51
	CV (%)	1.84	3.45	7.47	6.68	5.28	9.51	5.71
	P		**0.001**		**0.629**		**0.058**	
Seed width (mm)	Mean	3.07	3.03	2.93	2.96	3.18	3.25	3.07
	SD	0.07	0.13	0.30	0.19	0.24	0.31	0.21
	CV (%)	2.28	4.29	10.27	6.26	7.50	9.52	6.69
	P		**0.112**		**0.651**		**0.545**	
Average CV (%)		5.9	7.6	8.9	8.0	7.0	10.5	

Table 6: *Means, standard deviations (SD), coefficients of variation (CV) and t-test results (P, in bold) for the agronomic morphological traits for the four different sub-groups within the Upper Guinea Coast. UpperSL = material from Sierra Leone; UpperGB = material from Guinea Bissau; UpperGc = material from Guinea; Cluster 4-1 = material belonging to the sub-cluster of Cluster 4 with erect and semi-droopy panicles; Cluster 4-2 = material belonging to the sub-cluster of Cluster 4 with droopy panicles; 4-1 Erect = material of Cluster 4-1 with erect panicle; 4-1 semi droopy = material belonging to Cluster 4-1 with semi-droopy panicle.*

Botanical group		*Glaberrima*		*Indica*		*Japonica*		Cluster 4		Cluster 4-1	
Region / sub-cluster		Upper Gc	Upper-Other	Upper Gc	Upper-Other	Upper GB	Upper SL	Cluster 4-2	Cluster 4-1	4-1 Erect	4-1 Semi-droopy
Trait	N	19	13	13	12	18	28	13	18	8	10
Culm length (cm)	Mean	89.3	82.1	84.9	82.6	83.9	81.6	76.3	83.3	83.6	83.0
	SD	5.66	5.32	4.76	5.39	6.83	4.98	5.23	5.32	4.13	6.33
	CV (%)	6.34	6.48	5.61	6.53	8.14	6.11	6.86	6.39	4.94	7.63
	P		**0.001**		**0.260**		**0.198**		**0.001**		**0.826**
Plant height (cm)	Mean	112.8	105.2	107.1	104.3	105.1	103.2	97.9	104.6	104.3	104.9
	SD	6.25	5.80	4.70	5.84	7.95	5.68	5.76	6.04	4.51	7.28
	CV (%)	5.54	5.52	4.39	5.60	7.57	5.50	5.89	5.77	4.32	6.94
	P		**0.001**		**0.192**		**0.349**		**0.004**		**0.834**
Panicle length (cm)	Mean	23.6	23.3	22.2	21.7	21.1	21.6	21.6	21.4	20.7	22.0
	SD	1.08	1.57	1.05	1.17	2.06	2.23	0.98	1.43	1.13	1.44
	CV (%)	4.59	6.75	4.76	5.38	9.75	10.32	4.55	6.68	5.47	6.57
	P		**0.543**		**0.352**		**0.479**		**0.642**		**0.060**
Leaf length (cm)	Mean	43.1	41.1	43.6	41.5	46.1	46.3	38.5	45.6	48.2	43.6
	SD	1.77	3.01	2.04	2.82	4.05	4.03	4.21	3.45	3.34	1.84
	CV (%)	4.10	7.32	4.68	6.79	8.77	8.70	10.93	7.55	6.94	4.22
	P		**0.043**		**0.041**		**0.892**		**0.000**		**0.002**
Leaf width	Mean	1.49	1.40	1.08	1.05	1.51	1.62	1.04	1.01	1.05	0.98
	SD	0.13	0.07	0.15	0.14	0.23	0.18	0.18	0.09	0.09	0.09
	CV (%)	8.92	4.72	13.99	13.76	15.08	10.85	17.11	9.22	8.26	9.13
	P		**0.030**		**0.633**		**0.087**		**0.672**		**0.104**
# tillers / plant	Mean	4.7	5.0	4.7	4.3	3.2	3.1	4.2	4.7	4.9	4.6
	SD	0.66	0.97	0.63	0.66	0.61	0.56	1.02	0.63	0.47	0.74
	CV (%)	13.85	19.51	13.62	15.31	19.32	18.05	24.44	13.45	9.73	16.14
	P		**0.367**		**0.240**		**0.874**		**0.101**		**0.391**
# panicles / plant	Mean	4.3	4.4	4.1	3.8	2.7	2.7	3.6	4.2	4.3	4.1
	SD	0.43	1.00	0.57	0.54	0.48	0.44	0.92	0.72	0.57	0.84
	CV (%)	9.91	22.79	13.90	14.38	17.83	16.42	25.84	17.44	13.32	20.83
	P		**0.808**		**0.128**		**0.819**		**0.049**		**0.529**
Average 200 seed weight (g)	Mean	4.04	4.35	4.73	4.93	5.03	4.58	3.73	3.59	4.37	2.96
	SD	0.20	0.54	0.49	0.21	0.67	0.61	0.61	0.79	0.30	0.39
	CV (%)	4.95	12.41	10.29	4.28	13.36	13.31	16.27	22.16	6.81	13.14
	P		**0.064**		**0.196**		**0.024**		**0.580**		**0.000**
Seed length (mm)	Mean	8.37	8.45	8.98	8.78	8.95	8.43	8.13	7.51	8.20	6.96
	SD	0.32	0.25	0.54	0.66	0.72	0.84	0.51	0.82	0.25	0.68
	CV (%)	3.82	2.96	6.00	7.51	8.01	9.92	6.28	10.90	3.05	9.78
	P		**0.469**		**0.425**		**0.035**		**0.015**		**0.000**
Seed width (mm)	Mean	2.96	3.12	2.96	3.15	3.20	3.27	2.84	2.90	3.09	2.74
	SD	0.08	0.14	0.15	0.28	0.31	0.32	0.40	0.21	0.04	0.16
	CV (%)	2.70	4.49	4.92	9.01	9.69	9.71	14.07	7.36	1.26	5.98
	P		**0.002**		**0.062**		**0.469**		**0.632**		**0.000**
Average CV (%)		5.9	8.5	7.5	8.0	10.7	9.9	12.0	9.7	5.8	9.1

Mokuwa *et al*. [10] found that a group of japonicas from Sierra Leone were more niche adapted, whereas a group of japonicas from Guinea Bissau showed wide adaptation. Both the Sierra Leone materials and most of the materials from Guinea Bissau used in the experiments by Mokuwa *et al*. [10] are among the genotypes sitting in the upper part of the *japonica* cluster (PC 1 and 2; Figure 4). At molecular level one Sierra Leone variety (Nduluwai) clusters with the Guinea Bissau varieties. In Figures 10 and 11 these varieties are found in different sub-groups, clustering in idiosyncratic ways. What this suggests is that farmers in both regions have selected morphologically similar materials responsive to different agro-ecological conditions. This might reflect histories of adaptation and introduction for these japonicas [29]. Evidence supporting a different process of introduction and adaptation is the similarity of the varieties Aqua Blue ('blue water') from Ghana and Sefa Fingo (meaning 'black type' in Mandinka) from Guinea Bissau at molecular and morphological levels, perhaps indicating common origins via Portuguese trading networks. It is thought that Portuguese traders brought japonicas from Indonesia to Guinea Bissau from where they spread to other West African countries [38]. To emphasise the distinctiveness of this case, both varieties have a distinct colouration during flowering and maturation not observed in other varieties.

Farmers from the Ghana side of the Togo hills have been selecting japonicas with relatively narrow leaves, high tillering and panicle production, slender and long grains similar to some indicas. (Figures 6 and 7). The long grain size could be explained by the large demand for long grained rice in the market.

In Figures 4, 5, 6, 7, and 8, farmer hybrids (Cluster 4) in general formed a large cloud suggesting they are diverse, confirming the molecular findings. Based on the panicle architecture (PAMA) most widely used to distinguish *O. glaberrima* from *O. sativa* varieties, the farmer hybrids were assigned to three sub groups: erect panicles, semi-droopy panicles and droopy panicles. In Figures 4, 5, 6, 7, and 8 the farmer hybrids with erect panicles did not clearly separate from the farmer hybrids with semi-droopy and droopy panicles, although they did in Figures 10 and 11. Table 6 shows statistically significant differences in seed weight, length and width between farmer hybrids with erect and semi-droopy panicles. For these two groups no clear difference was observed in the clustering based on molecular data.

Figure 5 (PC 1 and 3) shows that the farmer hybrids with erect panicles from Guinea Bissau cluster closely together, whereas those from Sierra Leone are more scattered. This agrees with the molecular analysis. Particularly, erect farmer hybrids from Northern Guinea Bissau sit together. These varieties were considered weeds by Mandinka farmers from northern Guinea Bissau; they referred to these interspecific varieties by names they also used for *glaberrima*. The one from Southern Guinea Bissau was brought from Guinea and sits somewhat separated. The scattering of the farmer hybrids with erect and semi-droopy panicles from Sierra Leone in Figure 4 points to active selection by farmers.

The erect farmer hybrids of Guinea Bissau and Sierra Leone are known to be four months in duration from germination to ripening. The semi-droopy farmer hybrids from Sierra Leone and Guinea are three months in duration. These semi-droopy farmer hybrids can be further divided into those with small and slender grains and those with short and bold grains. The latter are visible in Figure 7 down among the semi-droopy farmer hybrids from Sub-cluster 4-1. Farmers have been selecting 'three month' varieties as hunger breakers because they ripen about one and half or two month(s) before the major rice harvesting time. In this respect the three-month group of farmer hybrids has been replacing some of the short cycle *glaberrima* traditionally used as hunger breakers. Compared to the erect farmer hybrids these 'three months' interspecific farmer varieties vary more for husk colour and seed size (see also Table 6).

Compared to the limited diversity represented by the erect farmer hybrids from Guinea Bissau, the larger diversity in droopy farmer hybrids from Guinea Bissau and Senegal (Sub-cluster 4-2 in Table 6) agrees with interview data that farmers actively select for droopy farmer hybrids in these regions. The farmer hybrids with droopy panicles split into two groups largely reflecting their area of collection. Figure 4 (PC 1 and 2) shows that only farmer hybrids with droopy panicles from Senegal are found in the area where *indica* and *japonica* overlap. Interviews with farmers indicated that the farmer hybrids in Senegal have their origin in Guinea Bissau. The droopy varieties spread to Senegal particularly during the independence war in Guinea Bissau from 1963 to 1974. However, the farmer hybrids with droopy panicles collected in Guinea Bissau are situated in the lower part of the cloud of farmer hybrids. This suggests that over a period of approximately 40-50 years a selection process has taken place, and that farmers in the case study areas in Senegal and Guinea Bissau prefer farmer hybrids with area-specific morphological characteristics. Overall, morphological characterisation of farmer hybrids underlines a conclusion that Cluster 4-2 is highly variable and shares characteristics with *japonica* and *indica*. At the molecular level, however, the farmer hybrids are all closer to *indica* than to *japonica*.

Geographical and climatic clustering

Figure 10 shows an unrooted tree based on 20 morphological traits, and Figure 11 based on agronomic traits only (see Table 2). The clustering in Figure 10 is largely according to botanical groups, with *glaberrima* and *japonica* making well-defined clusters and *indica* and the farmer hybrids consisting of several clusters. The *glaberrima* clearly forms three sub-clusters for Guinea and Sierra Leone, Ghana and Togo, and north Guinea Bissau and Senegal. For the other botanical groups some country based clustering patterns can also be observed, although less clearly. Some clusters contain material from several botanical groups. In the case of *japonica*, two clusters hold mostly material from Sierra Leone, and another cluster groups material from various countries. In the case of *indica* from the Upper Guinea Coast some clustering based on seed colour can be observed, but not for the Lower Guinea Coast. Some white seeded indicas cluster with light-coloured droopy farmer hybrids from Guinea Bissau, and some red seeded indicas cluster with red-coloured semi-droopy farmer hybrids from Sierra Leone and Guinea.

The clustering in Figure 11 is complex, with material from the four botanical groups clustering in various ways. To some extent the patterns may reflect agro-ecological selection pressures. This is perhaps particularly true for the glaberrimas, where grouping reflects geographical factors. The glaberrimas from Senegal and northern Guinea Bissau, for instance, cluster more closely with the glaberrimas from Togo and Ghana, with both areas having similar amounts of rainfall. For the other botanical groups no such clear separation is apparent. Another apparent indicator of agro-ecological selection pressures is the extent to which material from various botanical groups from one country, or two neighbouring countries, clusters together. For example, the erect farmer hybrids, most coming from Sierra Leone, and the indicas from Guinea cluster closely with the glaberrimas from Guinea and Sierra Leone. However, clusters can also be found grouping material from all countries, as applies to subsets of indicas and japonicas. Also the droopy farmer hybrids from Senegal form several small independent clusters.

Pericarp colour as a selection factor

Seed colour (pericarp) is an important characteristic often mentioned by farmers [9]. Depending on the farming system and social context, pericarp colour is a nutritional, gender, religious or cultural marker, and plays a role in the selection and acceptance of rice varieties [9]. Seed colour was not incorporated in the PCA because it could not be converted into a linear scale. Instead we labelled the materials of this study according to seed colour. Figure 12, 13 and 14 respectively show the combination of factor PC 1 and 2, 1 and 3 and 2 and 3 marked according to seed colour, country of collection and botanical group. Only a few relationships between pericarp colour, molecular, and morphological data were found. The clearest relationship was among the farmer hybrids, where varieties with erect and semi-droopy panicles have a red pericarp, and those with a droopy panicle have a white or light brown pericarp. The varieties Pugulu 'white' and 'red' from Ghana were found in neighbouring clusters in Figure 10 (B. Teeken, unpublished). This is a case of farmers using the same name with the addition 'white' or 'red' for varieties that are genetically different.

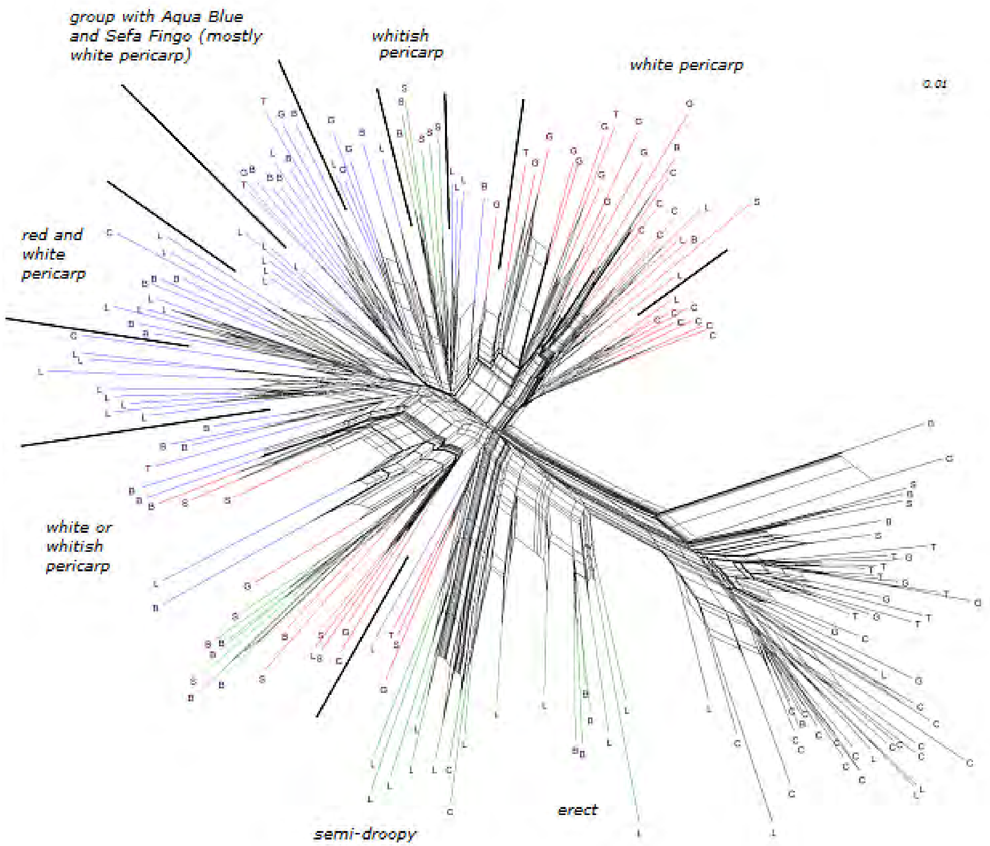


***Figure 10**: Phylogenetic relationships of 182 rice genotypes based on all morphological traits converted into dummy variables. Botanical groups are indicated by colours: Black = O. glaberrima, red = O. sativa ssp. indica, blue = O. sativa ssp. japonica and green = interspecific farmer varieties. Country of collection is indicated by letters: B = Guinea **B**issau, C = Guinea **C**onakry, G = **G**hana, L = Sierra **L**eone, S = **S**enegal, **T** = Togo.*

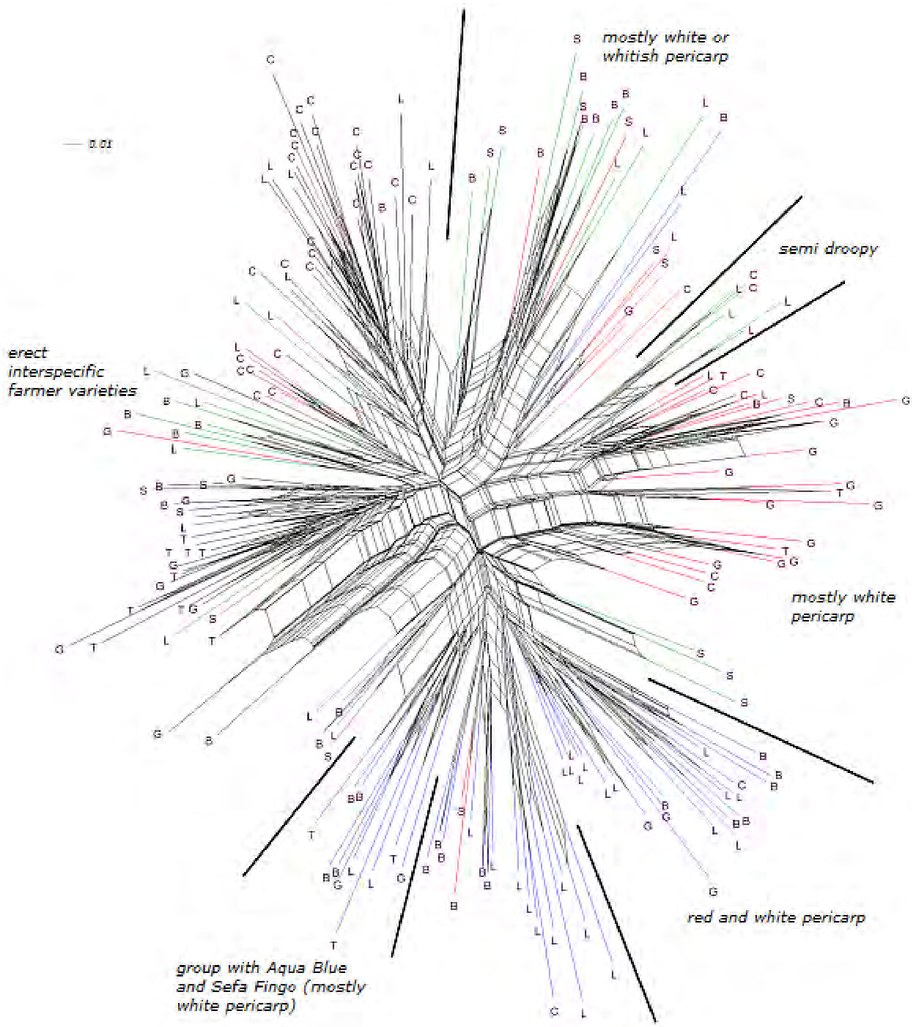


Figure 11: *Phylogenetic relationships of 182 rice genotypes based on the agronomic traits converted into dummy variables. Botanical groups are indicated by colours: Black = O. glaberrima, red = O. sativa ssp. indica, blue = O. sativa ssp. japonica and green = interspecific farmer varieties. Country of collection is indicated by letters: B = Guinea* ***B****issau, C = Guinea* ***C****onakry, G =* ***G****hana, L = Sierra* ***L****eone, S =* ***S****enegal, T =* ***T****ogo.*

Farmers from whom we collected material have no fixed ideas about the 'correct' morphological traits of rice varieties [39]. Rather than focusing on a particular ideotype they sustain what might be termed a broad flexset (combining a range of ideotypes depending on the conditions). Seemingly, this is a way to optimise benefits of cognitive flexibility, to be understood in relation to a long history of in situ domestication. Gross *et al*. [40] indicate that pericarp colour might be a phenomenon rather independent of trajectory of domestication. In

Ghana preference for white and red varieties was modulated by other traits, such as robustness, yield and intended usage. In the Ghanaian Togo hills, as well as in Sierra Leone, rice with a red pericarp is considered 'heavier' in the stomach (i.e. it digests more slowly than white rice, a valuable characteristic where sustained hard work has to be attempted). To make a meal last longer, white rice is sometimes mixed with some red rice before eating and in some cases (e.g. in Sierra Leone) it is sometimes mixed before sowing to allow easy milling. In Mandinka-dominated areas of Upper West Africa, red rice is regarded as "outmoded" and white rice is now preferred. There is also high demand for white rice in urban areas where people, because of their different labour pattern, tend to prefer rice that is more easily prepared.

Development of genetic diversity

Whereas the molecular data suggested that the *indica* group and farmer hybrids had greater genetic diversity than the *japonica* and *glaberrima* groups (see Table 7), Figures 4, 5, 6, 7, 8, and 9 suggest the differences in genetic diversity between the groups might be smaller than represented by the molecular analysis. Particularly for *japonica*, Figures 5, 6, 7, 8, and 9 and Figure 12, 13 and 14 show a large dispersion, similar to *indica*, for all components. For *glaberrima* only Figures 5, 6, and 9 show a large dispersion. Calculations of genetic diversity based on morphological traits (Table 7) confirm that *glaberrima* have less diversity, but that *japonica* has a higher level of diversity (see also Tables 5 and 6).

There seems to exist a relationship between the level of farmer selection and seed exchange and the level of diversity in botanical groups. Farmer accounts of the introduction or in situ development of new varieties related mainly to farmer hybrids, *indica* and to a lesser extent *japonica*. No such account related to *glaberrima*. In recent years farmers in Ghana have developed an idea that the morphology of *glaberrima* is fixed, and Mandinka people in Senegal and northern Guinea Bissau consider *glaberrima* to be a rice belonging to history. Only in a few areas (e.g. southern Guinea Bissau) are farmers actively re-introducing varieties of *glaberrima* [9]. This suggests there is little current active farmer variety development for *glaberrima*. By contrast, accounts concerning introductions and further development of farmer hybrids and/or *indica* are especially numerous in all countries where the research took place [6, 9, 39; A. Mokuwa, unpublished data).

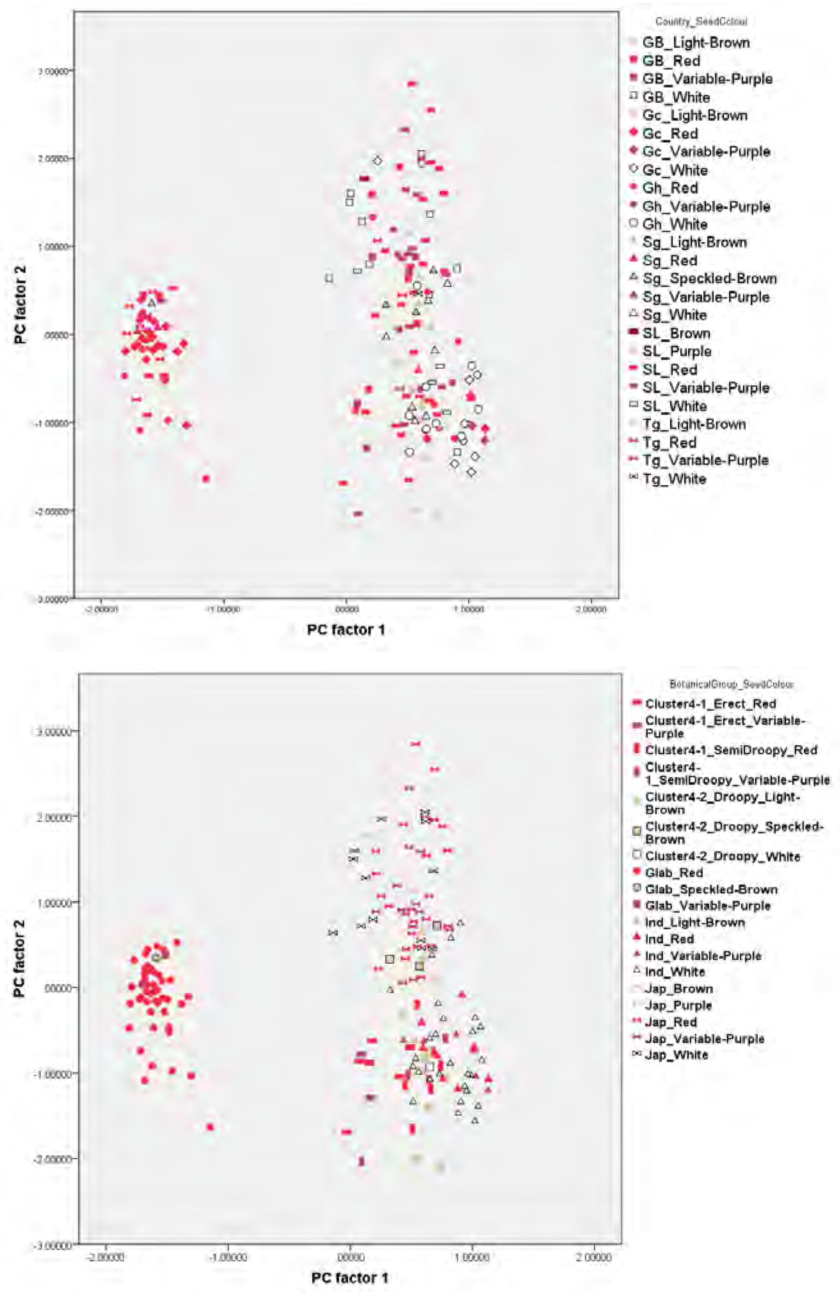


Figure 12*: Graphically repartition of materials based on morphological data of PC 1&2 marked according to country of collection and seed colour* as well as botanical group and seed colour. Country of collection is indicated by letters: Gc = Guinea Conakry, GB = Guinea Bissau, Gh = Ghana, Sg = Senegal, SL = Sierra Leone, Tg = Togo.*

** According to the seed colour chart of the Bioversity rice descriptor version 2007 [34]*

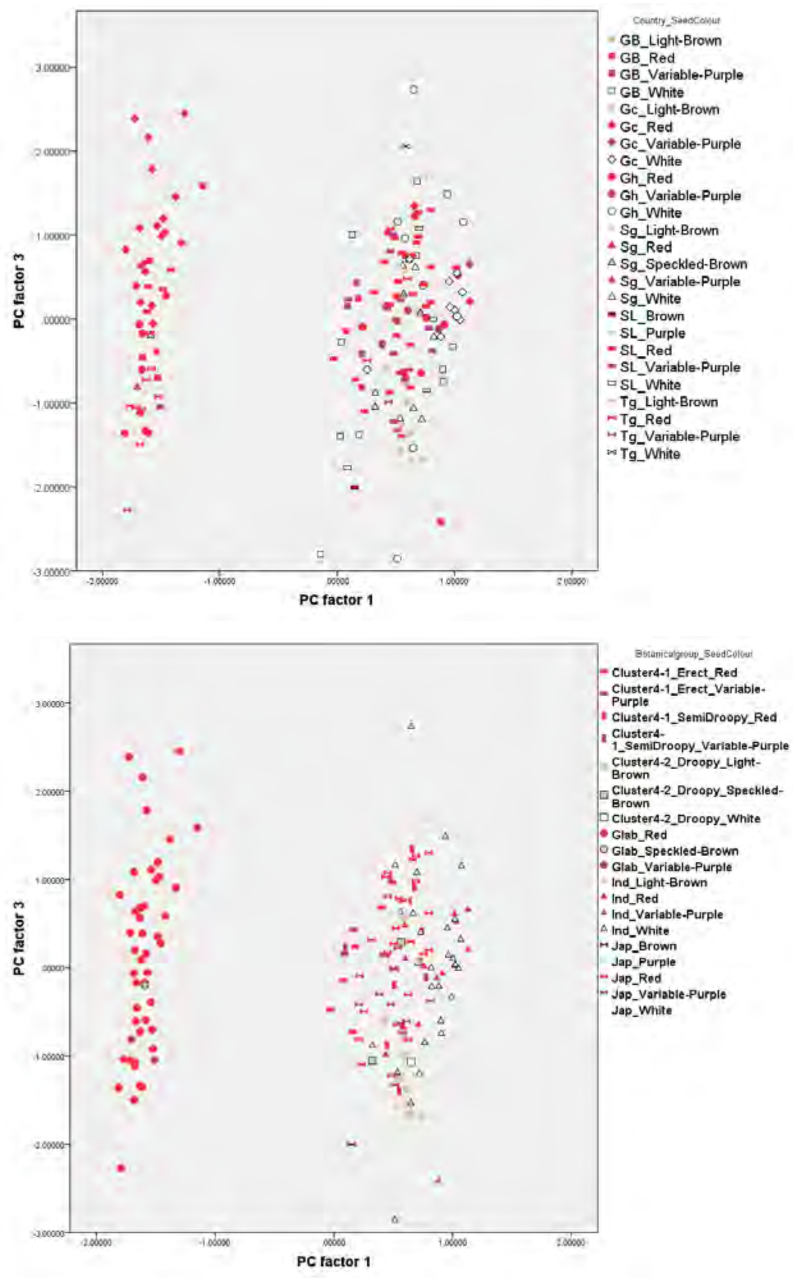
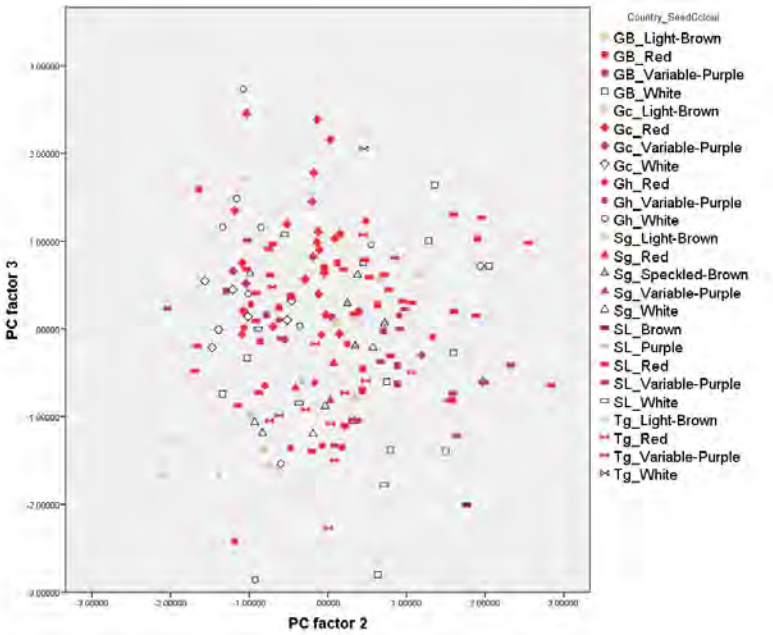


***Figure 13**: Graphically repartition of materials based on morphological data of PC 1&3 marked according to country of collection and seed colour* as well as botanical group and seed colour. Country of collection is indicated by letters: Gc = Guinea Conakry, GB = Guinea Bissau, Gh = Ghana, Sg = Senegal, SL = Sierra Leone, Tg = Togo.*

** According to the seed colour chart of the Bioversity rice descriptor version 2007 [34]*



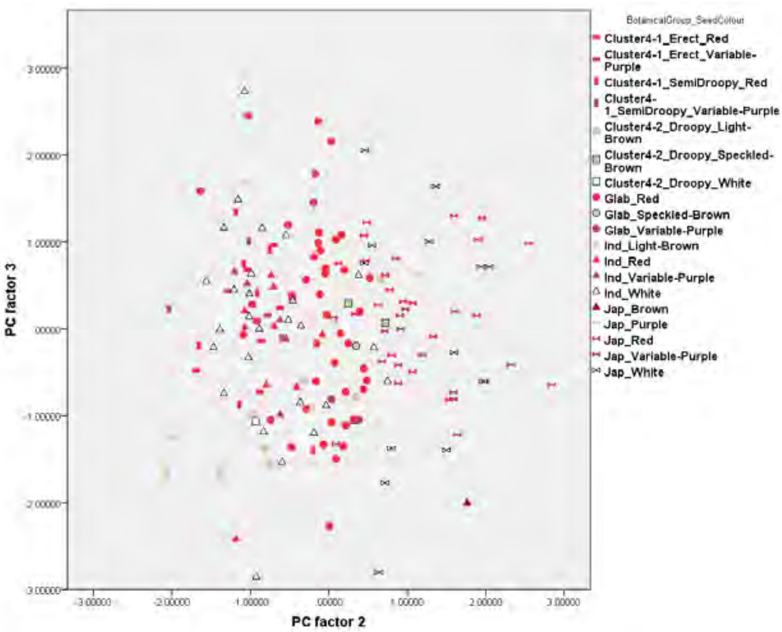


***Figure 14**: Graphically repartition of materials based on morphological data of PC 1&3 marked according to country of collection and seed colour* as well as botanical group and seed colour. Country of collection is indicated by letters: Gc = Guinea Conakry, GB = Guinea Bissau, Gh = Ghana, Sg = Senegal, SL = Sierra Leone, Tg = Togo.*

** According to the seed colour chart of the Bioversity rice descriptor version 2007 [34]*

***Table 7**: Level of genetic diversity of four botanical groups of rice in West Africa, calculated with Nei's index (He) and the fraction of polymorphic markers (P-value), based on molecular markers and morphological traits converted into dummy variables.*

Botanical group	N	Molecular markers		Morphological traits	
		He	P-value	He	P-value
O. glaberrima	49	0.042	0.430	0.189	0.762
Lower Guinea Coast	17	0.027	0.181	0.131	0.438
Upper Guinea Coast	32	0.047	0.362	0.185	0.724
Guinea	19	0.052	0.305	0.154	0.610
Other	13	0.035	0.152	0.190	0.552
O. sativa ssp. *indica*	46	0.099	0.653	0.218	0.800
Lower Guinea Coast	17	0.102	0.410	0.195	0.619
Upper Guinea Coast	29	0.070	0.429	0.208	0.733
Guinea	13	0.055	0.276	0.173	0.581
Other	16	0.072	0.333	0.208	0.590
O. sativa ssp. *japonica*	56	0.054	0.481	0.238	0.819
Lower Guinea Coast	8	0.033	0.143	0.173	0.476
Upper Guinea Coast	48	0.053	0.400	0.240	0.810
Guinea Bissau	18	0.035	0.200	0.236	0.676
Sierra Leone	28	0.056	0.371	0.225	0.705
Cluster 4	31	0.102	0.444	0.257	0.752
Cluster 4-1	18	0.060	0.274	0.223	0.629
Cluster 4-1 erect	8	0.038	0.143	0.149	0.400
Cluster 4-1 semi-droopy	10	0.065	0.219	0.169	0.495
Cluster 4-2	13	0.078	0.281	0.204	0.581

Country-specific findings

Sierra Leone. In Sierra Leone *japonica* varieties are extensively cultivated only in the southern half of the country while almost all upland varieties in the north are mainly farmer hybrids and *indica,* with a few *glaberrima*. This suggests that diversity of climate and agro-ecological conditions (upland and hydromorphic ecologies) is the main driver for selection of botanical groups [41]. The *japonica* in southern Sierra Leone and the farmer hybrids in northern Sierra Leone show considerable variation, suggesting that active cultivation plays a role in maintaining and developing genetic diversity. Close to the border with Guinea more extensive cultivation of *glaberrima* occurs with varieties that resemble varieties from Guinea, an area where *glaberrima* is still widely cultivated [7, 9]. An ethnic factor plays a part - the *glaberrima* were collected mainly among the Susu people who live on both sides of the border, linked by strong family ties and seed networking relationships.

Guinea. It is important to mention that in the Guinea case study area almost no *japonica* varieties are cultivated. In these conditions (soils of low pH) farmers mainly cultivate *glaberrima* and *indica* varieties. Among rice scientists it is thought that West African upland varieties are generally *japonica* rather than *indica* [38, 42, 43]. As a result, and in contrast to *japonica*, *indica* cultivars have yet to be fully evaluated regarding their adaptation to upland conditions in West Africa [44; 45, cited in 46].

The *indica* varieties collected in Guinea showed less diversity compared to varieties collected from the other study countries. This limited diversity partly relates to a fieldwork circumstance - varieties were collected from an ethnically homogenous group (Susu) growing essentially the same set of varieties along a 120 km transect from the Sierra-Leone borders (Bassia) to Kindia. These Guinean indicas are morphologically strongly differentiated from both *glaberrima* as well as from *japonica*. This is despite the fact that in Guinea *indica* and *glaberrima* are cultivated in the same upland conditions. For Susu farmers, selecting morphologically distinct genotypes helps avoid variety mixtures in the field. This part of Guinea (the Benna region in particular) was historically involved in an international rice trade to Freetown when local slave-manned plantations replaced the Atlantic slave trade. The Freetown rice trade demanded white rice [29]. Keeping field homogeneity (a relic of this long-dormant trade) is a cultural and managerial value lingering for nearly two centuries in some of these Susu farming communities [7]. That indicas with white and red seed colour cluster differently helps to confirm the significance of these socio-economic and cultural selection preferences in influencing genetic make-up of rice.

That the *glaberrima* from Guinea also show much diversity, points to active selection of African rice in this region. Mouser *et al*. [29] suggest that this may be linked to the food security needs of newly founded maroon communities of self-emancipated slaves fleeing Susu rice plantations.

Senegal. Senegalese *indica* (and hybrid) varieties resemble *japonica* in having fewer tillers and panicles, broader leaves and seeds than the *indica* from the other countries in the study. The land farmers work in Senegal mostly comprises hydromorphic soils, but also some uplands. The low tiller number is probably related to the relative earliness of local varieties. All farmer hybrids collected in Senegal had a light coloured pericarp as farmers strongly selected against red pericarp. A few off-types (representing old varieties) rogued from collected samples clustered with red seeded varieties from Guinea and Sierra Leone. This can be taken as an indicator that localised farmer preferences changing over time can influence the genetic make-up represented by the varieties cultivated.

Guinea Bissau. The collected farmer hybrids cluster with indicas and have low similarity to *japonica* from Guinea Bissau. Japonicas were cultivated under upland conditions and the farmer hybrids tended to be more frequently cultivated in hydromorphic zones. However, respondents said that in the past, when more labour was available for bird scaring, farmer hybrids were also cultivated in the uplands. The droopy farmer hybrids are genetically different from the erect farmer hybrids. One reason is seed colour. Mandinka farmers are unlikely to select an off-type with an erect panicle to develop it into a variety since they associate erectness of the panicle with (undesirable) red pericarp. The *glaberrima* from northern Guinea Bissau clustered with those from Senegal while those from southern Guinea Bissau clustered with those from Guinea and Sierra Leone. Climatic conditions are clearly different between the case study villages in the north and south of the country, but account should also be taken of the fact that historical relationships differ. The north is oriented towards Senegal (Casamance) and the south is oriented towards Guinea.

Togo Hills (Ghana and Togo). The relatively large diversity within the *indica*, *japonica* and *glaberrima* groups in the Togo Hills can be partly ascribed to the many different ecological niches found in a forested landscape that ranges from lowland to mountain where farmers take considerable advantage of intra-mountain basins for rice cultivation. These mountain basins offered the double advantage of more fertile soils and security. Rice diversity can thus be related to a history of refuge, displacement and enclaved social life in a region characterised by war and political instability. Seeking security, farmers strove to intensify farming on stony, acid and often sloping soils by emphasising *O. glaberrima*, the only rice available at that time. More recent factors include the developments in farming over the past 50 years. Until the 1960s, the main rice producing ecology was upland, where mainly *glaberrima* varieties were cultivated.

On the Ghana side of the range, farmers started to cultivate *indica* varieties in lowland areas from the 1960s onwards, while in the Togolese Togo Hills (mainly the Danyi Plateau) farmers continued - to this day- to cultivate solely *glaberrima* varieties, as no lowland ecologies were available to them. Lowland rice farming in the foothills of the Ghanaian Togo Hills has meanwhile become a major activity. It has also resulted in farmers introducing some *indica* varieties to hydromorphic and upland conditions. The cultivation of *glaberrima* is still maintained today, especially for its role in customary rites, and as a significant part upland cultivation clearly continues to set criteria for the selection and development of *indica* rice varieties [9]. This also helps explain why no farmer hybrids are found in the Togo hills. Here *O. glaberrima* and *O. sativa* are separated in the landscape by altitude, not grown side by side, as they have been for centuries, in Upper West Africa. It should also be noted that local customary rites demand use of pure *glaberrima* for feeding and sacrifice. This acts as a disincentive to any farmer inclined to select off-types intermediate between *O. glaberrima* and *O. sativa*.

Conclusions and Implications

Main conclusions

This paper has combined morphological and molecular data with socio-economic and cultural information to provide a better understanding of how cultivation practices combine with environmental pressures to shape rice diversity in six case study areas in coastal West Africa. Examples have been provided of how, per botanical group and case study area, these integrated data offer novel insights into the potential of neglected crop resources. The paper points both to the complexity of farmer rice genetic diversity management and to the significance of farmer innovation.

For *O. glaberrima* the molecular and morphological data largely agree with each other (see Figure 1). The morphological data showed clear differences in morphological features between *glaberrima* varieties from the Togo hills and the Upper Guinea Coast region, and between Guinea and the other countries of the Upper Guinea Coast. A relationship between genetic diversity and agro-ecology emerges. Farmers did not exchange *glaberrima* varieties over large distances, and we did not receive information about the development of new *glaberrima* varieties (the Guinea case excluded). What seems now to be true is that ethnic groups either stress the true-to-type maintenance of specific varieties or have abandoned the cultivation of *glaberrima* altogether.

For the other botanical groups a different picture emerges. Molecular and morphological data do not always agree. Particularly for the *japonica* group more diversity was observed at the morphological than at the molecular level. This could be caused by the possibility that the molecular markers used were more informative on other botanical groupings than on the japonicas. Taken in conjunction with the findings on differences in adaptation within *japonica* reported by Mokuwa *et al*. [10] the question arises about whether the *japonica* harbour more genetic diversity than observed.

At the morphological level the three non-*glaberrima* botanical groups did not group geographically (by country, or groups of neighbouring countries). Particularly for indicas and the farmer hybrids, much evidence of recently introduced or newly developed varieties was recorded. Particularly with the farmer hybrids, seed colour has a clear relationship with the genetic make-up of rice varieties. Such a relationship is non-existent (or less clear) for the *japonica* group.

Apart from *glaberrima*, farmers seem ready to cultivate any variety of the other three botanical groups that meets a certain minimum set of criteria, such as plant height, time of ripening, seed colour and digestibility. Even these criteria are used flexibly, depending on the other advantages a variety may possess. For example, in general farmers prefer tall varieties. In Ghana this is because a long stem is considered easier for threshing. In southern Sierra Leone farmers mostly harvest by panicle and seek to avoid too much stooping and an aching back. Short plants, however, may not always be selected against if they have compensating advantages such as earliness [39].

For *glaberrima*, socio-cultural selection pressures seem to reduce diversity, particularly at a more local scale, while for the other botanical groups they seem to have an enhancing effect on genetic diversity. However, *glaberrima* still plays an important role in determining the selection criteria of farmers and shaping variety development pathways. For instance, farmers in northern Sierra Leone select farmer hybrids with erect panicles. This implies these farmer hybrids are selected according to standards established for *glaberrima* cultivation. Most japonicas in southern Sierra Leone have a red pericarp. This results from historically-specific socio-cultural selection pressures [29]. The farmer hybrids from Senegal and Guinea Bissau show much overlap with, respectively, the japonicas and the indicas in the PCA analysis. This is apparently related in part to shared agro-ecological conditions. The droopy panicle and light seed colour of farmer hybrids in this region also reflect a history of *O. sativa* cultivation. In sum, at a regional level, farmer hybrids combine (advantageous) traits from different botanical groups by embodying responses to different local cultural and ecological considerations.

Because farmers in West Africa embark on risk spreading practices - e.g. growing varieties mixed-in with other varieties and assigning sections of their fields to different varieties [47] –

'in-situ' experimentation and on-farm hybridisation is facilitated. In Sierra Leone farmer hybrids are generally popular; they are said to perform well under low field management and when consumed enable farmers to sustain longer hours of work without hunger, and are thus similar to *glaberrima*. In Senegal, the farmer hybrids also perform well under low field management, but do not have a red pericarp and in that respect are regarded as being similar to the *O. sativa* varieties commonly planted. The farmer hybrids are a welcome enrichment of local planting resources since they are genetically rich and diverse and can be considered products of long trajectories of interaction between botanical groups, ecological, socio-cultural and economic factors.

Wider societal context and implications

The present paper belongs to a group of three that report an interconnected set of findings: we first described the emergence of a new rice type of interspecific hybrid origin in West African farmers' fields [23], then we analysed robustness and strategies of physiological adaptation within a large set of farmer varieties of African rice and Asian rice across West Africa [10] and third, this paper has compared morphological and molecular data with information on socio-economic seed selection factors, in order better to show how farmer practices and culture combine with environmental selection pressures to shape diversity in rice across coastal West Africa.

All three papers provide evidence that West African small-scale food-crop farmers conserve and develop valuable rice varieties, despite limitations of poverty, isolation, and formal education. A major implication of this result is that farmer practices and culture strengthen the conservation and development of genetic diversity. Modern varieties of many crops have little or no genetic disparity within cultivars. It has been estimated that as little as 20% [48] of the total diversity contained within the wild ancestors of rice, cassava, and soybeans is maintained through breeding of 'modern elite' varieties [49-51]. Our work shows, by contrast, that farmer innovation helps to protect this diversity and keep it 'in play' for future adaptation. Sustaining crop genetic diversity in situ is an especially important topic in an era of rapid climatic change. Our results, therefore, support calls for the protection and valorisation of farmer crop innovation processes, as a basis for addressing issues of rural food security in Africa.

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Author contributions

Supervised the research: EN HM PR PCS. Conceived and designed the experiments: AM EN FO BT HM PR PCS. Performed the experiments: AM EN FO BT. Analysed the data: AM EN FO BT. Contributed reagents/materials/analysis tools: AM EN FO BT. Wrote the paper: AM EN FO BT HM PR PCS.

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CHAPTER SEVEN

Review of main research findings and a general concluding discussion

Alfred Mokuwa

Main research findings reviewed

This thesis is organized in seven chapters.

Chapter 1 of this thesis outlined the main aims of the thesis: to assess and understand the effects of the civil war in Sierra Leone (1991-2002) on rice genetic resources, and (more generally) to study the management of rice by marginal farmers in central-northern Sierra Leone, to throw light on the scope of local seed selection for food security. The study has focused (in particular) on the role of African rice, both in wartime and in post-war food security strategies in central-northern Sierra Leone, especially under wartime enclave conditions (self-settled, internally-displaced farm populations).

Chapter 1 presented the research context and objectives, the research design and the general methodological orientation. The chapter also introduced the historical background to the case study on small-scale rice farming in central-northern Sierra Leone (the research area). Ethnicity and slavery were considered as historical factors shaping local attitudes to rice varieties. The main production ecologies for rice farming in the region were also described.

The general methodology adopted sought to combine technical and social tools in research in order to provide description and analysis of technological activity as a systematically related set of material and sociological processes (technography). The approach assumed the existence of real (if deeply embedded) causal mechanisms of both material/biological and sociological nature, to be identified and elucidated by research. Technography is thus located within a philosophical framework of critical realism. Under the technographic rubric, social and biological variables are assigned an equivalent epistemological status and treated within an integrated framework.

A range of methods was used to realise the proposed technographic research design, oriented on farmer adaptive management of plant genetic resources in extreme conditions. These included the following: collection and identification of farmer rice types; genetic/morphological characterization and agronomic assessment of relevant rice seed materials (in collaboration with projects in Ghana, Guinea, Guinea Bissau and Togo); direct observation of actual farmer management practices; farming systems description and analysis; ethnographic observation and analysis; survey-based instruments to access sociological, agro-ecological, economic and political/institutional variables; in-depth interviewing of key informants about the war, histories of displacement and enclavisation, food security strategy and adaptive experimentation.

It was a major objective of the study to determine which groups have been most active in harnessing the potential of “orphan” crops in extreme circumstances (here African rice is treated as such a crop), how groups have gone about this, and how well information has been shared. This aspect was further examined in Chapters 2 and 3.

Thus Chapter 2 began the study of war impacts on farmer rice planting material by documenting the main events of the civil war and war-based disruptions in farming communities in six chiefdoms of central-northern Sierra Leone. The main events of the war are documented, and war-based disruptions affecting small-scale rice farming in the six chiefdoms (Biriwa, Bramaia, Kamajei, Magbema, Kholifa Rowalla and Tonko Limba) are described. The objective was to examine if and how a low-intensity insurgency affected farmer rice seed selection. It has been widely assumed that such effects exist and that they are negative. This chapter sought to test this assumption by documenting the impact of insurgency and then examining farmer seed selection processes across three reported periods (pre-war, during-war and post-war) to assess what, if any, effect war had on the availability of seed types and on the logic of farmer choices. Much more detail on the logic across three reported periods was persistently and enduringly supported by, seemingly, robust local seed channelsmay have served to strengthen farmer choices in extreme (war-time) conditions given in Chapter 3. Chapter 2 contributes to research objective 1and research question 1, described in the general introduction to this thesis.

Chapter 3 focused on seed acquisition dynamics, based on field collection of varieties from three of the case-study chiefdoms. The data collection covered all family rice farms per selected village. The picture was then linked to the data on recalls concerning what was being grown by each farmer in the immediate pre-war period, during the war and immediate post-war period, as presented in Chapter 2. Chapter 3 argued that the kind of hit-and-run warfare typical of the Sierra Leone conflict hardly affected the content of local rice seed systems, even though it may temporarily have greatly reduced actual rice output. Apparently, farmer rice genetic resources were persistently and enduringly adapted to local agro-ecologies via strong selection processes and local adaptation strategies unaffected by the temporary contingencies of civil war. Chapter 3 does argue that in extreme (war-time) conditions farmers’ local seed channels, seemingly, are robust. Thishuman agency has persistently and enduringlycontributed to the food security of poor and marginalized farm households.Seemingly, selection for robustness (and strategies of adaptation within a large set of farmer varieties, as more thoroughly explored in Chapters 4-6) protected Sierra Leonean rice farmers against some of the worst effects of the war crisis. In this sense, therefore, the war may have served to strengthen and prolong farmer preferences for robustness, but it was not the cause of this preference. Chapter 3 contributes to research objectives 2, and3 and research questions 1, 2, 3 and 4, described in the general introduction to this thesis.

Having concluded (Chapters 2 and 3) that farmer selection preferences for robustness pre-dated and outlived the eleven-year civil war the focus of the thesis then shifted to understanding the basis for this preference. Chapter 4 characterised and compared 315 rice varieties collected in seven countries across the West African Coastal region. This included the sets of rices collected in Sierra Leone. The chapter explored the molecular diversity of the collected varieties. Results suggest that there is more genetic diversity in farmer rice selections in West Africa than often assumed by scientists and consequently represents an important gene pool with which breeders might work. The data also indicate the emergence of new types of rice of interspecific origin, in farmers' fields, and presumed to be the result of farmer selection. There is evidence that these farmer-selected interspecific types - clearly distinct from the recent Nerica releases - have been cultivated for a considerable period (for at least the last half century) and that their spread may reflect adverse conditions (including drought and war). In adapting to adversity (it is argued) farmers look for varieties able to perform well under harsh conditions and with less field management. This is one source of the preference for robustness identified in Chapters 2 and 3. Farmers and agrarian ecologies have always had to cope with and adapt to sub-optimality and climate change, with recurrent and continuing processes of seed selection playing a crucial role. Chapter 4 proposes spontaneous back-crossing events, and subsequent farmer selection, as the mechanism resulting in different groups of genetic diversity in different rice growing areas. The chapter concludes by suggesting that farmer hybrids should be treated as a potentially valuable resource, to be evaluated for inclusion in breeding and seed dissemination programs. Thus Chapter 4 (the first PlosOne paper) does say that in extreme (war-time) conditions farmers choose hardy types but much more detail on 'why, and how, were these adaptations effective' (question 1) is given in Chapters 2 and 3. The processes underpinning these adaptations were further evaluated (question 4) in Chapters 5 and 6.Chapter 4 contributes to the research objective 4 and research questions 3, 4and 5, described in the general introduction to this thesis.

Findings so far have implied that farmers' rice accessions in coastal Upper West Africa should demonstrate superior robustness and adaptive plasticity. Chapter 5 sought to address this hypothesis by analyzing the physiological performance of 24 farmer varieties of two rice species (*Oryz asativa* and *Oryza glaberrima*) selected from the 315 varieties studied in Chapter 4. Unfortunately, none of the farmer hybrids was selected, since the experiment was undertaken before the molecular analysis was complete. Field trials were organized in five West African countries (Ghana, Guinea, Guinea Bissau, Sierra Leone and Togo) to study the 24 farmer varieties in typical sub-optimal conditions. Performance of the varieties in terms of canopy development, yield components and yield were observed and compared across environments to understand underlying mechanism for adaptive plasticity. The findings suggested that farmers' selections are resilient to sub-optimal conditions. The paper proposes that these farmer selections might be a useful starting point for understanding adaptive processes to a range of uncertainties over the long term, including climate change. Several varieties displayed robustness, but expressed different strategies to cope with stress, making them suitable for a range of farmer conditions. It was concluded that farmer varieties may be suitable for breeding programs and should be incorporated, together with improved varieties, in dissemination projects to protect farmers' food security in adverse conditions. It was shown that varieties could be ranked in order of robustness of *Oryza glaberrima*, *Oryza sativa indica* and *Oryza sativa japonica.* Each sub-species clustered according to the clusters identified by molecular analysis (Chapter 4) and displayed different coping strategies. The different varieties displayed different adaptive strategies. *Indica* from Ghana and *japonica* from Sierra Leone showed some degree of crop failure outside the local environments to which they were adapted. The most robust varieties in the botanical groups were the most widespread varieties in their location of collection. Findings in Chapter 5 (the second PlosOne paper) provided evidence that farmers select accessions for robustness to assure yield stability in less than ideal agro-ecological circumstancesbut much more evidence on the interplay of artificial (farmer) and natural selection in low in-put farming systems and social context (question 5.2) isexamined in Chapter 6. Chapter 5 contributes to research objectives 5 and research questions3, 4 and 5(5.1), described in the general introduction to this thesis.

Chapter 6 (the third PlosOne paper) points to the complexity and significance of farmer innovation. The Chapter analyzed the morphological characteristics of 182 rice varieties selected from among 315 varieties collected in seven countries across the West African Coastal region. These were put into trial at a single site in one country (Sierra Leone). Measurements were taken of a range of plant qualitative and quantitative traits, and yields were studied and compared, better to understand morphological variation among the two species of rice. Thus Chapter 6 does say that in low in-put and extreme (rapid climate change and war-time) conditions farmers choose ideotypes that are the product of long and complex trajectories of selection governed by local human agency but much more detail on how well information has been shared (society interactions) is further given in Chapters 2 and 3. Chapter 6 contributes to the research objectives 6and research questions 3, 4 and 5(5.2), described in the general introduction to this thesis.

Chapter 7 (the present chapter) summarises key findings of the research. A General Conclusion (below) revisits the research questions and argues that the significance of long-term processes behind certain farmer adaptation strategies identified earlier in the thesis amounts to a local preference for robustness. In general, the war was a rather minor factor in altering the rice variety choices made by farmers. In effect, conflict did little more than confirm existing preferences for robustness. Farmers preferred more robust rice seed types, but varietal robustness was backed by a robust informal network for seed exchange operating pre-war, during the war, and in the post-war period. Farm households survived war better than might have been expected because they had access to robust local varieties and to a robust local system of non-marketized seed exchanges.

General conclusion

This research has investigated the assumption that war in Sierra Leone caused a reduction in farmer rice seed genetic diversity. The reason for such an investigation was both scientific and practical. The scientific objective was to gain a better understanding of the principles underlying farmer seed selection. Which kinds of seeds are selected, and how is varietal diversity maintained (or lost) under a range of operational conditions, including extreme events such as war? The practical concerns relate to seed development and supply considerations in humanitarian crises. As shown, the study creates space for humanitarian agencies to follow a rather different technological agenda to be further discussed below.

The basis for farmer rice seed selection in Sierra Leone is laid bare by the molecular and physiological analyses reported in Chapters 4-6. In particular, robustness of farmer rice selections was assessed through a cross-country experiment. Robustness was seen as the ability of a variety or group of varieties to perform well in a diversity of low-input cultivation conditions. It was found that according to this criterion farmer upland selections - especially selections of *O. glaberrima* - performed well across a range of difficult West African soil environments. This provides a basis for arguing that farmer selection leads to the emergence of varieties with broad adaptation to the kind of inaccessible but low fertility land available to mobile populations seeking physical security. This corresponds to the history of many rice farming groups in Upper West Africa, especially in the late 19th century. Thus it is not surprising to find that the recent civil war in Sierra Leone war had low impact on farmer seed choices, since these choices were pre-adapted to wartime conditions. The research reported here provides the basis for understanding this adaptation.

On that analytical basis this thesis has further documented that farmers in highly insecure war-time conditions knew *what* they were looking for among selection choices and *why*, even though these choices would not necessarily agree with agricultural research institution choices. The study has also shown that there is considerable variation among farmers' selections, reflecting local environmental differences. Evidence has been presented that farmers are engaged in the business of sorting out sustainability from unsustainable novelties. The data for Sierra Leone seem to suggest that this is a region in which farmers have for some time incorporated genetic heritage from robust *O. glaberrima* into more recently introduced Asian rice types. It is suggested that farmer selection of off-types from Asian rice and companion weedy African rice has resulted in the emergence of new rice types of interspecific hybrid origin. The war has not hindered, and has perhaps helped, the spread of these interesting new rices. It is unfortunate that none of these hybrid rices was included in the robustness experiment, since when that experiment was designed we did not yet have the results of the molecular analysis. Testing the farmer hybrids for robustness is certainly a step to be pursued in further research.

The robustness experiment confirmed that some farmer selections are rather broadly adapted, and might be useful outside their immediate locality. This is in contrast to the rather common belief that farmer selections tend to be suited only to local conditions. Farmer varieties, therefore, should be incorporated together with improved varieties in dissemination projects to protect farmers' food security under sub-optimal conditions. They may also be suitable for inclusion in breeding programmes.

Not all displaced farmers in the Sierra Leone civil war reached the security of displaced camps. Most of those in the present case study region were in the northern rebel enclave, or in the intermediate no-man's-land. In neither case was humanitarian relief (food or seed) available. Farmers in these two regions had to survive on their own resources, and (as has been shown) made good use of local, hardy adapted rice seed types. But does this mean that farmers facing similar conditions in future should be left to fend for themselves?

There are three overarching issues raised by the results of this research:

- What should be concluded from the fact that the insurgency in Sierra Leone had little impact on farmers' rice seed selection choices?
- What policy issues should be inferred from the ways in which poor-resource farmers in fragile environments selected for robustness of rice seed under difficult and challenging marginalized conditions?
- What should the relationship be between these farmers and research aimed at agricultural improvement of rice seeds?

On the basis of this study of farmer management of rice seed during insurgency in Sierra Leone the answer to the first question should be concluded from the fact that this research has investigated the assumption that war in Sierra Leone caused a reduction in farmer rice seed genetic diversity. It is argued that while war had many destructive side-effects, and disrupted farming, thus also temporarily disrupting local management of rice genetic resources and seed systems, there is little evidence to support a conclusion that long-term damage to rice genetic diversity resulted. Focusing on the events of the war in the case study villages, it seems clear that the "hit and run" pattern of the war did not destroy farmer knowledge of micro-ecological seed management strategies. The evidence is that these strategies once more became effective as soon as resettlement was possible.

What seems now to be needed still leaves us with an answer to what policy issues should be inferred from the ways in which poor-resource farmers in fragile environments selected for robustness of rice seed under difficult and challenging marginalized conditionsraised by the results of this research is given below?

This thesis has argued that breeders cannot afford to ignore local cultural, historical and environmental circumstances. By exploring the context of farmers' seed choices the thesis has made clear that the core concern in any attempt to assist low-resource farmers in contexts such as Sierra Leone should shift from attempts to remodel instrumental relationships between farmers and their environment to a more strategic and expansive level where the relationships between researchers and farmers themselves form part of a wider process of managing social learning.

The robustness experiment (Chapter 5) confirmed that robustness of the seed type is a function of three processes - genetic endowment (via natural out crossing), environmental selection, and intense farmer selection (G × E × S interaction) - that results in rather broadly adapted seed types. An implication is that farmer varieties will maintain their performance across a range of low input conditions and thus might be very useful to farmers in neighbouring countries. More efforts than hitherto should be focused on conserving, evaluating and distributing farmer selected rice planting materials in West Africa. Farmers themselves should be consulted about the best way to develop relevant modalities of dissemination, and need to involved directly in any such activity, via (for example) contributing to video-based farmer-to-farmer learning materials.

The findings of this thesis also have major implications for humanitarian interventions in post-war reconstruction. Such agencies should resist the temptation to remodel local agriculture through introduction of seed innovations seen to be "progressive" by outside standards. The thesis shows that farmers benefit not only from robust seeds of their own choosing, but from a robust system for generating and disseminating locally-developed seeds. Agencies should aim to protect farmer preferred choices, and to facilitate rather than hinder local (socially-embedded) dissemination practices.

This not (it should be stressed) a recipe for "freezing" the seed system in time. The research here reported has stressed the importance of factors such as exposure to variation in modes of labour mobilization and farming style, in accounting for why heads of households tended to diverge (but systematically) in their seed selection responses across a low-resource farming spectrum. In particular, seed choices may be altered to favour those varieties which require lower labour inputs.

On that analytical basis this study has also shown that the existing strategy in the Sierra Leone rice research institution may not be ideal. Farmers continue to show interest in seed aid and modern 'elite varieties'. The morphological analysis suggested quite a gap between traditional and modern varieties. Much could still be done to extend access to these varieties adapted to local conditions.

What seems now to be needed to revitalize low-resource upland farmers is what should the relationship be between these farmers and research aimed at agricultural improvement of rice seedimplied in the third overarching issues raised by the results of this research is given below.

At the most detailed level, it is important to make some statements about implications of this thesis for national research (e.g. National Agricultural Research Council) and international research organizations (e.g. AfricaRice [former WARDA]). Agencies such as Rokupr Rice Research Station and AfricaRice have recently begun to show some interest in the genetics of African rice, but as yet there has been little work on farmer management of the species itself and what lessons this might have for more effective cooperation between formal agro-science and low-resource farmers in the region.

Jusu (1999) posed a question about the kind of research strategy that will best support local selection initiative. This thesis has also clearly suggested that the established Sierra Leone national rice research agenda may require some adjustment. Farmers continue to show interest in "new" varieties, but the national list of recommended varieties should be extended to include the most widely disseminated farmer varieties.

This thesis has made clear that farmer seed selection agency is a resource not to be undervalued in plant improvement. Some institutional innovation is needed to pick on such lessons to make local farmers' selection experiments part of an interactive process linking farmers and researchers in a complementary relationship. Tools such as video communication are potentially useful to extend the range of inter-farm seed dissemination networking. It is also worth noting that the Ministry of Agriculture in Sierra Leone has already sought to disseminate at least one farmer rice variety in Sierra Leone, sourcing a large consignment of *pa kiamp* (or *saidou gbelie)* from neighbouring Guinea, for example) for this purpose. The success of this venture suggests the approach could be extended to a larger range of farmer materials.

In conclusion, rice farmers in coastal Upper West Africa have their own local ideas and genetic resources, and indicators of performance and quality, not well foreseen by scientific crop breeders. Results discussed in this thesis make clear that low-resource farmers in this region like a range of options and not just one or two high-performing cultivars. Strongly included in farmer selections were *glaberrima* materials ignored until recently by scientific plant improvement programmes.

In Sierra Leone the *glaberrima* legacy is also encountered in the form of a number of farmer selections of materials with inter-specific hybrid composition. Results have shown that this is locally originated material and not farmer adoption of Nerica releases. Some may wonder whether the Nericas (interspecific hybrids developed by scientists) meet farmer needs, but that is a topic beyond the scope of this study. Few Nericas were encountered during field collection, but probably fieldwork undertaken in 2007/2008 is too early to draw conclusions. Marginalized farmers in off-road communities in the case study (north-eastern Kamajei chiefdom and neighbouring areas, for example) were as yet unfamiliar with these releases, and this confirms that more needs to be done to extend access to these "*elite varieties*". This is a symptom of quite a gap between farmers and rice professionals.

If, as this thesis has shown, farmers are actively selecting from out-crossing materials then there is no case for an either/or choice between farmer selection and scientific breeding. Exotic materials bring in new genes, and enrich the pool from which farmers select interesting, adapted crosses. As Jusu (1999) found in north-western Sierra Leone, the apparent paradoxes alluded in this thesis only die away when we realize that exotic materials serve both as innovations in themselves and as ways of broadening the local genetic base from which farmer selection can draw.

Some institutional innovation is now needed to make farmers' selection a regular approach linking together low-resource upland rice farmers and researchers in a complementary manner. Given the findings of this thesis donors may now may have to adjust their research support and assessment procedures to channel more funding towards decentralized initiatives. This will need to include caution among humanitarian organizations in determining what varieties war-damaged farmers actually need in rehabilitation initiatives, and the adoption of new approaches to assessing the true impact of plant breeding programmes. Impact evaluation is still biased towards the assumption that introduced materials must be better. One such recent impact assessment initiative in Sierra Leone sought only to determine the impact of different subsidy regimes on distribution of elite materials, rather than asking whether the elite materials really did outclass farmer selections.

New tools and techniques may be key to better impact evaluation. For example, marker probes might be used to track the spread of useful genes, whether exotic, or locally derived, such as the genes responsible for the capacity of African rice to out-yield Asian rice in low fertility soils. In general, more attention needs to be paid to effective utilization of the farmers' eye for selection and experimentation as crucial skills for the tailoring of plants to local social and environmental need. Perhaps it is time to consider farmer agency itself is a candidate for a Nobel Prize

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Summary

Chapter 1 introduces an overview of the argument and brief summary of the research approach and methods used. It outlines the main aims of the thesis - how did populations cut off from humanitarian inputs (enclave populations) adapt to food insecurity during the war in Sierra Leone, and why, and how, were these adaptations effective? The aim is to throw light on the scope of local seed selection for food security. The study focuses (in particular) on the role of African rice, both in wartime and in post-war food security strategies in central-northern Sierra Leone, especially under enclaved agricultural conditions (self-settled, internally displaced farm populations). A major objective of the study is to determine which groups are active in harnessing the potential of "orphan" crops in extreme circumstances (here African rice is treated as such a crop), how they have gone about this, and how well information has been shared (see also Chapters 2 and 3).

Chapter 2 The objective of the chapter is to examine in case-study detail how insurgency in Sierra Leone affected the agricultural population. The methodology adopted is to document specific war impacts and then to assess their impact on rice farming. Extensive ethnographic data were collected in six chiefdoms from north-central Sierra Leone. These were chosen to include four distinct ethno-linguistic communities (Limba, Mende, Susu and Temne). Data were collected by interview and direct observation from head of households for all upland rice farms in each village. In all six chiefdoms, a total of 1352 farmers were involved. The basic data source used on war events is the countrywide conflict mapping report prepared for the Special Court for War Crimes in Sierra Leone during the period March 1991-January 2002. The chapter concludes that while the war may have depressed rice productivity, incidents of atrocity were not very frequent for the agricultural population as a whole, and did not heavily disrupt actual farming activities, though reduced mobility and market activity made self-reliance important. Farmers continued, as they had done before the war, to select rice seed varieties for robustness, and this robustness was valuable for self-reliance. The social and biological bases for robustness in rice seed systems are analysed in later chapters (Chapters 4-6).

In Chapter 3 the focus narrows to a picture based on 287 upland rice farms surveyed in the 2007-2008 season in six settlements selected from four chiefdoms (Biriwa, Magbema, KholifaRowalla in the north, and Kamajei in the south) of Sierra Leone capturing intra-village

and more specifically inter-farm dynamic aspects of variety choice, seed exchange and genetic erosion, as influenced by both local environmental and social selection factors. The chapter probes the impact of different seed distribution modalities to test further the provisional conclusions derived from Chapter 2 (see above). Reports of war-shaped seed dynamics are ground-truthed from collection records maintained for one village since 1983. Molecular and morphological analysis provides a basis for recognising four main rice groups, *glaberrima*, *sativa-indica*, *sativa-japonica* and farmer-hybrid groups, reported for three periods: *pre-war, during-war and post-war*. Reported values are compared with field measurements in 2007. Trends based on farmer reports are identified. Anthropological tools were employed to assess farmer seed system dynamics in relation to land use changes. There is little evidence to support a conclusion that long-term damage to rice genetic diversity resulted from the impact of war. The limited varietal changes attributable to the war are partly due to the pattern of the war itself and partly due humanitarian aid interventions. One main factor safeguarding seed diversity lies in the characteristics of local seed channel structures. The war had little more than a passing impact on the functioning of this local seed system. Effective informal seed distribution channels sprang back to life as soon as farmers resettled their villages. However, some organisational changes have occurred. Restocking via seed loans was important before the war but has declined to insignificance in the post-war period.

Having concluded (Chapters 2 and 3) that farmer selection preferences for robustness pre-date and outlived the eleven-year civil war the focus of the thesis then shifts to understanding the basis for these preferences.

Chapter 4 characterised and compared 315 rice varieties collected in seven countries across the West African Coastal region. This included sets of rices collected in Sierra Leone. In West Africa two rice species (*Oryza glaberrima* Steud. and *Oryza sativa* L.) co-exist. Although originally it was thought that interspecific hybridisation is impossible without biotechnological methods, progenies of hybridisation appear to occur in farmer fields. AFLP analysis was used to assess genetic diversity in West Africa (including the countries The Gambia, Senegal, Guinea Bissau, Guinea Conakry, Sierra Leone, Ghana and Togo) using 315 rice samples morphologically classified prior to analysis. Evidence for farmer interspecific hybrids of African and Asian rice, resulting in a group of novel genotypes, is discussed, and we then identify possible mechanisms for in-field hybridisation. Spontaneous back-crossing events may play a crucial role, resulting in different groups of genetic diversity in different regions developed by natural and cultural selection, often under adverse conditions. These new groups of genotypes may have potential relevance for exploitation by plant breeders. Future advances in crop development could be achieved through co-operation between scientists and marginalised farmer groups in order to address challenges of rapid adaptation in a world of increasing socio-political and climatic uncertainty.

If farmers, as argued in Chapter 4, select for adversity then farmer varieties should show superior robustness and adaptive plasticity. **Chapter 5** examines this hypothesis. It is shown that West African farmers selected rice varieties which perform well under diverse environmental conditions. The central experiment in the reported research aims to increase insight into complementary strategies of rice variety promotion, whereby farmer varieties could be recognised and further disseminated as a way of protecting West-African food security in a general environment in which development agencies seek to expand the range of high-yielding cultivars to meet urban rice demand. The study shows that farmer varieties are tolerant to sub-optimal conditions. Our experiments in five West-African countries showed that farmer varieties were robust but expressed different strategies to cope with stress, making them suitable to a range of farmers' conditions. *O. glaberrima*, considered a product solely of farmers' agency, was the most robust. The results showed that farmer varieties can adapt to different environments in contrast to the rather common belief that they adapt only to local conditions. Hence, farmer varieties may be material suitable for breeding programmes and should be incorporated (together with improved varieties) in dissemination projects to protect farmers' food security under sub-optimal conditions.

Farmer varieties are robust, it can be argued, as a result of a complex interplay between natural and artificial selection. **Chapter 6** investigates this interplay, from a morphological approach. Using 20 morphological traits and 176 molecular markers, 182 farmer varieties of rice (*Oryza* spp.) from 6 West-African countries were characterised. Principal component analysis showed that the four botanical groups (*Oryza sativa* ssp. *indica*, *O. sativa* ssp. japonica, *O. glaberrima*, and interspecific farmer hybrids) exhibited different patterns of morphological diversity. Regarding *O. glaberrima*, morphological and molecular data were in greater conformity than for the other botanical groups. A clear difference in morphological features was observed between *O. glaberrima* rices from the Togo hills and those from the Upper Guinea Coast, and among *O. glaberrima* rices from the Upper Guinea Coast. For the other three groups such clear patterns were not observed. We argue that this is because genetic diversity is shaped by different environmental and socio-cultural selection pressures. For *O. glaberrima*, recent socio-cultural selection pressures seemed to restrict genetic diversity while this was not observed for the other botanical groups. We also show that *O. glaberrima* still plays an important role in the selection practices of farmers and resulting variety development pathways. This is particularly apparent in the case of interspecific farmer hybrids where a relationship was found between pericarp colour, panicle attitude and genetic diversity. Farmer varieties are the product of long and complex trajectories of selection governed by local human agency. In effect, rice varieties have emerged that are adapted to West-African farming conditions through genotype × environment × society interactions. The diversity farmers maintain in their rice varieties is understood to be part of a risk-spreading strategy that also facilitates successful and often serendipitous variety innovations. We advocate, therefore, that farmers and farmer varieties should be more effectively involved in crop development.

Chapter 7 summarises the key findings of the research. The thesis approached the topic of robust farmer rice varieties by first examining the assumption that war in Sierra Leone caused a reduction in farmer rice seed genetic diversity. The reason for such an approach was both scientific and practical. The scientific objective was to gain a better understanding of the principles underlying farmer seed selection. Which kinds of seeds are selected, and how is varietal diversity maintained (or lost) under a range of operational conditions, including extreme events such as war? The practical concerns relate to seed development and supply considerations in humanitarian crises. As shown, the study creates space for humanitarian agencies to follow a rather different technological agenda. The basis for farmer rice seed selection in Sierra Leone is laid bare by the molecular and physiological analyses reported in Chapters 4-6. In particular, robustness of farmer rice selections was assessed through a cross-country experiment. Robustness was seen as the ability of a variety or group of varieties to perform well in a diversity of low-input cultivation conditions. It was found that according to this criterion farmer upland selections - especially selections of *O. glaberrima* - performed well across a range of difficult West-African soil environments. What seems now to be needed for low re-source upland rice farmers is the further extension of the kind of methodology explored in this thesis. Breeders need to monitor farmers' *indica*tors of performance and quality, but also to monitor selection processes from farmers' experiments with mixtures, and adjust according to the lessons they can derive from such monitoring in low-input conditions. The data and findings of this thesis provide a basis for arguing that farmer selection leads to the emergence of varieties with broad adaptation to the kind of inaccessible but low fertility land available to mobile populations seeking physical security.

This corresponds to the history of many rice farming groups in Upper West Africa, especially in the late 19th century. Thus it is not surprising to find that the recent civil war in Sierra Leone war had low impact on farmer seed choices, since these choices were pre-adapted to historical conditions of high human insecurity. The research reported here provides a basis for understanding this adaptation.

Curriculum Vitae

Gelejimah Alfred Mokuwa was born in Bo town, Kauwa chiefdom, Bo District, Southern Sierra Leone on 29th May 1974, the son of James Mokuwa and Kumba Bona. His secondary education was undertaken at Christ the King College, Bo. He entered the program for general agriculture at Njala University in 1996, graduating with a BSc in 2001. He completed a Master's degree in crop science at Njala in 2003, with a master's dissertation on crop-crop interactions which was supervised by Professor Edwin Momoh. He also worked for a number of years, both before entering and after leaving university, as a research assistant and researcher with a number of development agencies and food security programs in rural Sierra Leone. He is a practical agriculturalist, with a particular interest in animal rearing. In this context, he has an interest in crop and animal domestication (e.g. cane rats and the leafy vegetable *Piper umbellatum*). Much of his knowledge of agriculture comes from living with and closely observing village-based small-scale farmers over many years. He believes that small-scale farmers can be the backbone of a food security revolution in Sierra Leone, but that they deserve stronger support, especially in the area of land rights. This would open up farming to many younger people, he believes. He is author/co-author of a number of scientific publications.

Gelejimah Alfred Mokuwa
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the course	**Department/ Institute**	**Year**	**ECTS (= 28 hrs)**
A) Project related competences			
Complexity in and between social and ecosystems	CERES, WUR	2007	3.0
Technography: Researching Technology and Development	TAO, WUR	2007	6.0
"Management of African Rice (Oryza glaberrima) as a food security crop in and after armed conflict – lessons from Sierra Leone"	CERES summerschool, Hilversum	2007	1.0
B) General research related competences			
CERES orientation programme	CERES, Utrecht	2007	5.0
CERES presentation tutorials	CERES, Utrecht	2007	5.5
Literature review and research proposal development	TAO and CARE International, Bo, Sierra Leone	2007	6.0
C) Career related competences/ personal development			
Information Literacy and EndNote	Library, WUR	2011	1.5
Techniques for Writing and Presenting a Scientific Paper	WGS	2012	1.2
D) Seminars and Workshop presentations and Attendance			
"Robustness and strategies of adaptation within a large set of farmer varieties of African rice (Oryza glaberrima Steud) and Asian rice (Oryza sativa)"	WASS,WUR	2012	1.0
Oral presentation at advanced course in participatory plant breeding	Wageningen International, WUR	2007	2.0
TAO seminars	TAO, WUR	2007-2013	4.0
Total			**36.2**